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Author(s): R. Strachey

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been very bad for the last two or three years. Another result was that the people, instead of working hard in their boats, sat with their hands in their pockets, and so became demoralised. The interior of Newfoundland was not an agricultural country. The fine agricultural land which was sometimes described was rocks and bog, and the timber scrub. The other day on board a steamer he met the special commissioner of a London newspaper, who in his account said that in the interior the land was magnificent, and that any number of fortunes could be made there; but the truth was that the land there was very inferior. It can grow potatoes, oats, and vegetables, and help a fisherman to live, but it could not compete with Manitoba as an agricultural district.

Mr. HOLME said that though Labrador might not be in a perfectly satisfactory state with the Hudson's Bay Company, it would be much worse without it. If it were not for the Company there would be *neither law nor order* in the country. It was true that a government court-house—a ship—annually went round the coast, but a court which only called in for about ten minutes in each year was not of much force. More than this, the Company took the place of Poor Guardians. There were thousands of cases in which the people would have starved if it had not been for the Hudson's Bay Company, which supplied them with food and other necessities, and kept them going without any possibility of ever being paid for what they gave.

The PRESIDENT, in proposing a vote of thanks to Mr. Holme, said that Labrador was evidently not a hospitable country, or very inviting to English travellers. The falls of the Grand River must be very stupendous if they were of anything like the magnitude that Mr. Holme had suggested. He confessed he was somewhat sceptical on that point. Judging from the aneroid observations given in the paper, he should say that Lake Waminikapou must be 700 or 800 feet above the sea, and the authority for 2240 feet as the height of the tableland was doubtful. Anything like a fall of 2000 feet was hardly conceivable.

The vote of thanks having been agreed to, the meeting adjourned.

Lectures on Geography, delivered before the University of Cambridge,
1888.

By General R. STRACHEY, R.E., F.R.S., President, R.G.S.

LECTURE II.

February 25th.

HAVING thus traced the growth of our knowledge of the earth's figure, of the art of navigation and the preparation of maps, I pass on to notice the parallel onward course of geographical discovery.

In many other branches of science the successive steps by which our knowledge has been advanced bear little on the ultimate results arrived at, which are complete in themselves, and constitute a body of fact having no necessary relation to the persons by whom, or to the manner in which it was collected. But geography presents itself to us in a different light. Geographical discovery, followed as it immediately was by political movements among great masses of mankind, assumes an extremely important part in the history of man; there being, indeed, no

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country which has not been affected by the course of discovery during the last four hundred years. Had Columbus, for instance, made his famous voyages under the flag of England instead of Spain, which seems to have been at one time possible, it can hardly be doubted that the history of modern Europe would have been wholly different.

The study of geography, like that of astronomy, first took a definite shape in Greece. The earliest geographical conceptions were necessarily based on ideas of position in relation to the locality where the ancient geographers lived and wrote, and upon these the gradually increasing knowledge of the civilised world was engrafted, and developed around the eastern end of the Mediterranean Sea, where the Phenicians, the earliest of European navigators, had established the centre of their commerce, extending their voyages to the Red Sea and Persian Gulf on the east, and the coasts of Britain on the west. Herodotus, writing 450 years before the Christian era, may be taken as the exponent of the earlier forms of Greek geography. The junction of the Mediterranean with the Atlantic was then known; ideas of the North and West of Europe were vague; the form and position of the Caspian were fairly ascertained; the descriptions of India did not extend beyond the Upper Indus; and the coasts of Asia seem to have been unknown beyond the Persian Gulf. The circumnavigation of Africa was referred to, but it may be doubted whether this was more than mythical. It is a curious illustration of the result of absence of effective publication, that though Herodotus had a just general notion of the form of the Caspian, Ptolemy entirely misconceived it, and it was not recovered till within the last two hundred years.

Alexander's expedition, 330 B.C., passing through Asia Minor, Persia, and Bactria, reached the Indus, where his traces and those of his successors are still to be found, and the Greek names given to some of the great geographical features of the country he passed through, are still in use on our maps. Of the Greeks who accompanied him some went into India Proper; while Nearchus on his return followed the coast from the Indus to the Persian Gulf, and ascended the Tigris beyond Baghdad. The successors of Alexander's captains in the Bactrian kingdom which they founded extended their knowledge to Eastern India, and one of their envoys visited Palibothra, believed to be Patna, on the Lower Ganges. About the same time Carthage, originally a Phenician colony, which had become the most important maritime power in the Mediterranean, appears to have sent expeditions along the western coast of Africa, reaching perhaps to the Equator, while its ships also visited France and are said to have sailed round Britain. The trade between Egypt and the east was maintained from Berenice in the Red Sea, and other ports at the mouth of the Persian Gulf, of which Hormuz was the mediæval representative, and through them the commerce with Europe was carried on.

Up to the Augustan age, the only additions to geography were obtained through the Roman conquests in Western and Northern Europe. In the time of Pliny, the coasts of Asia had hardly been described with certainty beyond the mouths of the Ganges, and only vague conceptions of China had been formed. These ideas had become more defined, and extended to the Malay Peninsula, Sumatra, and Java, by the time of Ptolemy, A.D. 150.

Till the end of the twelfth century, the further progress of geographical, like that of all other branches of knowledge, was very inconsiderable. Something was done by the Arab geographers in the early period of the growth of Mahomedan power, and something by Norwegian Vikings whose voyages extended to Iceland, Greenland, and eventually to the coasts of North America. But in the thirteenth and following centuries, when the civilisation of Europe was becoming consolidated, the spirit of enterprise was gradually awakened.

The formation of the powerful republics of Venice and Genoa, and the spread of their commerce, under the stimulus of many causes, of which the Crusades may be reckoned as one of the most prominent, was followed by a development of maritime habits, knowledge, and enterprise among the nations bordering the Mediterranean, which was destined to produce great results.

The institution of the orders of friars, the desire to spread Christianity, and the terror produced by the incursions of Jenghiz Khan into Eastern Europe, were followed by journeys, of which one of the most remarkable was that of the monk Rubruquis, 1253 A.D., into Central Asia. The growth of commercial activity sent forth the Polos, 1265, on similar expeditions, which extended to Mongolia and China. The friar Odoric, 1320, visited Persia, Western India, Sumatra, and Java, as well as China, returning by Tibet, and being the first European to reach Lhasa. Thence he travelled by Cabul and Tabriz to Venice. His accounts are unquestionably the basis of much that is found in Sir J. Mandeville's travels, which there is much reason to think are mainly, if not wholly, fictitious.

Among the travellers of this period should also be specially mentioned Ibn Batuta, an Arab of Tangier, 1325-55, who, after visiting Egypt and Arabia, went through Persia, Afghanistan, and India, whence he was sent by Mahomad Toghlak, then king of Delhi, on an embassy to China. He travelled thither by sea down the west coast of India to the Maldives and Ceylon, and on through the Eastern Archipelago to China. His journeys are reckoned to have extended over 75,000 English miles. Thus, we are brought to the eve of that great series of voyages which are the glory of the fifteenth and sixteenth centuries, and among the most remarkable events recorded in history, opening out the way to Eastern Asia round the Cape of Good Hope, and adding in the west a new continent to the known world.

The honour of taking the initiative rests with the Portuguese. Soon after 1415, a course of maritime exploration was entered on, and continued for many years under Prince Henry, which led to the successive discoveries of Madeira, the Azores, the Cape de Verd Isles, and at length, 1484, extended along the west coast of Africa beyond the Equator. In 1486, King John sent out Diaz to endeavour to reach India by sea, the belief having become established that this could be done by passing round the continent of Africa ; but this expedition advanced little beyond the Cape of Good Hope.

Eleven years later, and two years after Columbus had returned from his first voyage, Vasco da Gama, the largest of whose ships did not exceed 120 tons burden, doubled the Cape of Good Hope, and passing along the east coast of Africa to Mozambique and Mombasa, crossed the Arabian Sea and arrived on the western coast of India, near Calicut, in 1498 A.D. Cabral in 1500, on his way to India by the same route, discovered the coast of Brazil. Many similar voyages followed, and in the course of the next few years the western and eastern coasts of Africa, and the shores of the Arabian Sea were explored ; the islands of St. Helena, Tristan da Cunha, Madagascar, Socotra, Bourbon, and Mauritius were made known ; and the Portuguese under Albuquerque had established themselves at numerous places along the coast of Arabia and India, making Goa the seat of their government. Their advance to Malacca immediately followed, and they explored Sumatra, Java, and the much coveted Spice Islands or Moluccas, their ships reaching China for the first time in 1514. Their settlements at Macao, near Canton, date from 1537. Thus in less than fifty years from the discovery of the Cape of Good Hope the Portuguese had opened out the whole of the coasts of Africa and Southern Asia as far as China, as well as a large part of the Eastern Archipelago.

Almost simultaneously, Spain, adventurers from which had already reached and occupied some of the Canary Isles, entered on a course of discovery and conquest still more remarkable. After the final triumph of Ferdinand over the Moors, the perseverance of Columbus was rewarded by the acceptance of his proposals to attempt to reach the Indies by sailing across the Atlantic, in the hope of thus finding a shorter route than that which the Portuguese were seeking round the continent of Africa.

It was in 1492 A.D. that Columbus, guided by a truly scientific course of induction, for the first time so applied by any navigator, embarked on the first of the celebrated voyages which resulted in the discovery of what were at the outset supposed to be the eastern shores of Asia ; an error largely due to mistaken reliance on Ptolemy's vastly exaggerated longitude of those shores, and on distances deduced from the itineraries of Marco Polo and other travellers. The settlements first made on the newly discovered islands, ever since known as the West Indies, were

soon extended to the neighbouring coasts of the narrow isthmus between the gulfs of Darien and Panama, and the discovery, by Nunez de Balboa, of the Pacific Ocean, followed in 1513. The accounts of this were received with an interest little less keen than that which had followed the discoveries of Columbus, indicating as it did the existence of another great ocean still intervening between the new continent found by Columbus, and Eastern Asia. The exploration of the Gulf of Mexico, and the entry of Cortez into that country in 1520, and its final conquest followed in rapid succession. In 1521 the first advances were made along the shores of the Pacific; Peru was first seen in 1526, Pizarro landed there in 1531, and the whole of that country and Chili were shortly added to the Spanish kingdom.

Meanwhile the discovery of Nunez had led to the despatch of the expedition under Magellan, a Portuguese who had sailed under Albuquerque, but had entered the service of Spain in order to undertake the new enterprise of reaching the shores of Asia by passing round the extremity of the new continent, and crossing the lately discovered Pacific Ocean. This object he successfully carried out. The Straits called after Magellan were passed in 1520, and first the Ladrone Islands and then the Philippines were discovered, where Magellan was killed in a conflict with the natives. His companions, however, continued their voyage, and passing through the Indian Archipelago, where the Portuguese had already established themselves, one of the ships, which alone survived, reached Spain again in 1522, having for the first time in the history of man accomplished the circumnavigation of the globe.

The enterprise of Spain thus completed that great work of maritime discovery in which Portugal took so honourable a share, and which in a period of less than fifty years had led to the acquisition of a knowledge of the distribution of the principal areas of land and sea in their main features.

It was soon after the commencement of this course of discovery, 1494, that an agreement was come to by Spain and Portugal, and submitted to the Pope for his sanction, for the division between the two countries of the newly discovered parts of the world. A Bull was accordingly issued by Alexander VI., which declared that a line should be drawn from pole to pole, across the globe, 100 leagues, afterwards extended to 370 leagues, west of the Azores and Cape de Verd Islands, and that all newly discovered territories to the east of this line should fall to the share of Portugal, all those to the west, to Spain. This arrangement determined the direction given to the voyages undertaken by the two countries. The line proposed is nearly on the 50th meridian west of Greenwich, and the corresponding line in the other hemisphere is on the 130th meridian east. Its adoption as a boundary served to confirm Portugal in its occupation of Brazil; but subsequently led to a conflict as to the right of Spain to the Philip-

pinos and Moluccas which lie along the 120th meridian. It is a singular circumstance that the Pope was once more referred to, only a year or two ago, to arbitrate on the occasion of a dispute with Germany as to the territorial rights of Spain over the Caroline Islands; and, if I mistake not, the Bull of Alexander was adduced as evidence in the discussion.

Before the end of the sixteenth century the exploration of the western shores of the North Atlantic as far as the polar seas had been completed by English and French sailors. The earliest English voyages of discovery are those of Cabot, believed to have been a Venetian, who had settled at Bristol in the reign of Henry VII. In 1494, when in search of a north-west passage to the Indies, he reached Newfoundland, and his sons sailed along the American coast as far south as Florida, already known through the Spaniards. Later Frobisher and Davis, 1576-1585, explored Labrador and the west coast of Greenland, and entered Baffin's Bay, so called after Baffin, who in 1616 penetrated still further, and reached lat. 78° N., but only to find the way onward blocked with ice, and impracticable.

In the latter part of the same century the Spaniards sent several expeditions from Peru across the Pacific, still seeking the Philippines and far-famed Spice Islands, and for the first time visited various groups of islands in that ocean, the Marquesas, the Society Islands, and the New Hebrides. Drake, 1577, passing through Magellan Straits, extended his explorations up the western coast of America as far as California, and for the second time accomplished the circumnavigation of the earth.

So far as the great geographical features of the globe are concerned, all that then remained to be done was to define the position and extent of the continent of Australia, and this was virtually accomplished by the Dutch in the next half century. The voyages of the Dutch into the Eastern Seas began about the year 1600, and this enterprising nation by degrees displaced the Portuguese from their possessions in the Eastern Archipelago, establishing themselves in their place, and in this position they still remain. A Dutch expedition bound for the Eastern Islands first determined, 1616, the true extremity of the South American continent by rounding Cape Horn. The northern and parts of the western coasts of Australia were explored by the Dutch in 1627, and in 1642 Tasman sailed round Australia, discovering Van Diemen's Land, now called after him, believing it to be a portion of the mainland, as well as New Zealand, thence passing on through the Fiji and Solomon groups, by New Britain and round New Guinea. In 1606 Torres, a Spanish commander, in a voyage from Peru, had already reached the north-east angle of Australia, and passing through the straits since called after him, had sailed up the south-west coast of New Guinea, thus showing that the extreme north-eastern limit of Australia had here been reached.

It is worthy of notice that all the voyages across the Pacific were directed almost along the same line, from the extremity of South America

towards New Guinea, doubtless with the object of reaching the Moluccas or Philippines, which, from a belief in the wealth there to be acquired by commerce and plunder, had become the centre of attraction of all classes of adventurers, whatever flag they flew; and to this cause may be attributed the circumstance that the geography of Australia and the northern Pacific was not made known until a much later period.

With the latter part of the seventeenth century we reach the period when a spirit of commercial enterprise had in a great degree replaced the old spirit of adventure and love of conquest, which had stimulated the earlier voyages of discovery. Concurrently with this change a great development of scientific knowledge had taken place, and expeditions, mainly for purposes of scientific discovery and investigation, began to be despatched to many distant or little known parts of the earth. Of the results of these it is only necessary to refer specifically, first, to the discovery by Behring, in 1728, of the straits separating Asia from America, through which Cook also, fifty years later, after traversing the Pacific from south to north, penetrated as far as lat. $70^{\circ} 40' N.$, when he was stopped by ice; and, second, to the fact established by the last-named great navigator, that, whatever land there may be around the South Pole does not extend beyond the Antarctic circle.

A position had now been reached in which the further progress of geography chiefly required a more exact delineation of details, and the extension into the interior of the great continents of the explorations which at first had to so considerable an extent been confined to the sea-coasts. In this labour the services of France and England were most conspicuous until the commencement of the present century. As we approach the present time, there has been a general co-operation among all civilised nations in the advancement of geographical knowledge, and the scientific value of the work done by explorers both by land and sea has become greater, as the full extent of the requirements of scientific investigation were more completely realised.

So thorough has been the success with which these labours have been prosecuted that it would now be hardly possible to describe what is known of the earth, otherwise than by pointing to what is still unknown, and this might be summarised in a very few words.

Besides the interior of Borneo and New Guinea, and the portion of Central Africa where Stanley is for the present moment lost to view, no considerable part of the earth's surface is unexplored, with the exception of the polar regions, which have till now proved inaccessible. The maps of the interior of Africa now supply trustworthy representations of a vast system of rivers, lakes, and mountains, till recently wholly unknown to the civilised world, and what remains to be done is little more than to fill in the details of well-ascertained large outlines. Australia has been crossed and recrossed in many directions. The darkness which so long enveloped Central Asia has been entirely

cleared away, and though parts of Tibet are yet to be visited, the true nature of the central plain lying between that country and Siberia is completely known. The geographical features of North America are little less perfectly mapped than those of Europe; but large parts of the interior of South America, much of which is covered by forest, are still unsurveyed. The southern border of the North Polar Sea and the very complicated system of islands and channels along the northern margin of the American continent, between Behring Strait and Greenland, have been precisely delineated, and the boundary of the same sea along Northern Asia has also been determined. The highest northern latitude reached is about $83\frac{1}{2}^{\circ}$ N., that is within 500 miles of the Pole. The nearest approach to the South Pole has been in $78^{\circ} 11' S.$, but the difficulties arising from climate have till now stood in the way of any satisfactory survey of the land seen at some few points in the Antarctic area.

I have thus far traced in broad outlines the manner in which our present knowledge of the form and magnitude of the earth, and of the features of its surface, has been acquired in the course of many centuries by the mental and physical efforts of a long succession of remarkable men, to a few only of whom was it possible that I should make special reference. The part of my subject to which I shall next ask your attention will principally regard the operation on the inorganic constituents of the globe of the great physical forces, gravity, heat, and chemical affinity, which control and determine its movements, form, and constituents, and underlie the distribution of land and sea and all the conditions of its surface.

The figure of the earth, and its existing features, have had their origin in a former state of the planet, during which it has been subject to the gradual changes that accompanied its cooling from a previously much higher temperature. The forces of nature which are still at work, including the most wonderful of all, life, have operated upon the globe while it thus passed through the stages which have led to what it now is; producing varied conditions of surface, from which have arisen as direct consequences, differences of climate, and corresponding variations in the forms and distribution of living creatures, vegetable and animal. Thus it is that while every part of the earth has its own characteristics, the general system of nature is one and the same everywhere; the special characters of the several regions being due to the action of local features or conditions, which are no sooner called into existence than they in turn become secondary efficient causes of the infinitely varied phenomena that our globe presents to us. In this manner has been evolved the face of nature as we now see it; nature, which working with never-varying forces, appears to man in the present as his type of stability, whilst it is constantly leading, through ever-varying forms, from the hidden shapes of an impenetrable past to those of an unknown future.

The influence of the movements and figure of the earth may everywhere be traced among the phenomena brought to our knowledge by the more and more complete exploration of its surface.

The daily and annual motions of the globe, subject to the effects of the spherical form of the earth and the direction of its axis of rotation, determine at all parts of its surface the amount of heat and light received from the sun, and thus regulate all the conditions of existence upon it; they give rise to the varying length of days and of seasons at different places, and to a multitude of recurring phenomena which characterise or influence the animate and inanimate world. In whatever direction we turn are to be found alternations of what may be termed terrestrial work and rest; day and night, summer and winter, periodical winds extending over longer or shorter periods, seasons of rain and dry weather. The tides of the ocean, and the less apparent, though not less regular, periodical oscillations of the atmosphere, as well as the little understood variations in terrestrial magnetism, are consequences of the same general causes. All nature, indeed, is subject to them. Under their control the ocean currents flow, the rivers rise and fall, the fields yield their harvests, the mountains are covered with snow, the florets of the daisy close and open, and the lark and nightingale pour forth their song; they regulate the migrations and hibernations of animals, the daily labours of man and beast, the hours of active life and sleep, the increase and decrease of disease and death.

Though many of the diurnal changes thus observed would equally follow as consequences of the sun moving round a stationary earth, yet it is not difficult to find direct evidence, which immediately appeals to the senses, of the rotation of the earth on its own axis. This is very completely supplied by what is known as Foucault's experiment, which is performed by means of a pendulum consisting of a somewhat heavy plummet attached to a long and slender string, which therefore has a long period of oscillation, while the direction of its motion, when swung, is not liable to disturbance by torsion of the suspending string. If such a pendulum be set in motion, with suitable precautions, over a line drawn on the earth's surface, it will be found that the direction of oscillation gradually departs from that of the line over which it commenced, the divergence being caused by the gradual change of the absolute direction of the line, consequent on the revolution of the earth on its axis—a change not communicated to the pendulum, which, being only connected with the earth by means of the flexible string, continues to swing in the same direction as that given to it when it was first set in motion. The apparent angular motion of the pendulum will be equal, but opposite in direction, to the angular motion of the earth on its axis multiplied by the sine of the latitude of the place where the pendulum is swung; which at London would give an angular velocity of 1° in about five minutes. This, with a pendulum that swung

through an arc of 10 feet, would produce an apparent displacement of about two inches in ten minutes, taking place from south, round by west, north, and east.

The movements of the atmosphere and of the currents of the ocean supply evidence of the same truth, though in a less obvious manner. The air and water everywhere, when undisturbed, acquire the velocity of rotation of the earth, which is dependent on the latitude, being greatest at the equator, and diminishing gradually towards the poles. The velocity thus acquired gives an apparent eastward impulse to all air or ocean currents moving from the equator towards the poles, and an apparent westward impulse to air and water moving the other way. This had long been recognised as the true cause of the directions of trade winds and monsoons. More recently the direction of the south-west and north-east gales that characterise our own coasts has been seen to be due to the same cause, called into operation by the passage over our islands of areas of low or high pressure, which, according as they give rise to currents of air from the south towards the north, or *vice versa*, produce winds with westerly or easterly tendencies. The revolving winds or cyclones, which are developed within the tropics in so intense a form, also carry with them a terrible testimony to the true direction of the earth's rotation on its axis from west to east.

The remarkable force inherent in the globe, known as terrestrial magnetism, which gives a determinate direction to a freely suspended magnetic needle, and is of inestimable value to man, has long been the subject of observation and study. The general properties of the magnetic needle were known and applied to navigation by European sailors early in the eleventh century, but much earlier by the Chinese. The fact that the direction of the needle deviates from the true north, such deviation being termed its variation or declination, was probably known before the time of Columbus; but to him is due the first record of the gradual change which takes place in passing from one place to another, he having observed in his voyage across the Atlantic that the variation which had at first been easterly at length became westerly. At an early period also, 1576, the dip of a properly balanced magnetic needle, or the inclination from the horizon at which it comes to rest, had been observed by Norman, an Englishman, as well as the fact that this angle also varies with geographical position.

The conception that the earth itself is a magnet, and gives the needle its direction, is due to Gilbert, also an Englishman, about 1600 A.D. Halley, who, in 1676, had visited St. Helena to make astronomical observations, and in 1698 undertook a special voyage to study terrestrial magnetism, first put forward a consistent theory of the variation of the compass. His final conclusions, based upon his own observations and all available data derived from other navigators, were published in

1701; when he showed that the complicated movements of the needle might be referred to the influence of four poles of magnetic force—two in the vicinity of either pole of the earth—a view which, with some qualifications, subsequent investigation has confirmed.

Halley's conclusions were derived from a comparatively small number of observations of the declination and dip alone, measurements of the intensity of magnetic force not having at that time been made. This force, too, is now known to vary from place to place. The more ample collection of facts relating to both intensity and direction since brought together from all parts of the earth, has led to somewhat modified views as to the phenomena of terrestrial magnetism. It is now established that there are two magnetic poles, one in each hemisphere, at which the needle would point vertically upwards and downwards. Their position, which is not coincident with the geographical poles, is found to have varied according to some yet unknown law. In the year 1878 the northern pole was in lat. 70° N., long. 96° W., and the southern in lat. $73\frac{1}{2}^{\circ}$ S., long. $147\frac{1}{2}^{\circ}$ E. Between these poles, a line that has been termed the magnetic equator, where the needle assumes a horizontal position, is found to pass round the earth, following an unsymmetrical line which, in 1878, lay almost wholly to the north of the terrestrial equator in the hemisphere east of Greenwich, and to the south of it in the western hemisphere.

It further appears that the magnetic force is not evenly distributed on the earth, and that the points of maximum intensity do not coincide with either of the magnetic poles. In the northern hemisphere there are two foci of maximum force of unequal intensity, the most powerful lying at about lat. 52° N., long. 92° W., near the great American lakes, the weaker in lat. 65° N., long. 115° E., in Siberia. For the southern hemisphere, the available data are far less numerous, and the determination of the foci of force is less reliable. It is, however, believed that here also there are two points of maximum, of nearly equal power, and not far removed from one another, one in lat. 65° S., long. 140° E., the other in lat. 50° S., long. 120° E.

The unit by which magnetic force is measured has been assumed, adopting English standards of weight and length, to be that which would impart to a weight of one grain a velocity of one foot in one second of time. On this scale the magnetic force, where least, is found to be 6.0; the northern maxima are 14.2 and 13.3 respectively, and each of the southern 15.2.

The declination, or variation of the direction of the needle from the true meridian, is a consequence of these unequal forces operating upon it, the westerly or easterly tendency of the needle (as the case may be) following the geographical position of the place of observation in its relation to the several foci of force, with a general result of considerable complexity. Up to the sixtieth parallel of latitude, north or south,

the declination, whether easterly or westerly, rarely exceeds 30° ; and, speaking generally, it is easterly in the Pacific and westerly in the Atlantic and Indian Oceans. Near the poles, where the dip becomes high, the directive force of the earth's magnetism becomes much reduced, and the magnetic needle becomes comparatively unreliable and of little use.

As what is termed the north pole of a magnetic needle or bar, attracts the south pole and repels the north pole of another needle, the magnetism of the earth at the north pole should strictly speaking be called south polar, and *vice versá*. To avoid confusion from this cause, the north and south poles of the needle are now frequently termed the red and blue poles respectively. It may also be mentioned that magnetic declination is always measured from the true north, being described as positive when westerly, and negative when easterly.

The nature and mode of operation of magnetism, and the allied phenomena of electricity, continue to be subjects of speculation, no explanation of them having yet been proposed such as that which refers heat and light to the vibrations of an elastic medium. Our knowledge of the phenomena of terrestrial magnetism therefore still remains in the empirical stage; they are, however, held to show that the earth's magnetism is distributed through its mass, and that the magnetic force either wholly or mainly resides in the interior, and cannot be attributed to external influences, though it may be affected by them. Whether, or not, geographical features have any influence on the distribution of this force is doubtful.

Observation shows that all the elements of the earth's magnetism not only vary from place to place, but from time to time; the variations being in some cases periodical and dependent on the time of the day or the season of the year, and in others extending, with no apparent tendency to periodicity, over considerable lengths of time. The gradual alteration of the declination at London was first noticed in 1622, and the diurnal variations in 1722, in which year also the first attempt was made to measure the magnetic force. The manner in which these variations occur is still a matter of investigation, and their causes are doubtful, but the diurnal and annual changes are probably connected with changes of the temperature of the earth or its atmosphere, and may be influenced by geographical conditions. The non-periodical changes that have been recorded are very large. For instance, the declination in England, having been $11^\circ 15'$ E. in 1580, became $24^\circ 34'$ W. in 1820, and is now $18^\circ 30'$ W. The dip has changed from $71^\circ 50'$ in 1576, to $74^\circ 42'$ in 1723, and again to about $67\frac{3}{4}^\circ$ at the present time. These variations have been attributed by some to changes going on in the condition of the interior of the earth, and by others to external influences; but they continue to be among the most obscure of physical phenomena.

Besides the variations above-mentioned, there also arise other irregular

disturbances of the indications of the magnetic needle, of short duration, which are sometimes spoken of as magnetic storms. They occur with a frequency which shows a tendency to periodicity, diurnal or annual, and often almost simultaneously at distant parts of the earth, with nearly identical effects, and with a marked increase in intensity with increase of latitude. They likewise exhibit a period of increase and decrease coinciding with that observed in the sun-spot area, thus giving additional reason to connect them with modifications of the magnetic or electric condition of the earth or atmosphere arising in some manner from the action of the sun. The probable connection of these disturbances with the electrical condition of the atmosphere is indicated by their frequent occurrence simultaneously with appearances of the aurora, and with electrical earth-currents. The frequent, if not continuous, display of the aurora in the vicinity of the magnetic poles, further suggests a relation between the electrical and magnetic conditions of the earth. The true nature of all these phenomena is however, still very imperfectly ascertained.

As the phenomena most directly dependent on the form and movements of the earth became more completely known, and as the conceptions arising from their study were more clearly developed, inquiry was naturally extended to the nature of the earth's solid crust, and to the forces by the action of which its surface received its existing outlines, elevations, and depressions. The science of geology is the result; and the relation of geography to this science is what we have next to consider.

A very little observation and thought threw discredit on the ancient cosmogonies, and showed that they failed to give any satisfactory solution of the problems submitted by the advance of knowledge. If the extravagant myths of Asiatic origin, which peopled the earth millions of years ago with races of anthropomorphic demigods, and heroes descended from the sun and moon, could not bear the test of facts; neither have those traditions fared better which unveil the earth fully equipped with all the present forms of life and specially prepared to be the dwelling-place of man, some few thousand years ago. Precise observation has now supplied satisfactory proof that the earth's surface, with all that is on it, has been evolved through countless ages, by a process of constant change. Those features that at first sight appear most permanent, yet in detail undergo perpetual modification, under the operation of forces which are inherent in the materials of which the earth is made up, or are developed by its movements, and by its loss or gain of heat. Every mountain, however lofty, is being thrown down; every rock, however hard, is being worn away; and every sea, however deep, is being filled up. The destructive agencies of nature are in never-ceasing activity: the erosive

and dissolving power of water in its various forms, the disintegrating forces of heat and cold, the chemical modification of substances, the mechanical effects produced by winds and other agencies, the operation of vegetable and animal organisms, and the arts and contrivances of man, combine in the warfare against what is.

But hand-in-hand with this destruction—nay, as a part of it—there is everywhere to be found corresponding reconstruction, for untiring nature immediately builds up again that which it has just thrown down. If continents are disappearing in one direction, they are rising into fresh existence in another. Though the ocean tears down the cliffs against which it beats, the earth takes its revenge by upheaving the ocean's bed.

When we look back, by the help of geological science, to the more remote past, through the epochs preceding our own, we find complete evidence that the globe has passed in succession through an infinitude of anterior states, by means of small modifications extending over a vast period of time, but not differing in essentials from those which we now see to be going on. There are still preserved to us the remains of land and marine plants and animals—which lived, produced other generations, and died—possessed of organs proving that they were under the influence of the heat and light of the sun; indications of seas whose waves rose before the winds, breaking down cliffs, and forming beaches of boulders and pebbles; of tides and currents spreading out banks of sand and mud, on which are left the impress of the ripple of the water, of drops of rain, and of the tracks of animals; of volcanoes pouring forth streams of lava; and all these appearances are precisely similar to those we observe at the present day as the result of forces which we see actually in operation. Every successive stage, as we recede in the past history of the earth, teaches the same lesson. The forces which are now at work, whether in degrading the surface by the action of seas, rivers, or frosts, and in transporting its materials into the sea, or in reconstituting the land by the elevation of mountains, or by raising beds laid out in the depth of the ocean, or in volcanic eruptions, are traced as having continued in action from the earliest times.

Pushing back our inquiries, we at last reach the point where the apparent cessation, or failure of evidence, of former terrestrial conditions such as now exist, requires us to consider the relation in which our planet stands to other bodies in celestial space; and, vast though the gulf be that separates us from these, science has been able to bridge it. By means of spectroscopic analysis, it has been established that the constituent elements of the sun and other heavenly bodies are substantially the same as those of the earth. The examination of the meteorites which have fallen on the earth from the interplanetary spaces, shows that they contain nothing foreign to the constituents of the earth. The inference seems legitimate, corroborated as it is by the manifest physical connection between the sun and the planetary bodies circulating around it,

that the whole solar system is formed of the same kinds of matter, and is subject to the same general physical laws. These conclusions further support the supposition that the earth and other planets have been formed by the aggregation of matter once diffused in space around the sun; that the first consequence of this aggregation was to develop intense heat in the consolidating masses; that the heat thus generated in the terrestrial sphere was subsequently lost by radiation; and that the surface at length cooled and became a solid crust, enclosing a nucleus of much higher temperature.

The heat of the interior of the globe increases about 1° F. for every 50 or 60 feet of depth below the surface. The surface appears to have now reached a temperature which is virtually fixed, the gain of heat from the sun being just compensated by the loss from radiation into surrounding space. As the exterior gradually cooled, contractions necessarily ensued, producing change of form and dimensions; and to these, acting in combination with gravity, are, no doubt, largely due the greater irregularities of the earth's surface. The strains set up by these forces must have continued to cause movements for a vastly prolonged period, and are doubtless still in action.

But the irregularities of the surface constitute only a small part of the effects of internal heat on the earth, and mineralogy is the branch of science to which reference must be made, for a knowledge of the many simple and compound substances that have issued, under the operation of chemical forces, from the vast laboratory contained within the cooling crust of the once incandescent globe.

The solid nucleus of the earth, with the ocean and the atmosphere, as we now find them, may be regarded as the products which have resulted after the globe, by cooling, had attained a condition of practical equilibrium, and after the more active process of aggregation had ceased, and the combination of its elements, under the requirements of the laws of affinity, into the various solid, liquid, or gaseous matters found on or near the surface, had been completed; and it is not a little remarkable that two residual collections of matter, as I may term them, the air and the sea, which constitute a mere film on the solid earth's surface, should exercise so predominant an influence on terrestrial economy.

During the passage of the globe to its present state many wonderful changes must have taken place. The ocean, after its condensation from a gaseous state into that of liquid, must have long continued in a state of ebullition, or bordering on it, surrounded by an atmosphere densely charged with watery vapour. Apart, however, from the movements in the solid crust of the earth caused by its gradual cooling and contraction, its early higher temperature hardly enters directly into any of the considerations that arise in connection with its present climate; and it must remain doubtful how long and to what extent those conditions of climate

which interest us most, as having occurred during the period in which the existence of life is indicated, have been affected by such early higher temperature.

In the absence of any direct means of ascertaining the condition of the earth's interior, aid has been sought from mathematical science, by which it has been established, that the thickness of the solid outer shell of the earth must be considerable; and that if the interior is in a fluid state at all, which is very doubtful, it must be covered by a great thickness (probably not less than several hundred miles) of solid, comparatively unyielding matter; and it is argued, with apparent force, that no passage can exist, by which molten matter, if there be any, could ascend from such depths to the surface. Recent speculation has consequently suggested that even volcanic phenomena may be consequences of the heat developed by intense pressures set up by the mechanical forces concerned in the movements of the cooling outer solid crust, and that they are not immediate results of the very high temperature which almost certainly still subsists at great depths in the earth's interior. A more probable explanation would seem to be that by some local or partial removal of pressure in the otherwise solid interior, a portion of intensely heated matter is able to pass into the fluid state, and so finds a way through some fissure to the surface.

It is still an open question among geologists, whether the explosions accompanying volcanic eruptions are due to gases generated in the formation of the ejected melted matter, or to the sudden conversion of water into vapour in cavities containing such melted matter; the latter view being supported by the facts that great volumes of steam are discharged by volcanoes during eruptions, and that the majority of active volcanoes are on islands, or if on continents, are near the sea.

LECTURE III.

March 10th.

THE subjects of which I last spoke related to the globe viewed as a whole, and its interior. I next pass to the consideration of its exterior, with which geography is mainly concerned.

In the ocean we see the waters of the earth accumulated, after their condensation, in pre-existing depressions of the solid surface. We find almost everywhere evidences of movements of the earth's solid crust on a very large scale, and of frequent changes in the distribution of land and sea. The great continents include the areas that have last risen above the sea, and clusters of islands in many cases appear to indicate the remains of former continents now disappearing.

The gradual building up of the existing face of the earth can be

traced in the succession of deposits, often of vast thickness, collected around ancient land-surfaces; and indications are everywhere to be found of subsidences and elevations, though apparently without any altogether fundamental change in the great features or relative positions of the chief areas of land and sea, which seem to have been preserved for very long periods; so that we may not improbably still see relics of the earliest forms taken by the surface soon after it attained a solid condition. Movements such as these have continued till the latest geological times, and there is complete evidence that it was during this period that mountains among the highest in the world, the Himalaya and Alps, attained their present elevations.

Mountain ranges, which are due either to pressures arising from irregular contractions of the earth's crust, or to other internal forces capable of producing an upward thrust, occur in various forms. Frequently the areas of elevation with which mountains are associated cover very large tracts, and assume the character of tablelands or plateaus, often broken up by minor mountain ranges or elevations, which frequently follow some determinate direction. In the larger mountain masses the valleys often appear to occupy lines of rupture or fissure determined by the tensions produced by the strains that gave rise to the elevation; and attempts have been made to explain the characteristic directions observed in the elementary portions of such mountain masses, on mechanical principles. In the case of areas of elevation long as compared to their width, such as the Himalaya and Tibet, the very constant combination of long ridges and valleys with shorter intervening transverse ruptures or connections, may be thus accounted for; and it has been argued that radiating ridges and valleys accompany a roughly circular area of elevation. That valleys are very frequently caused in great part, or wholly, by erosion, due to the action of surface drainage or ocean currents, especially in unconsolidated deposits, is beyond dispute, but even in such cases their origin often appears to have been in a fault or rupture of the strata through which they pass.

The great masses of land which cover a large part of the northern hemisphere are connected around the north pole, and send out diverging offshoots towards the south; these, however, do not reach within 50 degrees of the south pole, with the exception of a small portion of South America. Generally speaking, the coasts of the continents rise steeply from great ocean depths, and very frequently high land occurs along or near their shores. In many cases the mountain-chains which bound or traverse the continents are of vast lineal extent, indicating dislocations of the solid crust of the earth which reach over very great distances and to great depths, and their frequent parallel direction suggests a probable association in the causes and time of their production. The usual distribution of volcanoes along continuous lines, extending in

many cases over thousands of miles, can hardly be explained otherwise than as being consequent on the existence of ruptures in the solid crust of the earth penetrating to very great depths. The superficial extent of many of these dislocations of the earth's crust is not less remarkable than their lineal development, and leads to similar conclusions. Such were the movements that raised the tablelands of Asia Minor, Persia, and Afghanistan, and the great desert plateau of Central Asia, and above all, the vast protuberance of Tibet, and its component gigantic mountain-chains, including the Himalaya. The high lands in both North and South America supply evidence of the same nature.

There was at first no little disinclination to accept theories which accounted for the observed facts of geology by the continued action through vast periods of time of forces now in operation. But these objections have at length disappeared, and with them the school that explained the successive steps which led to the great differences between the past and the present, by a series of catastrophes, or convulsions of nature, for which we have no authority in actual experience.

Should any still hesitate to believe that vast mountains like the Himalaya or the Andes, and analogous depressions of the bed of the ocean, can have been produced by a mere secular change of the earth's temperature, I would remind them that the forces called into action by the earth are proportionate to its magnitude, and that their effects must be on a corresponding scale. It has been calculated on sound data that the contraction of the diameter of the earth, consequent on the fall of temperature from a fluid state to its present condition, has been about 190 miles. At this rate a subsidence of five miles, which is the approximate greatest depth of the ocean, would correspond to a fall of temperature of about 200° F. But the elevations and depressions of the earth's surface were probably produced by a comparatively much smaller loss of heat, and were due rather to tangential strains than to direct upthrust or subsidence.

An illustration may assist in forming a proper estimate of the irregularities of the earth's surface, which, though apparently great, are insignificant when viewed in relation to its actual dimensions. This hall might contain a globe 40 feet in diameter. If this globe represented the earth it would be on a scale of 1 foot to about 200 miles; and 1 inch would be equivalent to a distance of $16\frac{2}{3}$ miles, or 88,000 feet. On such a globe the difference between the polar and equatorial diameters would be less than 1 inch, and the greatest elevations in Britain would be about the thickness of a threepenny-bit. The highest mountains and the deepest seas would be shown by elevations and depressions of hardly more than one-third of an inch; and if they were distributed as such features are on the earth, they would be visible only with difficulty, and to the unaided eyes of a casual observer would hardly interfere with the apparent perfect smoothness of the globe's surface.

The conception of the vast duration of geological time is one with which most persons are now more or less familiar. It is well to remember that great though the changes in human affairs have been since the most remote epochs of which there are records in monuments or history, nothing indicates that within this period there has occurred any appreciable modification of the main outlines of land and sea, or of the conditions of climate, or of the general characters of living creatures. The distance that separates us from those days is as nothing when compared to the remoteness of past geological ages. No numerical estimate on which reliance can be placed has yet been made of the duration even of that portion of geological time which is nearest to us; and we can say no more than that the earth's past history, as recorded in what we now find upon it, or as inferred from what we find, probably extends over hundreds of thousands or millions of years.

The duration of the successive ages of the earth's past existence is measured almost wholly by reference to the fossil remains of animals and plants included in the rocks of which the crust is composed. The likeness of existing forms to those that characterise each gradually receding period constantly diminishes, and the more ancient shapes which connect the present with the several stages of the past, often, by their diffusion, supply indications of the synchronism of deposits at distant places. Light is thus thrown, though it be an imperfect one, on the former distribution of land and sea, and on the existence of antecedent communications by land and sea between parts of the earth now severed, or the converse.

It is through the facts of geography as now acquired and interpreted, that the geologist is supplied with the means of arriving at the true signification of much that occurred in past time, the traces of which survive in physical features or organic forms. He finds that the most important agencies in determining and modifying the present conditions of existence on the earth, whether as affecting inorganic nature or organic beings, are closely connected with the actual distribution of land and sea, and the configuration of the surface; and he learns that it is through these agencies that he must seek to unravel the intricacies of the past.

The study of geology, in its turn, enables the geographer to understand many things that would otherwise be unintelligible to him. He thus learns how the boundaries of sea and land have been determined; where connections formerly existing have been severed; how islands have risen from the ocean and may be sinking below it; to what causes are due the rocky coasts and headlands, the indentations of the coasts, the formation of bays and fiords; at what time and by what means mountains have been raised up, plains laid out, valleys excavated, and the courses of rivers and positions of lakes fixed; and he is taught the constituents and qualities of the materials forming

the surface of the earth, of the soil upon it, and of the minerals beneath it.

And as a better insight is obtained into the natural relations of the mountains, the plains, the valleys, rivers, lakes, and seas, the conviction arises that the ever diversified details of the face of the globe are in no sense accidents or fortuitous results, little worthy, as such, of admiration unless for their picturesque forms or wonderful proportions; but that they are the direct, orderly, and necessary outcome of the action of forces simple in themselves, and operating in accordance with well-known and invariable physical and mechanical laws. The perception of general characteristics of structure among the various features of the earth's surface, that pass under our review, is, indeed, too often overshadowed and obscured by their magnitude, by the multitude of their details, and by the variety of their forms, which at first produce impressions of hopeless confusion; but, when once the idea of subordination to common laws is duly conceived, it receives confirmation at every fresh step taken.

The area of the dry land is very greatly exceeded by that which is covered with water. The whole surface of the earth being 197 millions of square miles, about 55 millions are land, and 142 millions water. The average height of the land above the sea-level is also very much less than the average depth of the sea-bottom below that level; so that a rearrangement of the surface is quite possible by which the whole of the land might be submerged with comparatively little disturbance of the present level of the sea, or reduction of its average depth.

The highest measured peak of the Himalaya, known as Mount Everest, which is also the highest in the world accurately determined, just rises 29,000 feet above the sea-level, but such elevations even as 15,000 feet are, elsewhere, with the sole exception of parts of Tibet, confined to isolated peaks or very narrow bands along the crests of a few of the highest mountain ranges. The area above 12,000 feet is about 2 per cent. of the whole land, and that above 6000 feet less than 9 per cent. From a careful computation recently made, it would appear that the mean height of the surface of the land above the sea-level is about 2250 feet; the continental areas having the following elevations:—Europe, 939 feet; Asia, 3073 feet; North America, 1888 feet; South America, 2078 feet; Australia, 805 feet.

The greatest depths measured in the ocean exceed 27,000 feet, and it has been estimated that the mean depth is about 12,500 feet. About 5 per cent. of the ocean area is less than 600 feet in depth, and a somewhat smaller proportion, more than 18,000 feet. About 17 per cent. is less than 3000 feet. The ocean bed generally appears to present very extensive, comparatively uniform plateaus, varied only by moderate undulations, possibly to be attributed to contractions

of the earth's crust caused by cooling; these range in depth from 12,000 to 17,000 feet, and their general direction maintains a rough parallelism with that of the neighbouring continents. Submarine deposits derived from the land do not extend beyond 300 or 400 miles from the shores; but at great depths deposits are being formed with extreme slowness, which are probably derived from decomposed organisms, or from cosmic, volcanic, or other matter, carried down through the water.

Accepting these estimates, it will appear that the volume of land above the sea-level is about $\frac{1}{15}$ th part only of the volume of the ocean. This relatively very small volume of land, and comparatively uniform great depth of the sea over very large areas, when considered in connection with the evidence that exists of the continuity of the earth's history within the range of geological time, strengthens the view, based on other considerations, that the chief masses of land as we now find them have not greatly varied from their original position. Owing to the great depth of the sea, any upheaval of the sea-bottom, sufficient to form new land, would be likely to displace a volume of water greater than that of the new land, unless it were accompanied by an equivalent subsidence and increase of depth in some other locality. Failing this, such an upheaval would be followed by an encroachment of the sea on the land, which would necessarily lose an area corresponding, at all events approximately, with the volume of water displaced, and the area thus lost might easily be greater than that gained.

With the latest additions made to our knowledge of the depth of the ocean there has also been acquired an altogether new series of facts bearing on its temperature, and its capacity for supporting life. The variations of heat and cold, due to change of season or to day and night, which affect the surface, descend to a comparatively small depth, being greatly reduced in the first 100 fathoms, and below that depth for the most part eliminated, so that at 300 or 400 fathoms, an approximately uniform temperature is met with. With increased temperature at the surface, there is increased evaporation, followed by greater density, by reason of which the surface water sinks, and the higher surface temperature is partially communicated to the subjacent strata. Further, it appears that though the surface temperature of the ocean varies generally with latitude, reaching a maximum of 86° , or perhaps a few degrees higher, yet at the greatest depths, or say generally at 2000 fathoms (with an exception to be explained immediately), the water has in all latitudes a nearly constant temperature but little above the freezing-point. This is mainly due to the flow of glacial water from the Antarctic polar area towards the warmer equatorial regions, along the sea-floor, to which it sinks by reason of its greater density. The exception referred to occurs in the case of any area which is cut off by an intervening shoal from communication with the

deep glacial waters. In such cases the bottom temperature is determined by the mean winter temperature of the surface, unless the temperature of the external oceanic water at the level of the shoal be the lower of the two. Thus in the great basins of the Pacific, Indian Ocean, and Atlantic, which are of such a depth as to be in free communication with the Antarctic seas, the bottom temperature ranges from 32° F. to 36° F. In contrast with this, in the Mediterranean, which is cut off from the deep waters of the Atlantic by a shoal at a depth of about 200 fathoms, an effectual barrier is interposed to the entrance of water of a lower temperature than about 54° F.; and no lower temperature than 55° F., which corresponds to the mean winter temperature of the surface, is found even at 2000 fathoms. In the Red Sea a similar result is observed, the bottom temperature not falling below 71° F., at a depth of about 700 fathoms.

From the mobility of water, and its high specific heat, which is almost four times that of the materials composing the land-surface, the sea-surface can never acquire a very high temperature. At the same time, the evaporation which is constantly going on from the whole surface of the ocean, leads to a large quantity of the heat it receives from the sun becoming latent, and powerfully aids in preventing an accumulation of heat. These facts render the ocean one of the most important factors of terrestrial existence; it furnishes to the atmosphere the moisture which is one of the essentials of life, and serves by the circulation of its waters, and the diffusion of vapour derived from it, to equalise the temperature of the globe, by moderating the extremes both of heat and cold. Hence the greater or less proximity of the sea directly affects all conditions of climate.

The circulation of the waters of the ocean, which is set up chiefly by the action of winds on the surface, but in part by variations of temperature and of density, and by the effects of evaporation, is controlled in all its details by geographical features.

The trade-winds, which maintain over a large part of the ocean an almost constant current of air in a westward direction between the tropics, converging towards the equator, give rise to the great equatorial oceanic currents, which, impinging on the eastern shores of the continents, are deflected to the north and south along them, and tend to establish systems of circulation in the several oceanic basins, north and south of the equator, and between the east and west shores of the continents between which they lie. In the northern hemisphere the movement is from south to north and east along the eastern shores, and from north to south and west along the western shores; while in the southern the direction is the reverse, from north to south and east along the eastern shores, and from south to north and west along the western shores. These currents from or to the equator conform generally to the directions that would be imparted to them by the rotation

of the earth, and no doubt acquire additional force from this cause, particularly where the prevailing winds blow in the same direction, as they frequently do.

The most remarkable of the ocean currents is, without question, that along the east coast of North America, commonly spoken of as the Gulf-stream. It acquires great persistency from a combination of causes, which enables it to carry a very high temperature into the Arctic Circle to the north of Norway, and most powerfully to influence the climate of Western Europe, which hence offers an astonishing contrast to that of the eastern coasts of the Atlantic in the same latitudes. Thus the isotherms of sea-surface temperature, from 75° F. to 40° F., on the American coast range in the summer months between latitudes 35° and 50° N.; that is, over about 10° of latitude, or 700 miles. On the coasts of Europe and Africa the same isotherms range between 20° and 70° N., or rather beyond these limits; that is, over more than 50° of latitude, or 3500 miles. In the former case there is a change of temperature at the rate of one degree in 20 miles, in the other in 100 miles.

There are many other interesting peculiarities in the distribution of ocean temperature, to one of which I will refer. It is the occurrence of narrow tracts of relatively very cold water along certain parts of the west coasts of Africa and America, in close contiguity to areas presenting the normal temperature corresponding to the latitude. This peculiarity has been referred, with apparent reason, to the effect of the prevailing winds, which, blowing from the east, drive the surface-water away from the coasts, where it is constantly replaced by the cold water which rises from below.

How greatly local conditions of surface are able to affect the operation of the most far-reaching forces of nature is well illustrated by the tides of the ocean. The combined attraction of the sun and of the moon tends to produce a twofold tidal wave in opposite hemispheres; the crests of these travel from east to west, or in the opposite direction to that of the earth's rotation, succeeding one another at intervals of 12 hours 24 minutes, half the period of the moon's revolution round the earth, and if undisturbed would follow the apparent place of the moon, the effect of which luminary is about double that of the sun. This result is actually produced in the more open part of the ocean, chiefly in the more southern latitudes; but the distribution of the great masses of land is such that elsewhere the progress of the tidal wave in the normal direction is not possible. In the Indian Ocean and the Northern Atlantic the principal tide is propagated from south to north, and, speaking generally, in our own seas the tidal wave approaches the west and south coasts, travelling from west to east, or in a diametrically opposite direction to that of the force which generated it; while on the east coast it flows from north to south, entirely reversing the direction in which it passed

up the Atlantic. In the open sea, as observed on small islands, the rise and fall of the tide is very little, amounting to one or two feet only; but the range is in some places more than forty feet, as in the Bristol Channel, at St. Malo on the French coast, and in the Bay of Fundy. These very high tides, as well as the strong currents which in some localities accompany the flow and ebb, are secondary results due to the gradually contracting area or diminishing depth of the portion of the ocean in which the tidal wave is propagated, that wave originating in a movement of oscillation, not of translation.

The great importance, for purposes of navigation, of a knowledge of the extent and periods of the rise and fall of the tide, which vary with the distance and apparent place of the moon, has directed the attention of mathematicians to the subject, and methods have been devised by which the daily times and heights of high and low water at any port may be calculated and predicted with great precision, after a comparatively short series of observations.

It has been calculated that the forces of attraction which produce the tides of the ocean are sufficient to cause some deformation of the solid globe. The whole of the movements due to these forces being in a direction opposite to the earth's rotation, give rise to friction which leads to an extremely slow gradual reduction of the velocity of rotation. In former conditions of the earth and moon, such as there is reason to think have occurred, the changes thus produced may have been very much more rapid, and their effects may have had extremely important consequences when the globe was in a semi-fluid state. It has been suggested, in connection with speculations of this nature, that the corrugations of the cooling globe from which the existing great masses of land and the ocean beds received their original forms, may have been caused by the tide-producing forces of attraction.

The motion of the tidal wave is so greatly interfered with by the land, that the velocity of its transmission is eventually reduced to that of a free oscillating wave. This velocity, which depends on the depth of the water in which it is propagated, possibly averaging 400 or 500 miles per hour through the open seas, does not differ materially from that of the great seismic waves caused by the eruption of Krakatoa in 1883, as deduced from the numerous records obtained from various parts of the earth, including the coasts of France and England, to which the disturbances reached.

Among the influences which give to the earth the characteristics that most immediately affect its fitness for occupation by man and the support of life generally, those due to the atmosphere are, without doubt, the most prominent. These, under the designation of climate, are constantly affecting us. But of all recognised branches of science, that which treats of the atmosphere—meteorology—is at the present time

certainly the most backward. The reasons are not far to seek. The air is invisible, and in its upper regions inaccessible. The changes it undergoes are difficult to observe, and, from their great complexity, difficult to grasp, while what we know of them is almost wholly confined to the immediate proximity of the earth. It is pretty certain that the most important among the causes which operate on the atmosphere are changes of temperature; but the application of mathematical reasoning to the movements of an elastic fluid such as the air, charged with watery vapour, when submitted to changes of temperature upon a rotating sphere, presents very serious difficulties, and little has been done to grapple with them. What is known of these subjects is as yet almost exclusively empirical. Instrumental appliances are here far in advance of theories, and it is not to be disguised that great waste of labour too frequently results from an exaggerated refinement in observation, and subsequent numerical computation, which has no real value.

The air is a highly attenuated fluid medium, beneath which the whole surface of the earth is immersed, and by which all that is on the earth is surrounded, supported, and penetrated. It is the vehicle through which warmth, moisture, and the gaseous necessities of life are supplied to all living things. The variations of the temperature, of the pressure, and of the motion of the air, and of the quantity of vapour it contains, give rise to the great series of phenomena which are included under the general term climate. Of these variations the primary causes are the action and reaction of the mechanical and chemical changes set up by the sun's heat as influenced by the earth's motion, terrestrial position, and the condition of its surface, as well as by fluctuations of the sun's heat itself, though of these last we know too little to do more than recognise their presence.

The conditions which determine at any place the greater or less degree and duration of direct exposure to solar radiation, and therefore the quantity of heat received there, are position in relation to latitude, combined with the diurnal and annual movements of the earth. The nature of the surface regulates the local accumulation of heat, by reason of the varying power of absorption or radiation possessed by different substances; while with elevation above the sea-level as the density of the air becomes less, the sensible temperature and the quantity of watery vapour are subject to corresponding change. The whole of the results thus produced, moreover, are modified by movements in the air consequent on atmospheric changes from place to place, or from time to time.

All the determining causes of variation of climate just mentioned are brought into prominently contrasted action over areas of land and water. The equable sea climates on the one hand, and on the other the extreme variations of heat and cold, of drought and flood, on the great

continents, with the multitude of local results dependent on them, supply well-known illustrations of this truth.

The inequalities of the earth's surface, which are insignificant when viewed in relation to the whole globe, are of the greatest importance in relation to the atmosphere. For owing to the laws of elastic fluids, the great mass of the air and of the watery vapour it contains are concentrated very near the surface. One-fourth of the air and one-half of the vapour are found below 8000 feet from the sea-level; one-half of the air and nine-tenths of the vapour are below 19,000 feet, which hardly exceeds the average elevation of the highest ranges of the Himalaya Mountains; while three-fourths of the air and virtually the whole effective vapour lie below 30,000 feet, and therefore within the influence of the highest summits of those mountains. That portion of the atmosphere which is nearest the surface is manifestly the most likely to be acted upon by irregularities of relief, and by local variations in the power of absorbing or radiating heat or diffusing vapour. Hence it is certain that it is the movements of the lower strata of the atmosphere that chiefly affect all conditions of climate, though no doubt there are great movements in the upper regions to bring about the restoration of equilibrium, which is being constantly disturbed from below.

The principal periodical winds—such as the trade-winds, the monsoons, the land and sea breezes—are found to be essentially dependent on periodical variations of atmospheric pressure, accompanying variations of temperature due to geographical position or surface conditions. The proximate causes of the more characteristic winds of the west of Europe, and especially of our own islands, have also been well made out. These, too, are due to atmospheric disturbances producing areas of high or low pressure; the rapidity and intensity of the development of which, with the direction of their paths and their position, determine the force of the wind, the direction in which it blows, and the manner in which it veers or backs, that is, changes its direction. But how the changes of pressure are determined, and what causes the transfer of the disturbed area, commonly under the form of an atmospheric eddy or vortex, in a definite direction, usually from west to east, is still to be ascertained; though here, too, it is obvious that the distribution of the land and sea areas, and of the ocean currents, on which the temperature of the superincumbent air so immediately depends, combined with the rotatory motion of the earth, are among the principal agencies at work. The winds of our islands have commonly, more or less distinctly, the gyratory character which, as before noted, is one of the secondary results of the rotation of the earth. The precise conditions under which the great cyclones or hurricanes of the tropics are generated are still uncertain, but there is sufficient knowledge of the manner of their occurrence to show that they are disturbances set up by changes of temperature, and to enable the instructed mariner in most cases to escape their worst consequences.

With the ocean, the air performs the part of equalising temperature, and mitigating excessive local accumulations or losses of heat; and as the ocean supplies the source of moisture, so the air distributes it, first taking it up as vapour, and then carrying it off and delivering it up, with the heat absorbed during evaporation, at distant places.

Among the most intricate problems of meteorology are those relating to the evaporation of water, the formation of vapour and its diffusion and suspension in the air, and its condensation as cloud, rain, or snow. The low specific gravity of aqueous vapour, and the constant evaporation that releases it at the earth's surface, tend to diffuse it in accordance with the mechanical laws which govern elastic fluids. But the reduction of the temperature of the air in ascending above the surface renders this diffusion impossible beyond a certain point; and observation shows that the quantity of vapour actually existing in the upper parts of the atmosphere is mainly dependent on temperature, and amounts to not more than one-fourth part of what would be present if it were diffused freely, and simply obeyed the law of hydrostatic pressure. It follows that a height in the atmosphere is at length necessarily reached where condensation must take place and clouds or rain be formed; and that, speaking generally, the vapour in the upper strata of the air is constantly tending to a condition of unstable equilibrium, from which it may readily be once more restored to the earth in the shape of water. Thus, assuming the temperature of the air at the sea-level to be 80° F., and the quantity of vapour to be 80 per cent. of what air at that temperature can hold in suspension, the free diffusion of the vapour would cause it to ascend in such quantity that condensation would take place at a height of between 3000 and 4000 feet, that being the elevation at which, the temperature of the air being about 70° F., the ascending vapour could no longer remain in suspension. Consequently clouds or rain would be formed at this elevation, and any further movement of the vapour upward would be arrested. This sufficiently accounts for the rarity of a perfectly cloudless sky, which indeed can hardly exist, excepting where such a movement of the air is going on as will carry off the aqueous vapour, as fast as it is formed by evaporation, to a region where the temperature is high enough to prevent its condensation.

The great activity of the air in discharging the function of equalising temperature and distributing moisture over the earth is remarkable. If the whole quantity of moisture in the air at any moment were condensed so as to leave it absolutely dry, the resulting stratum of water, if distributed evenly over the whole earth, would be less than one inch in depth. Yet it is estimated (though perhaps on insufficient data), that the mean rainfall over the whole globe is not less than 60 inches in the year, and falls of ten times this amount are known to occur in some localities. Observations of the velocity of the wind at marine stations show that these results are due to the almost unceasing passage of air highly charged with vapour over the regions where, and

during the time in which, rain thus falls, and to the unceasing renewal of the supply of moisture by evaporation. The relatively very large sea-area has an important effect in maintaining the supply of the rain that falls on the land; and the immediate dependence of rainfall on local geographical features is too well known to call for more than a passing remark. The presence of mountains forming a barrier in the path of the vapour-bearing winds may determine, on the one side a climate of perpetual cloud and rain, and on the other vast tracts of desert. Where no mountains exist to cause condensation such winds may pass on, leaving deserts behind them, and carry their waters to fertilise more fortunate lands beyond.

The action of the periodical winds or monsoons in bringing with them the seasons of rain in the tropical and semi-tropical regions of the earth, is of the greatest practical moment. The water-supply and the production of the ordinary food-crops are often wholly dependent on such rains; and the light thrown by science on the controlling causes of their failure or abundance may enable us to foresee the possible occurrence of drought, so as to guard against its worst consequences.

Instances of the fall of rain in excessive quantities on the windward faces of mountains exposed to winds blowing from over the sea, with relative drought to leeward, may be found in every part of the globe. In the British Isles, may be mentioned the excessive rain on the hills of Cumberland exposed to the south-west winds that blow directly up the Irish Sea and St. George's Channel. In Ireland the same facts are to be observed on every one of the clusters of hills that stand up above the otherwise low flat surface. The contrast between the fall of 73 inches at Bergen, on the coast of Norway, directly exposed to the south-west, and its reduction to one-third of that quantity at Christiania, and to one-fifth at Upsala on the continental side of the Scandinavian Peninsula, is most striking. The rainy and well-wooded eastern slopes of the Andes may be contrasted with the barren western flanks of the same chain, where it hardly ever rains; and the rainless district of Chili on a west coast, south of the equator, coinciding with the region of the south-east trade, where there is a constant current of air from the coast seaward, displays almost the exact reverse of what is observed north of the equator on parts of the west coasts of Europe and Asia, where the rain falls in torrents during the seasons when the south-west winds blow inland from over the ocean.

A few words will indicate the magnitude of the forces which are called into silent and comparatively unobserved operation in the atmosphere by the sun's heat, in the production and recondensation of aqueous vapour. It has, as I noticed, been estimated that on the average 5 feet of water falls annually as rain over the whole earth. Supposing that condensation takes place at an average height of 3000 feet above the surface, the force of evaporation must be equivalent to a power

capable of lifting 5 feet of water over the whole surface of the globe, 3000 feet during the year. This, not reckoning the force required for the transport of the rain in a horizontal direction, would involve lifting 322,000 millions of pounds of water 3000 feet in every minute, which would require about 300,000 million horse-power constantly in operation. It may assist in the apprehension of these numbers to mention that the engines of the largest ironclad do not exceed 12,000 horse-power. Of the huge energies thus exerted a very small part is transferred to the waters that run back through rivers to the sea, and a still smaller fraction is utilised by man in his water-mills; the remainder is dissipated in celestial space.

A well-known consequence of the physical properties of the air is the gradual reduction of temperature observed in ascending mountains. This, amounting to 1° for about 300 feet of elevation, gradually produces a change of conditions similar to that caused by passing from the equator towards the poles; and at the greatest elevations an arctic climate is established even under a tropical sun.

Among the sublimest sights furnished by nature are the great ranges of mountains which traverse or approach the tropics; rising into the regions of perpetual snow, they discharge important functions in the economy of the globe. By the intrusion of the solid terrestrial surface into the upper part of the atmosphere, the low temperature there, which otherwise could have produced no effect on the earth, is brought into active operation; great rivers spring from the melting fields of snow and ice that crown the mountain summits, and swollen by the copious condensation of rain on their slopes, flow down to the plains below, which are fertilised by their perennial waters.

Ice, whether in the shape of glaciers excavating their mountain beds, or as the floating fragments of glaciers which, forming icebergs, tear up the floor of the ocean, or when by expanding in the fissures of rocks it rends them asunder, is one of the most energetic of destructive agents. The recurrence in the earth's past history of glacial epochs alternating with epochs of greater heat, of which geology supplies evidence, is of much interest, and has given rise to much speculation. Among possible causes of this are to be reckoned the variations which in the lapse of time take place in the ellipticity of the earth's orbit, combined with changes of the position of the axis due to precession. At a period of maximum ellipticity, the quantities of heat received by the earth, at its least and greatest distances from the sun respectively, must be increased and diminished accordingly; and should it happen that at such a time the change in the direction of the earth's axis caused by precession, brought either hemisphere to face the sun fully when nearest to the earth, very considerable effects on the summer and winter temperatures of the two hemispheres must be produced, without affecting the mean temperature of the globe; in the more directly exposed hemisphere the

summer would be shorter and hotter, and the winter longer and colder, while in the other hemisphere there would be a milder and shorter winter, and a longer but colder summer. Displacements of the earth's axis of rotation have also been suggested as a means of accounting for some of the great local changes of temperature indicated by geology; but the evidences of such displacements hardly amount to more than arguments, based on mathematical reasoning, which show that they are not incompatible with established facts.

GEOGRAPHICAL NOTES.

Result of the first year's Examination for the Scholarships and Prizes offered by the Society to Students in Training Colleges.—The Education Department have communicated to us the names of the students who have most distinguished themselves in geography at the examinations last December, and to whom the Examiners have awarded the Society's prizes:—Male Candidates: Scholarship (15*l.*): J. W. Goodyere, Borough Road College; Prizes (Books): Fredk. Baker, Cheltenham College; H. Grover, Battersea College, and J. E. Quaife, Borough Road College (equal); A. J. Berry, Battersea College.—Female Candidates: Scholarship (15*l.*): A. E. Alexander, Whitelands College; Prizes (Books): A. Eve, Bishop Stortford College; K. Charlton, Lincoln College; Isabella Junes, Warrington College; Gertrude Martin, Chichester College.—The prizes will be presented at the Anniversary Meeting of the Society, May 28.

Connection of the Mobangi with the Welle-Makua.—It is reported from Brussels that the interesting problem of the outcome of the Welle—the fine river discovered by Schweinfurth in the Niam Niam country—has at length been solved by the persevering Belgian explorer Captain Van Gele.* He has found it to be continuous with the Mobangi, and therefore a tributary of the Congo. Details of the journey, and especially information regarding the navigability of the river, which leads from the great Atlantic Congo into the heart of Africa and the best parts of the Soudan, will be anxiously looked for.

Physical Geography of the Congo.—M. Édouard Dupont, Director of the Brussels Natural History Museum, has just returned from a visit of several months to the Congo, during which he examined the banks of the river as far as the mouth of the Kassai. In a lecture to the Belgian Society of Engineers he has given some of the results of his examination. He believes he has found the key to the process by which the Congo has been able to reach the ocean across the barrier of mountains which separate its upper course from the coast. The interior waters of equa-

* For Captain Van Gele's first exploration of the Mobangi *vide* 'Proceedings R.G.S.,' 1887, p. 440.