THE INTRODUCTORY COLLECTION.

ASTRONOMICAL RELATIONS OF THE EARTH.

This introductory collection properly begins with the more important astronomical relations of the earth, or with the earth as a planet, illustrating especially the relative distances, magnitudes, and motions of the sun and moon, which are the principal sources of the energy of the various agencies operating upon the earth's surface. The relative sizes and distances of these bodies are shown by the two models one of which is suspended in the upper part of each window case. The gilded ball represents the sun on the scale of about 225,000 miles to one inch, and the round black dot in the center of the square white plate shows the earth on the same scale, their diameters being approximately as 1 to 110. The distance between these models represents the mean distance of the earth and sun, about 93,000,000 miles, on the same scale as the models; while the orbit of the moon is represented by a circle on the square plate, at its proper relative distance from the earth, about 240,000 miles. The moon itself, on this scale, would be microscopic, being represented by a dot having one fourth the diameter or one sixteenth the area of that representing the earth.

[1] These two sections are to be regarded as one, the specimens on each shelf continuing across from left to right; with one set of numbers, the odd decades being on the left and the even decades on the right.

The earth fills $\frac{1}{2,200,000,000}$ part of the solar sky, *i. e.*, it intercepts that almost infinitesimal fraction of the light and heat which emanate from the sun on all sides. The corresponding fraction in the case of the moon is about $\frac{1}{1500}$. The sun and moon are interesting to us chiefly, not by virtue of their vast dimensions and distances, but as sources of force or energy; and we can form some conception of their stupendous importance in this regard by comparing the fractions given above with the energy actually intercepted by the earth. This energy comes to us chiefly in two forms: *gravitation* and *heat*.

It is gravitation that holds the earth and moon in their orbits, the mutual attraction of the sun and earth for example, being equivalent to a powerful cord connecting the two bodies and preventing the earth from moving off in a straight line. The strength of this invisible restraining force is as great as if every square foot of the earth's surface lighted by the sun's rays were connected with the sun by a steel rod between one third and one half of an inch in diameter. The attraction of the sun and moon also produces the oceanic tides.

The amount of solar heat received annually by the earth is sufficient to melt a layer of ice 136½ feet thick, covering the entire surface of the earth. Or, expressed mechanically, it is equivalent to more than two horse-power acting continuously on each square meter of the earth's surface. On the surface of the sun itself, the solar radiation is equal to the continuous action of more than 100,000 horse power per square meter.

The model over the right or west window-case illustrates chiefly the relative positions and motions of the sun, earth, and moon. The large central globe represents the sun; and on turning the crank the smaller globe, representing the earth, is carried around it; while the smallest ball, representing the moon, is carried around its primary, the earth. The mechanism is so adjusted that the distance between the earth and sun varies with the seasons, being greatest at the summer solstice (June 21) and least at the winter solstice (Dec. 21). The model of the earth is suspended in such a manner that its axis remains parallel to itself, *i. e.*, maintains a constant direction in all phases of its annual revolution around the sun; so that, the earth's equator being inclined at an angle of $23\frac{1}{2}^{0}$ to the ecliptic or the plane of the earth's orbit, the north pole is constantly turned toward the sun in our summer (Mar. — Sept.) and the south pole in our winter (Sept. — Mar.) The apparatus is always adjusted for the current month, and thus illustrates and explains the changes of the seasons.

The earth is not a perfect sphere but is flattened at the poles the polar diameter or the earth's axis (7,899 miles), being about $26\frac{1}{2}$ miles shorter than the equatorial diameter (7,926 miles). The earth is, in other words, an oblate spheroid; but, although its variation from the true spherical form seems actually large, the flattening at the poles is relatively so small that an exact model of the earth could not be easily distinguished from a perfect sphere.

INTERNAL CONSTITUTION OF THE EARTH.

Before noticing the surface configuration of the earth, we may observe the most probable constitution of its interior.

The weight of the earth has been determined by entirely independent experiments with the plumb-line, the pendulum and the torsion balance; and the closely accordant results which they afford show that the earth is about five and a half times heavier than a globe of water of the same size; *i, e.*, the mean density or specific gravity of the earth is about 5.5. But the average density of the materials composing the superficial portions of the earth, the common minerals and rocks, is less than half as great, or 2.6. Hence it is evident that the interior of the earth must consist of much heavier materials than the exterior.

There are several distinct lines of evidence pointing to the conclusion now generally accepted that the earth's interior is mainly composed of one substance — iron. Many of the volcanic rocks, and especially those which, from their homogeneity, we may suppose to have come from the greatest depth in the earth, contain a larger proportion of iron than is found in the materials normally forming the earth's surface. This is shown by the first series of specimens in this case (**12–16**). Gneiss (**12**) is taken as the typical representative of the earth's crust or surface, with less than five per cent. of iron. Then comes diabase (**13**) as the most representative eruptive rock, with from 5 to 15 per cent. of iron. And, lastly, we have the so-called ultrabasic eruptive rocks represented by the porphyritic magnetite from Cumberland, R. I., (**14**), containing 15 to 40 or more per cent. of metallic iron, or so large a proportion that they are essentially ores of iron. The meteorites (**15–16**), which, as the specimens show, are either pure iron or highly ferruginous, are believed to be, in a general way, average samples of the materials of which the earth is composed.

The density of the earth as a whole is readily explained, as Professor Dana has shown, if we assume that it is two thirds iron, or iron from the center to within 500 miles of the surface. And in the present state of the science we are justified in thinking of the earth as possibly a ball of iron some 7000 miles in diameter, surrounded by a thick layer of stony material, in which the percentage of iron and density diminish gradually toward the surface.

It seems inexpedient, in the present state of our knowledge, to attempt to illustrate the probable distribution of heat and of solid and liquid materials in the interior of the earth. Any views on these subjects are necessarily largely speculative; and the following statements are designed merely to show the narrow limits of our actual knowledge, and the general tendency of geological opinions on these subjects at the present time.

Numerous observations in mines, artesian wells, etc., show that the temperature of the ground always increases downwards from the surface; and the much higher temperatures of hot springs and volcanoes show that the heat continues to increase to a great depth, and is not merely a superficial phenomenon. The observed rate of increase is not uniform, but it seldom varies far from the average, which is about 1° Fahr. per 53 feet of vertical descent, or, in round numbers, 100° per mile. This rate, if continued, would give a very high temperature at points only a few miles below the surface; and until within a few years, the idea was generally accepted by geologists that the increase of temperature is sensibly uniform for an indefinite distance downward; that in the central regions of the earth the temperature is far higher than anything we can conceive, and that everywhere below a depth of 20 to 40 miles the temperature is above the fusing point of all rocks; and hence that the earth is an incandescent liquid globe covered by a thin shell or crust of cold, solid rock.

There are, however, several important considerations which now oblige us to modify this view. It is certain that the temperature of the earth cannot increase downward at a uniform rate, but only at a constantly and rapidly diminishing rate; and it is probable that below a depth of 300 miles the temperature is everywhere sensibly the same, and nowhere incomparably higher than temperatures we are acquainted with on the earth's surface. The lavas emitted by volcanoes in all parts of the globe prove that the subterranean temperature is sufficient to fuse ordinary rocks; but many geologists hold that the enormous pressure to which matter must be subjected in the deeper portions of the earth, and which is supposed to favor solidification, neutralizes the high temperature and keeps the great central mass of the earth solid in spite of the heat. The existence of the oceanic tides and certain astronomical phenomena are believed to support this view. All that we actually know, however, is that the temperature of the ground increases downward until it becomes sufficient to fuse considerable volumes of rock.

EXTERNAL CONFIGURATION OF THE EARTH.

The inequality of the earth's polar and equatorial diameters is relatively small; but the inequalities of relief presented by its surface, and which we call continents and oceans, mountains and valleys, etc., are utterly insignificant compared with the vast dimensions of the earth itself. This is clearly illustrated by the two large diagrams on the wall in the west window-space. Each diagram represents a sector of the earth one degree or about 70 miles broad. The first one is drawn on a radius of 8 inches or a scale of 500 miles to the inch; the middle circle represents the surface of the earth, while the inner circle marks the thickness of the earth's crust, and the outer circle the upper limit of the atmosphere. The colored portion of this diagram is all that is included in the second diagram, which is drawn on a radius of 800 inches or a scale of 5 miles to the inch, and shows the thickness of the solid crust of the earth (assumed as 35 miles), the hight of the atmosphere (also assumed as 35 miles), the probable extreme depth of the ocean (about 30,000 feet), the probable mean depth of the ocean (about 15,000 feet), the mean hight of the land (about 1,000 feet) and the extreme hight of the land (29,000 feet). To fully appreciate the diagram it is necessary to remember that the two converging vertical lines representing the radii of the earth would meet at a distance of 800 inches or 66⅔ feet from the blue line which represents the surface of the ocean.

The area of the earth's surface is 197,000,000 square miles, of which 144,500,000 are water and 52,500,000 are land, the proportion being nearly 275 to 100, or approximately 8 parts water to 3 parts land. The mean depth of the ocean greatly exceeds the mean hight of the land, so that while the land has nearly three eights the area, it has only one fortieth the volume of the ocean. The general distribution of land and water is shown by the physiographic map of the world on this wall-space.

The general contours or vertical forms of the continents and ocean-basins are also shown on this map by the shading, the boundaries of the different tints being, as explained on the map itself, essentially contour lines. This map shows further that the actual shore-line is not necessarily the true border of the continent and ocean. Along some coasts, as that of New Jersey, the true continental edge is submerged, and the water deepens very slowly at first, so that the 100 fathom line is 50 to 150 miles from the shore, while a few miles farther brings us to the 500 fathom line; the more abrupt descent indicating that we have crossed the true boundary line between the continent and ocean basin.

In accordance with this principle, all islands standing on these submerged borders of the continents are classed as continental, while only those rising from the deep waters of the ocean are properly oceanic. Thus Great Britain and Ireland are a part of the European continent; Newfoundland and the Grand Banks belong to North America, and the Malay Archipelago to Asia.

The positions and directions of the principal mountain-ranges of the globe are indicated by the heavy black lines on the small maps of the continents; and it will be observed that these axes of elevation are, for the most part, grouped near to and parallel with the coast-lines. These small maps and the accompanying sections of the continents also illustrate the following general laws in the reliefs or surface forms of the continents: (1) The continents have in general elevated mountain borders and a low or basin-like interior. (2) The higher border faces the larger ocean.

The distribution of land in high latitudes, so far as known, is shown more clearly by the maps of the polar regions in the case (**6**); and the physiography of the United States is represented in greater detail by the colored map at the top of the case (**2**) and the shaded map below it (**3**). The latter represents a model of the United States viewed from above, and also the middle belt as seen obliquely from the south, bringing out the east-west profile more distinctly. Far superior to these illustrations, however, is the model itself—the large relief map of the United States. This is constructed so as to show the natural curvature of the earth's surface; and, except that the vertical scale is necessarily exaggerated, it is a faithful representation of the main relief features of our country. The longest diameter of the model, it will be seen, embraces but a small section of a complete circle; and it thus shows almost as clearly as a globe how small a part of the terrestrial sphere the United States actually covers. The model, which is in a large degree self-explanatory and will repay careful study, shows not only the configuration of the land, but also the subaqueous contours of the great lakes and the adjacent parts of the ocean, thus developing the true form and relief of this part of the continent, and showing, as previously pointed out, that the continental border is often outside of the actual shore line. The mean annual isothermal lines are also traced upon the map.

CIRCULATION OF THE ATMOSPHERE — ATMOSPHERIC CURRENTS OR WINDS.

The wind map (**4**) illustrates the circulation of the atmosphere, or the prevailing winds of the globe. The atmosphere, under the influence of gravity, tends always to adjust itself so as to be in a state of equilibrium, the chief condition of which is a uniform density at any given altitude, the density diminishing upward with the decreasing pressure. But the continuance of this equilibrium requires uniformity of temperature, as well as of pressure, in all parts of the same stratum of air.

If any stratum is unequally heated in different parts, the equilibrium is destroyed. The warmer portion expands and becomes lighter; and being pressed upon by the adjacent colder and heavier air, it rises, and its place is occupied by the latter. This process results in an ascending current from the region of greatest heat, and horizontal currents flowing from all directions towards that region.

Hence from the permanent inequality in the distribution of heat in the tropical and polar regions, there results, in each hemisphere, a constant circulation of the atmosphere consisting of (1) an *ascending current*, in the zone of highest average temperature; (2) a *polar current* flowing upon the surface, from each pole towards the equator; and (3) a *return current* flowing from the equator towards either pole partly in the upper air and partly on the surface.

The upward motion of the ascending current is imperceptible, the atmosphere seeming to be in a state of rest; hence this is known as the zone of equatorial calms. Near the tropics, where the return currents descend, there are also belts of calms; but these are less defined than the equatorial belt. The three belts of calms are represented by the yellow color on the map.

In consequence of the earth's rotation, the normal direction of the polar current is northeasterly in the northern hemisphere, and southeasterly in the southern; and the return currents become southwesterly winds in the northern hemisphere and northwesterly in the southern. These directions are plainly indicated by the arrows on the map, and also by those within the circumference of the circle in the diagram.

Since the earth performs one entire revolution on its axis every twenty-four hours, the velocity of rotation at the equator must be somewhat more than 1,000 miles an hour. As each successive parallel towards the poles has a less circumference than the preceding, the velocity of rotation diminishes with increasing latitude, until at the poles it is zero. If, therefore, particles of air move from the polar regions towards the equator, each step in advance will bring them upon parallels where the rotation is more and more rapid. The new velocity cannot be instantly acquired; consequently, at each successive parallel the moving particles are left a little behind, or to the west of their previous position; and when they reach the tropics they are many degrees west of the meridians upon which they left the polar regions. A similar cause operates to give the return currents their eastward tendency. The particles moving towards the poles find, at each successive parallel, a rotary velocity less than at the preceding. Not acquiring the new and less rapid motion instantaneously they gain a little at each parallel, and find themselves in advance or to the east of their former position.

The general law of atmospheric circulation explained above gives rise to three distinctly marked wind zones on each side of the equator; namely:— (1) the zone of *constant* or *trade-winds*, extending to latitude 25° or 30°, represented by the pink color on the oceanic portions of the map; (2) the zone of *variable winds*, with alternate polar and equatorial currents dominating, extending to latitude 60°, or near the arctic circle, and indicated by the green color on the map; and (3) the zone of prevailing, though not constant, *polar winds*.

The positions of the various wind and calm zones change with the seasons, all advancing northward and retiring southward with the apparent motion of the sun. The northern and southern limits of the trade-winds and equatorial calm belt, for the four seasons of the year, are shown in the diagram in the lower left-hand corner of the map.

CIRCULATION OF THE OCEAN–MARINE CURRENTS.

The next map (**7**) illustrates the oceanic circulation, the principal currents being represented by the bands of light and dark green, and their directions by the arrows.

The main causes of these vast movements in the ocean are found in the winds, the excessive evaporation within the tropics which tends to lower the level of the water there, and the differing temperatures of the polar and equatorial regions.

Two series of currents of opposite character pervade the sea in high latitudes: the *cold*, flowing from the polar regions toward the equator, and the *warm*, flowing in the opposite direction, the tendency of both currents being to restore the equilibrium distributed by the trade-winds, the intense heat and the evaporation within the tropics. In the middle latitudes, where the opposing currents meet, the cold, being heavier, sink beneath the warm and disappear, continuing their course in the deep waters. These cold under-currents, having reached the intertropical seas, gradually rise again to the surface, where they become heated; and contributing their waters to the great equatorial current, which flows westward on each side of the equator, they finally return to the poles.

The westward flowing equatorial currents are due chiefly to the incessant action of the trade-winds; and, if they were not intercepted by the continents, they