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THE drama of the earth's history consists in the struggle between the forces of uplift and the forces of degradation. The forces of uplift are mainly the outward expression of the inner energy and heat of the earth, whether they be the volcano belching its ashes thousands of meters into the air, or the earthquake, with the attendant crack or fault in the earth's crust, leading to a sudden displacement, and sending, far and wide, a death−dealing shock, or those mountain−building actions, which, though they may be as gentle and gradual as might be produced by the breathing of mother earth and the uplifting of her bosom thereby, nevertheless, end in the huge folds of our mountain ranges.

Against these, there are always working the forces of degradation—the slow rotting of weathering caused by the direct chemical action of the moist atmosphere or the alternation of hot and cold which crumbles rocks far above the line where rain never falls. Once the rock is rotten and decayed, it yields readily to the forces of degradation, which drag it down—the beating of the rain, the rush of the avalanche or of the landslide, the tumult of the torrent, the quieter action of the muddy river in its lower reaches or the mighty glacier which transfers fine and coarse material alike toward the sea.

These actions are always going on. Are they always equally balanced, or are there periods when the forces of elevation are more active, the forces of degradation not so powerful, as against other times in which the forces of degradation alone are at work? If there is inequality in the balance and struggle of these contending forces, the great periods or acts in the geologic drama might thus be marked off as Chamberlin suggests. Newbery, Schuchert and others have pointed out that there seem to have been great cycles of sedimentation which may be interpreted as due to the alternate success, first of the factors of elevation, then of those of degradation.

Suppose, for instance, that there has been an epoch of elevation, that mountain chains have been lifted far into the sky and volcanoes have sent their floods of lava forth, and fault−scarped cliffs run across the landscape and that then, for a while, the forces of elevation cease their work. Little by little, the mountains will be worn down to a surface of less and less relief, approaching a plain as a hyperbola approaches its asymptote—a surface which W. M. Davis has called peneplain.

But where will the material thus worn go? Into the sea. Going into the ocean it will raise the level of the sea slowly but surely. At present, for every four feet of elevation taken off the land, there will be something like one foot rise of the ocean level, and this rise may take only thirty thousand years—a long time in human history, but not so long in the history of the earth. All the time, then, that the forces of the atmosphere are wearing down the surface of the earth to the sea level the sea is rising and its waves are producing a plain of marine denudation which rises slowly to meet the peneplain which is produced by degradation. In the beginning of this cycle, where the forces of degradation have their own way, coarse material may be brought down by torrents from the mountains, and the glaciers, which find their breeding place in these high elevations, may drag down and deposit huge masses of boulder clay. But, little by little as the mountains are lowered, the sediments derived from them will become finer and finer and glaciers will find fewer and fewer sources.

Not only that, but the growth of seas extending over the continents will tend to change the climate, we shall have a moister, more insular climate, we shall have a greater surface of evaporation, and thus, on the whole, a more equable temperature throughout the world. We know that, at present, the extremes of cold and hot are found far within the interior of the continents. Continental climates are the climates of extremes, and on the whole extremes are hurtful to life. So then as the forces of degradation tend to lower the continents beneath the sea level glaciers and deserts and desert deposits alike must also disappear. Vegetation will clothe the earth, and marine life swarm in the shallow seas of the broadening continental shelf. Under the mantle of vegetation, mechanical erosion will be less, that is, the breaking up of rocks into small pieces without any very great change, but the rich soil will be charged with carbon dioxide, and chemical activity will still go on. Rivers will still contain carbonates, even though they carry very little mud, and in the oceans the corals and similar living forms will deposit the burden of lime brought into the sea by the rivers. Thus, if forces of degradation have their own way, in time there will be a gradual change in dominant character, from coarse sediments to fine, from rocks which are simply crumbled debris to rocks that are the product of chemical decay and sorting, so that we have the lime deposited as limestone in one place and the alumina and silica, in another. We shall have a change from local deposits, marine on the edges of large continents, or land deposits, very often coarse, with fossils few and far between, to rocks in which marine deposits will spread far over the present land in which will appear more traces of that life that crowded in the shallow warm seas which form on the flooded continents. We shall have a transition from deposits which may be largely formed on the surface of the continents. lakes, rivers, salt beds and gypsum beds, due to the drying up of such lakes and the wind−blown deposits of the steppes, to deposits which are almost wholly marine.

Now, I need not say (to those who are familiar with geology) that we have indications of just such alternations in times passed. There are limestones abounding in fossils, with a cosmopolitan life very wide spread to be recognized in every continent, such as used to be known as the Trenton limestone, the mountain limestone, the chalk. Perhaps every proper system and period should be marked by such a limestone in the middle. The time classed as late Permian and Triassic on the other hand was one of uplift, disturbance, volcanic action and extreme climates, which gave us the traps of Mt. Tom, the Palisades of the Hudson, the bold scenery of the Bay of Fundy and the gypsum and red beds which are generally supposed to be quite largely formed beneath the air and beds of tillite formed beneath glaciers. Then in the times succeeding, in many parts of the world, degrading forces were more effective than uplifting so that the mountains became lower, and the seas extended farther over the continents. Then the prevalence of lime sediments was so great that the "chalk" was thought to be characteristic everywhere. And about the time the "chalk" the land was reduced to a peneplain. A similar cycle may be traced from the Keweenawan rocks to the group of limestones so widespread over the North American continent and so full of fossils, which to older geologists and oil drillers have been known, in a broad way, as Trenton.

All this introduces a question—to which I wish to suggest an answer—How is it that these cycles came to be? Were the outer rock crust of the earth perfectly smooth the oceans would cover it to the depths of thousands of feet and it is only by the wrinkling of such a crust that any part of it appears above the ocean. If the earth had a cool thin crust upon a hot fluid interior, and that thin crust were able to sustain itself during geologic ages so that the shrinkage should accumulate within, until finally collapse came, giving an era of uplift, it is obvious that we could account for such cycles. There is very clear evidence that the outermost layer of the earth's crust is but a thin shell like the outer shuck or exocarp of a butternut, so thin that it is not at all possible that it can sustain itself for more than a hundred miles or so, or for more than a very few years at the outside. Hayford's[1] investigations are the latest that show that the continents project because, on the whole, they are lighter, they float, that is, above the level of the oceans because there is a mass of lighter rock below, like an iceberg in the sea. Here the likeness between nut and earth fails and it would be more like the earth if the outer shuck were thicker in certain large areas. If this extra lightness or "isostatic compensation" is equally distributed, Hayford finds[2] that the most probable value of the limiting depth is 70 (113 km.) miles, and practically certain that it is somewhere between 50 (80 km.) and 100 (150 km.) miles; if, on the other hand, this compensation is uniformly distributed through a stratum 10 (16 km.) miles thick at the bottom of the crust so that there is a bulging of the crust down into a heavier layer below to balance the projection of the mountains above, as I think much more likely, then the most probable depth for the bottom of the outer layer is 37 (60 km.) miles. This layer is much thinner than the outer layer of the figure and is supposed to yield to weight placed as, though more slowly than, new thin ice bends beneath the skater.

[1] The figure of the earth and isostasy from measurements in the U.S. Dept. of Commerce and Labor, 1909, p. 175.

[2] loc. cit., p. 175.

There are a number of facts which support this so−called theory of isostasy, according to which the crust of the earth is not capable of sustaining any very great weight, though it may be at the outside rigid, but is itself essentially like a flexible membrane resting on a layer of viscous fluid. However viscous this fluid may be and *rigid to transitory quickly shifting strains like those produced by the earth's rotation, it does NOT REMAIN AT REST in a state of strain (at any rate if this strain passes limits which are relatively quite low). Not only are, according to Hayford's observations, the inequalities of the North American continent compensated for by lighter material below, so that the plumb− bob deflections are only one twentieth what they would be if they rested upon a rigid substratum of uniform density, but other facts that lead to the same conclusion are the apparent tendency of areas of sedimentation to slowly settle under their load, the apparent settling of the Great Lake region under a load of ice and springing up again since the removal of the ice. But if the theory of isostasy is true, one would at first say that there could be no great accumulation through a geologic period of stresses which would finally yield in the shape of folded mountain ranges. It has, in fact, been suggested that mountain ranges have been slowly folded and lifted as the stress which produced them accumulated and this would seem to be true if one considers only the outer crust, but on the other hand, as we have pointed out, there are indications in the history of the earth of periods of relative quiescence followed by periods of relatively considerable disturbance.*

How can these two theories be reconciled in accordance with what we know of the laws of physics and chemistry and those of the earth's interior? It seems to me they can by making suppositions which are perfectly natural regarding the state of the earth's interior.

We are at liberty to suppose if the facts point that way that there are the following layers in the earth's masses:—First, the external, rigid and brittle layer; second, a layer under such temperature and pressure that it is above its plastic yield point and may be considered as a viscous fluid. The pressure must continue to increase toward the center. We do not know what is the temperature, but it is perfectly possible that at a greater depth the earth may become rigid once more if the effect of pressure in promoting solidity and rigidity continues, as Bridgman tells me he thinks probable. We do not even have to assume a change in the chemical composition of the earth's substance, though it is perfectly allowable. This, then, will be a third layer, once more rigid, perhaps extending to the center and of very considerable thickness and capable of accumulating strain from long periods. Blanketed as it would be by thousands of meters of the first two layers, any change must be relatively slow.

Kelvin in his computation of the age of the earth from cooling assumed for the interior of the earth constant conditions. It is now generally accepted that this is not probable, and that whether it cooled from a gas or coagulated from planetesimals, it became solid first at the center which then would be hottest, and both Becker[3] and A. Holmes[4] assume an initial temperature gradient. If that gradient were greater than the gradient of steady flow the conditions of steady flow would be approached most rapidly at the exterior, the loss of heat and energy would be altogether from within and it is easy to arrange for conditions mathematically in which almost all the loss of energy would come from the very interior, near the center. What will be the effect? A paradoxical one, if the part outside the center is rigid enough to be self−sustaining. The central core will become a gas!

[3] Bull. Geol. Soc. Am., Vol. 26, 1915, p. 197, etc.

[4] Geological Magazine, March and April, 1913.

This is so contrary to our ordinary experience and ideas, in which loss of heat tends to change from gas to fluid and solid, that we must look into it a little to make it sound reasonable. The recent brilliant work of P. W. Bridgman (contrary to the earlier speculations of Tammann) indicates that the effect of increased pressure, at high temperature, makes a substance solid and crystalline. Crowd any atoms close enough together, and no matter how fast they expand or contract under the influence of heat the crystalline atomic forces will get to work when they are crowded within their range, and the closest packing, hence that which will yield most to the pressure, hence that which is likely to take place, is when they are all regularly arranged facing the same way. Such an arrangement we call crystalline. Just so when they want to pack the most people into the car of an elevator they ask them to all face to the front. Keep this metaphor a moment. Any one who should try to penetrate such a crowd would find it a hard job. They would offer a very effective rigidity. Now suppose them to sweat in those confined quarters their fat away, their phlogiston, their caloric. If the walls of the car remained rigid while the individuals therein shrunk they might after a while be able to turn around or even move around in a car. Such is then the supposed condition of the atoms in the FOURTH, the central, layer of the earth's crust. This assumes that the middle layer is rigid and sustains itself, like the shell of a nut, as in the figure, while within the atoms are in a less rigid condition. That such a shell might be self−sustaining is suggested by an experiment of Bridgman, who put a marble with a gas bubble in it under a pressure of something like 150,000 pounds to the square inch without producing any perceptible change.

As loss of energy from the earth's interior went on this central core of gas would enlarge until the middle shell was hardly self−supporting. Then, probably at some time of astronomic strain when the earth's, orbit was extra elliptical, it would collapse, in collapsing generate heat, and so stop the process. The collapse would be transmitted to the viscous layer which might be increased, motions set up in it, and so a wrinkling of the outer thin crust on which we live.

Then there would be four layers to the earth like the butternut of the figure. First, the inner kernel of gas; second, the hard shell or endocarp; third, a viscous layer like the sarcocarp or pulp, and outside of all the wrinkled crust of exocarp. If such is the structure of the earth we may have in the very structure of the earth itself a reason why from time to time there are collapses of the middle layer leading to elevations of portions of the outer rind, and marking off the chapters in geological history, the lines between geological systems.

There are reasons in facts of observation for believing that such is the structure of the earth, of which I have as yet said nothing. We see the interior of a glass marble, I saw the bubble in the interior of Bridgman's glass marble, how? By waves, vibrations, which start from the sun or some other source, and going through it reach my eye. Though the earth is not penetrated by sunlight it is penetrated by the waves and vibrations that start from that jar produced by a crack which we call an earthquake. These vibrations can be received by that eye of the geologist called a seismograph. The seismologist tells us there are three kinds of waves sent out in an earthquake. If you notice the explosion of a blast at a little too close distance you will notice that you see it first, then hear it, and then perhaps a little later a few chips of rock may come flying past your ears. These three things correspond somewhat to the three kinds of waves which spread forth from an earthquake. But in the case of the explosion we see the blast first, then hear later. The waves which produce the sensation of sight are, we know, lateral disturbances, the waves which produce the sensation of sound are waves of condensation, whose motion is in the direction of their propagation and they come later. In the case of the jars of earth, the reverse is true. The first set of waves to arrive are the waves which are due to compression—vibrations in the direction in which the waves are produced—and correspond to sound waves. Later come waves which are transverse sidewise disturbances of the solid mass of the earth. As we can easily see, in an earthquake jar traveling from the opposite end of the earth, there should be no insurmountable difficulty in recognizing the jar, which is a direct upthrow from one which would tilt it to the right or left. Now there is a law of Laplace by which the velocity of spread of sound waves through gas may be calculated. That this law should hold at temperatures and pressures so high as those that must exist in the middle of the earth is, of course, a question, but it will be interesting to see how nearly the actual velocity of about 10 kilometers a second compares with the velocity which such waves should have in gas of a density and under a pressure such as a gas near the center of the earth must have. Using Oldham's figures (and they seem to be confirmed by the recent investigations of E. Rudolph and S. Szirtes[18]), we find that the time of transmission of these first and fastest preliminary compression tremors is about twice the velocity of such a jar according to Laplace's law in as dense a mass of gas, provided the ratio of the specific heat of a gas at constant pressure to that of a gas at constant volume remains 1.4, which is for many substances. But as it is 1.6 for mercury the discrepancy is not more than I had expected.

[5] Gerlands, "Beitrage zur Geophysik," XI., Band, 1 Heft, 1911, p. 132. "Das kolumbianische Erdbeben am 31 January, 1906."

The second preliminary tremors arriving later are due to the lateral disturbance. Their propagation is much less rapid when the point of origin is nearly opposite the point of receival. In other words there is a core within the earth about 0.4 of the radius in radius, in which according to Oldham, these lateral waves have much less velocity. Now in a gas there is less resistance to lateral displacement than in a solid, and the less the resistance the less the velocity, so that this fact fits in with the idea of a gaseous core perfectly. If there is such n core, moreover, of less rigidity it would have less refraction. Consequently waves not striking the border above the angle of total reflection would be totally reflected, and just as around a bubble there is a dark border where the light does not get through so at a certain distance from the source of an earthquake there would be a circle (it is really about 140 degrees of arc away), where no second tremors would be felt. Here again, though seismograph stations are as yet few, fact and theory are apparently going to correspond.

The last type of earthquake waves follow around the outer layer of the crust.

There is one farther line of verification to which I had addressed myself. Is it likely that the loss of heat and energy from the central nucleus, at the rate which we know at the surface from a central nucleus of anything like

0.4 the radius of the earth, would give a shrinkage of anything like the amount indicated by the mountain ranges, in anything like the time which we are led to assign on other grounds to the geologic periods?

Rudski has also attempted to connect the shrinkage and age of the earth. Both these methods depend on how fast the earth is losing heat, that is on the geothermal gradient. Since at present, owing to the apparently large but unknown contribution of radioactivity to that gradient we know very little about what the other portion is, it seems unwise to give any figures, especially as almost all the numerical data are largely guess work. It will, however, be fair to say that very long times for the age of the earth seem to be indicated, nearer millions of millions than millions unless the radius of the gaseous core was mainly small or its rate of contraction with loss of temperature high.