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NOTE ON THE "AGE OF THE EARTH."[1]

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ROUGHLY classified, there are four principal ways of estimating the duration of geologic time, of which two are geologic and two non-geologic. The first of these is based on sedimentation, and the second on erosion; the third is based on terrestrial temperature and supposed rate of cooling, and may be designated physical; the fourth method rests on inferences as to the cooling of the sun and other cosmic changes and conditions, and may be called astronomical.

The sedimentation estimate, as commonly applied, depends on an erosion estimate for its unit; usually it is assumed that the rate of degradation of the land is a foot in 3,000 to 7,000 years, and that in the long run the rate of sedimentation on the sea-bottoms of the globe is the same. The unit rate commonly accepted is that determined by Humphreys and Abbot from measurements of the matter transported by the Mississippi River, or one foot in 6,000 years = 1 mile in about 30,000,000 years. In earlier decades the aggregate thickness of sediments was usually placed at a few miles only, but probably no modern geologist acquainted with the results of researches in the Algonkian rocks of the Lake Superior and other regions would venture to estimate the total thickness at less than 50 miles; and this rate and thickness of sediments would indicate a period of 1,500,000,000 years for the deposition of the stratified rocks of the earth. It is probable that geologic process was more active in the earlier ages than at present; on the other hand, the deposition of the stratified rocks represents only the closing episode in the history of the earth — ages must have been required for the antecedent cooling and encrusting of the planet before the transfer of materials by hydric agency began.

Until recently the erosion estimate has seldom been applied, except as a unit for the sedimentation estimate; and even now it is applicable only to the later eons without the introduction of so many unknown quantities as to vitiate its results. Perhaps the most favorably conditioned region for the use of this method thus far studied is that found in eastern United States. Here rate-units have been determined from the measurements of recession of Niagara Falls and other cataracts, and these have been corroborated by measurements of the recession of Saint Anthony and other cataracts in the Mississippi Valley. These rate-measures and the measures of the volume of material removed from the gorges since the disappearance of the latest ice-sheet of the Pleistocene yield a fairly consistent chronometer for the post-glacial period, giving a value ranging from a few thousand to as many as 50,000 years. Toward the margin of the glaciated area in eastern United States there is another series of gorges, of which that of the Potomac, between Great Falls and Georgetown, may be taken as the type, representing erosion since the close of the Columbia period, or since the end of the first ice-invasion of the Pleistocene. A number of these gorges have been studied by Chamberlin, Salisbury, Gilbert, and others, as well as by the writer; and all geologists familiar with them are agreed that, if the post-glacial erosion is represented by unity, the post-Columbia erosion must be represented by two figures. These post-Columbia gorges themselves are excavated in the bottoms of many times longer and wider gorges recently shown to have been cut since the deposition of the Lafayette formation — e.g., the post-Columbia gorge of the Potomac is not over 12 miles long, a quarter of a mile in mean width, and 100 feet in mean depth, or $\frac{1}{17}$ of a cubic mile in content; while the post-Lafayette gorge of the upper river with its principal tributaries may fairly be put at 600 miles in aggregate length, 1 mile in mean width, and 250 feet in mean depth, or 30 cubic miles in content, or more than 500 times greater than the post-Columbia gorge.

The recent estimates for the post-glacial period derived from the Niagara and other gorges are shorter than of old, ranging from 5,000 to 10,000 years; it is not conservative to estimate the post-Columbia gorges at less than 20 or 30 times as old (assuming erosion to be uniform), or, say, 200,000 years. Now the post-Lafayette period is represented not only by the gorges trenching the Piedmont and Appalachian regions, but also by the widespread ravining and hill-sculpturing of the pre-Lafayette base-level peneplain of these regions, by great estuaries hundreds of feet deep and scores of miles broad traversing the coastal plain, and by the entire removal of two-thirds of the volume of the Lafayette formation (nearly all along and north of the Potomac) and extensive degradation of subjacent rocks, i.e., by erosion fully 500 times greater in the gorges and many thousand times greater over the general surface than the post-Columbia erosion; and it is accordingly hardly conservative to estimate this period at less that 20, 50, or 100 times longer than the post-Columbia period, or say 5,000,000 or 10,000,000 years. In this estimate allowance is made for the discrepancy between the figures based directly on relative erosion and those derived from the Humphreys and Abbot coefficient (1,000,000 or 2,000,000 years for the 200 or 300 feet of post-Lafayette degradation). It is, of course, to be remembered that erosion, *per se*, does not give a trustworthy time-measure, since stream-work is a function of declivity rather than time; but in eastern United States the physiographic conditions affecting stream-declivity have varied so little as to render the erosion-rate here exceptionally uniform.

In brief, while the erosion estimate of geologic time is subject to a large probable error, even to a considerable "factor of safety," the phenomena of eastern United States indicate an enormous lapse of time, probably reaching into millions of years, since the deposition of the late Neocene-Lafayette formation; yet this is one of the latest episodes in the development of the continent.

Combining the erosion estimate and the sedimentation estimate by employing the former so far as applicable and then using sediment ratios beyond, with a "factor of safety" beginning at 4 for the last and shortest period and raised to successively higher powers with each successive period and age counted backward into the past, the following values are obtained[2]: —

Period or Age.	Mean Estimate.	"F. of S."	Minimum Estimate.	Maximum Estimate.
Post-glacial period...	7,000	4	1,175	28,000
Post-Columbia.......	200,000	16	12,5 0	3,2 0,000
Post-Lafayette. ..	10,000,000	64	156,000	640,000,000
Cenozoic (including Lafayette)........	90,000,000	64	1,406,000	5,760,000,000
Mesozoic	300,000,000	256	1,172,0 0	76,800,000,000
Paleozoic.............	2,400,000,000	1024	2,343,000	2,457,600,000,000
Age of the Earth.....	6,000,000,000		10,000,000	5,000,000,000,000

[1] The meeting of the Geological Society of Washington, held April 12, 1893, was devoted to a symposium on the age of the earth, based chiefly on the recent article on that subject by Mr. Clarence King (Amer. Jour. Sci., vol. xiv., 1893, pp. 1-20); and these paragraphs are a revised abstract of remarks made on that occasion.

[2] American Anthropologist, vol. v., 1892, pp, 329-340. Through a simple and evident arithmetic error in this paper, Dana's ratios of 1, 3, and 12 for the Cenozoic, Mesozoic, and post-Cambrian Paleozoic are computed as 1, 3, and 36.

These general estimates are indefinite, and the minima, mean, and maxima are alike unworthy of final acceptance; but they stand for a real problem and not a merely ideal one, and represent actual conditions of the known earth; and, so far as the science of geology is concerned, the maximum estimate is quite as probable as the minimum, while the mean is much more probable than either.

As commonly made, the physical and astronomical estimates of the age of the earth are based on the assumption that the planet is (1) homogeneous, and (2) simple in structure. Thus the cooling of the earth would appear to be assumed analogous to that of a heated spheroid immersed in an ocean, and cooling at a rate determined by relative temperatures of spheroid and water, i.e., at a progressively decreasing rate. Now the actual planet is (1) heterogeneous and (2) complex in structure; and it may be questioned whether sufficient allowance is made for these facts in the non-geologic estimates.

By reason of terrestrial heterogeneity, the temperature of the earth's surface is not directly dependent on the relative temperatures of the terrestrial interior and surrounding space, but is chiefly determined by a complex and wonderfully efficient mechanism for collecting and conserving solar heat, in which the atmosphere and the liquid envelope play important *rôles*. Most geologists and physicists are of opinion that glacial periods might be explained by geographic changes, and hesitate to adopt such a theory only because of the dearth of positive evidence, or the existence of negative evidence, of such changes; and it is commonly recognized that, other conditions of sun and earth remaining unchanged, the earth might be materially chilled or warmed if the land and sea were disposed in zonal or meridional belts in such manner as to cut off or facilitate aqueous and aërial circulation. There is, indeed, reason for supposing that if the earth with its present mean interior temperature were divested of its heat-conserving mantles of air and water it would become a frozen planet. Thus, whatever may have been the case in the pre-geologic stages of planetary development, the present temperature of the external earth, and so its rate of cooling, depends on the sun rather than on the proper heat of the planet; and if (as is probable) the aggregate quantity of air and water enveloping the planet is diminishing, the efficiency of the terrestrial mechanism for conserving solar energy must have been even greater during the earlier ages of geologic development than now.

Again, the earth is complex in chemic constitution, and, moreover, it is probable, if not certain, that this complexity is correlated with temperature. If the course of terrestrial development, as commonly recognized, could be reversed for a time, the constitution of the earth-crust would be materially modified; as the temperature rose through a few degrees, the oxidation and fermentation of certain substances would doubtless be accelerated; with a few dozen degrees increase, life would be destroyed and the highly complex compounds manifesting that form of energy would be broken up; with a few hundred degrees rise, the coals would be consumed and the carbonaceous shales and limestones would be transformed, and these changes would be accompanied by profuse development of energy in the form of heat; and with a few thousand degrees increase in temperature, most of the compounds of the earth-crust would be modified or destroyed and the elements separated or re-combined in simpler forms. Consideration of the effects which would necessarily follow reversing the mechanism of planetary development indicates that the history of planetary growth is one of chemic differentiation coupled with molecular degradation, in which at least such molecular undulations as those of light and heat have progressively decreased in vigor. Moreover, this law appears to pervade the cosmos. It is probable that, as long since suggested by Kirkwood, the temperature of the cosmic bodies varies directly, while their chemic complexity (as determined by the spectroscope) varies inversely with their volume; and the meteorites, which give some indication of the constitution of other parts of the solar system, if not of still more distant portions of the cosmos, are made up chiefly of elements common to the earth, yet are united in frequently distinct and usually simpler compounds. Thus the phenomena of the planet, of the cosmos in general, and of meteorites appear to express a law of inverse relation between chemic constitution and temperature, i e., a law of chemic differentiation accompanying molecular degradation; and this law is in accord with the results of some of the latest researches concerning the ultimate relations of matter and energy. It follows that an aged planet like the earth must have stored up within it a vast amount of latent molecular energy; and incidentally that the law of cooling based on bodies of simple constitution is inapplicable. So it may be questioned whether the simple law of cooling, supposed to indicate the age of the earth, is more trustworthy than would be a formula for the volume-temperature relations of H_2O, derived from laboratory experiments on ice when extended to a body of the same substance passing through the gaseous, liquid, and solid conditions; or whether the simple law of cooling deduced largely from laboratory experiments conducted under circumscribed conditions are much more applicable to the highly complex earth than to the body of a hibernating animal.

In short, the geologic estimates of the age of the earth are based on direct observation under actual conditions so fully known, that, although certain factors are variable, all may be safely assumed to be known; while the factors involved in the non-geologic estimates — surface and sub-surface temperatures, thickness of the earth-crust, properties and conditions of rocks, etc. — must be furnished by the geologist, so that, at the best, such estimates represent nothing more than the grist ground from a mathematical mill; and, moreover, it usually happens that unknown factors are introduced to give texture to the product, but which, at the same time, so far adulterate the grist as seriously to affect its value. The geologic estimates concerning the age of the earth are based on real processes and actually observed conditions in such manner as practically to eliminate inaccuracies growing out of complex and unknown factors, and are thus strictly pertinent to the case; while the non-geologic estimates are based on ideal conditions immeasurably simpler than those actually attending a planet, and thus, interesting and instructive as they are in the abstract way, have very little to do with the concrete case.

It is significant that the discussion of geologic process by students who are not geologists is commonly trammeled in two diametrically opposite ways. The student of the "exact" sciences is seldom willing to grant so high a degree of mobility in the terrestrial crust as is required by the geologist to explain current continent movements, and is given to rejecting or ignoring the evidence of such movements; while, on the other hand, he is the first to reject as excessive the time-estimates of the geologist based in part on, and in complete harmony with, these observed movements. This mental habit, growing out of the methods and postulates employed in certain lines of study, is constantly to be borne in mind in weighing non-geologic opinion concerning the rate of geologic process, just as the opposite tendency on the part of geologic study is to be guarded against.

THE STANDARD COLOR SCHEME.

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IN *Science* for Feb. 26, 1892, I gave a brief account of a color scheme, first proposed by myself in 1880, and set forth in more elaborate form in a paper read before a meeting of the Society of American Naturalists held in Boston, Dec. 31, 1890. During the present year, through the courtesy of the Department of Physics of Wesleyan University, of whose laboratory and apparatus I was allowed free use, the standards previously selected by the consensus of a number of color experts have been located by wave lengths and, as far as possible, also by the prominent absorption lines of the solar spectrum. Since there are vibrations of an infinite variety of wave-length, any number of standards might be selected, but it is not, of course, desirable to select a larger number than the eye can readily distinguish. Six colors are clearly recognized by every normal eye in the solar spectrum, and this number has been chosen for the scheme of standard colors, as being both convenient and practical. These colors are red, orange, yellow, green, blue, and violet. For the area of the solar spec