IS THE EARTH GROWING OLD?

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When geology treats of the age of the earth, it bears in mind only a portion, indeed only a very modest fraction of the period of the earth's existence. This relates to the time taken for the formation of only the outer shell of the whole earth's globe, where there lies the possibility of geological exploration.

For the evaluation of that length of time which elapsed from the very beginning of this earth to its present state we have no certain basis, no sufficiently sure means for estimations. The confines of the universe provide no further help than such as can be gained relative to the hypothetical evolution of the stars based upon the phenomena of the meteors, the planets, the suns, and the varied forms of the nebulæ. Though such ideas rest upon physical laws, nevertheless they are purely hypothetical. The length of time for observation by mankind, so far elapsed, has not been sufficient for us to have convincing observations as to the development of a star. Even the "novæ" give us no clue; in their short life of brilliancy we gain knowledge only of an all too short catastrophic episode in the life of a giant star, knowing nothing of the star's life previous to the catastrophy.

Whatever hypothesis as to the development of the earth we keep in the foreground for the following details, the history of the earth, in point of time, begins with the moment recorded for us by the oldest observed rocks.

What we know of the rocks of this outer layer of the earth—with the exception of relatively few and quantitatively trivial samples from the bottom of the oceans—relates only to the continents and islands. In comparison with the earth's whole bulk, these rocks are an extraordinarily small portion.

We can penetrate into the earth's crust only a little over 2¼ kilometers, about one two-thousand-and-eight-hundredths of the

[1] A discourse (introductory paragraphs omitted) delivered in the new hall of the Royal Frederick-William University, Berlin, by the rector on Aug. 3, 1926, at the celebration held in memory of its founder. Translated and published by permission.

earth's radius. This is in the deepest boring, that of Czuchow,[2] in upper Silesia, driven by the Prussian Government, purely for the solution of important scientific questions. However, the crust fortunately does not cover the earth as a homogeneous layer. It is broken up endlessly into fragments. The separate pieces are multifariously and greatly piled upon and against one another. Great masses are often folded and thrust into the most complicated patterns. Therewith is offered to us the possibility of gaining an insight into a considerably greater depth of the earth's crust. Take, for example, northwest Germany. Despite the slight differences in the altitude of this region, because of the juxtaposition of portions of the earth's crust belonging to very different geological formations and ages, we can here inspect an equivalent thickness of 12 kilometers of sedimentary rocks, dating from the Devonian to the end of the Cretaceous.

American geologists estimate the possibility of thus gaining an insight down to a depth of 100 or more kilometers of the earth's crust. This is surely too large an estimate. It results from a summation of the greatest depths estimated from rocks occurring in separate regions. The addition of such maximum magnitudes gives us a false picture, since in the different regions of the earth, in the same geological epoch, under differing geological conditions, quite different thicknesses of rocks may have been formed. A depth of 30 kilometers is hardly too small an estimate for the depth of the rocks belonging to all the known strata of the earth. Here we consider primarily the layers of sedimentary rocks—sandstones, limestones, etc.—which occur in numerous modifications due to the action of the atmosphere, water, ice, wind, organic life, and which form the unique evidences of the earth's history.[3] But nowhere is this documentary rock book, making up our knowledge of the earth's history, complete throughout the 30, or let us say 100 kilometers. Nowhere at the surface of the globe have there occurred continuously throughout time the formation and conservation of these stratified rocks.

The first rock of sedimentary nature could be formed upon the earth only when there was already a solid substratum upon which and from which sedimentation was made possible. The examination of the oldest and deepest known rocks—those of the Archean age—shows the simultaneous occurrence of sedimentary as well as igneous rocks. The latter exist in such relationship to the sedimentary ones that it is indeed impossible that out of these solidified masses the first

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[2] Czuchow, which was the deepest German and Old World boring, has been surpassed by the boring of Prickett's Creek, W. Va., reaching a depth of some 40 meters more than Czuchow.

[3] F. W. Clarke has computed that the mass of all the sedimentary deposits is sufficient, if spread in a layer over the whole earth's surface, to cover the earth only to a depth of 800 meters, if we take in consideration a thickness of the earth's crust of 16 kilometers.

substratum could have been formed upon which was laid the first sedimentary stratum. By the manner and means of its occurrence, one type of rocks always requires the existence of the other. It is therefore impossible that the oldest known rocks were the first formed.

Now let us postulate, instead of the more generally known Kant-Laplace hypothesis, the Chamberlin-Moulton planetesimal theory. The latter surely more readily explains many phenomena of the solar planetary system than does the older hypothesis. With Chamberlin and Moulton we see the earth increasing in mass through the accretion of those small cosmic bodies, the planetessimals. The earth is thus increasing even at the present, although, indeed, in comparatively small amount, through its encounters with meteors and shooting stars.[4] According to Chamberlin the earth could support organic life by the time it had reached the diameter of Mars; that is, with a volume of only one-ninth of its present amount. Be that so, the earth, in order to sustain life, must then already have had a rocky crust and pressing upon this a hydrosphere and an atmosphere. The formation of sediments would then have taken place, and since that time the earth's crust, in round numbers, must have increased in thickness some 3,000 kilometers. How very decidedly thin is the earth's shell, which we know, in comparison with this great thickness!

Compared with the great size of the earth itself, that part of its crust which is known to us is indeed very petty and the lapse of time necessary for its formation surely vanishingly small compared with the eons which have passed since the birth of the globe itself.

Since the arbitrary appraising of the complete age of the earth by Buffon, now more than 150 years ago, as 74,600 years, repeated researches have been undertaken to evaluate the lapse of time required not only for the formation of the earth's crust but also for the formation of the various rock strata which make up that crust. The various estimates differ greatly. The various premises lead to divergent results.

Figures for the length of time which must have elapsed to account for the formation and accumulation of the sedimentary deposits known within the earth's crust have been obtained from the abrasive effects of the surface waters, from the amount of the newly accumulated sediments, and from the extent of the geological changes at the earth's surface. The resulting values for

[4] An unpublished computation made by my esteemed friend, E. A. Wuelfing, indicates a total of some 3,650,000,000 shooting stars which the earth annually encounters. Their mass could easily amount to a respectable number of tons.

the absolute age of the sediments within the earth's crust vary greatly among themselves, from 30 up to 400 million years.[5] This should not be surprising, for if to-day the rate of formation of sedimentary matter varies greatly in different localities so it must have been in the past. It is, moreover, difficult in the estimation of the lapse of time to make satisfactory premises.

It is an undoubtable supposition that the salt content of the oceans originates from the rocks of the continents (the last end of volcanic activity) and that this salt was carried by the fresh water of the land into the oceans, increasing their salinity; from estimates of the rate of import and deposition we can determine the lapse of time for the existence of the oceans, at least since pre-Cambrian times, and therewith the ages of the sediments in the sea regions of past ages. Values of 100,000,000 to 340,000,000 years have thus been reached.[6]

Apparently very trustworthy estimations of the lengths of smaller durations of time in geological history have been recently made.

The water melting from the inland Scandinavian ice has resulted in the formation of the so-called Bändertone. De Geer recognizes in these, in their alternation of fine sand and clayey material, the influence of yearly variations in the rate of melting of the ice, whence, for the Scandinavian peninsula, he has computed the time elapsing from the beginning of the retreat of the diluvial ice until the present as 12,000 years. Sörgel saw in the rock sequences of the Thuringian diluvium the decisive influence of cosmic factors, the cyclical variation in the obliquity of the ecliptic, the eccentricity of the earth's orbit, as well as the variation of the perihelion distance of the earth and the variation in the intensity in the sun's heat dependent upon these. From these he placed the beginning of the north German diluvium more than 580,000 years ago.

The physical chemists consider that the surest method of estimating the ages of rocks depends upon the amount of the radioactive transformation products present, due to the passage from uranium and thorium to lead and helium, respectively, in the minerals of volcanic origin. The basis for this surety is the fact that radioactive processes are wholly independent of surrounding chemical and physical conditions and pursue their transformations slowly indeed, but at the same speed for all time. Using the rate of transformation of uranium or thorium, the absolute age of a number of volcanic rocks, differing in geological periods, has been computed. Although the values obtained are not fully concordant, generally the results are

[5] We quote only a few values: Sollas reckoned 34,000,000 to 80,000,000; Phillips, 38,000,000 to 96,000,000; Walcott, 55,000,000 to 70,000,000; de Lapparent, 67,000,000 to 90,000,000; Geike, 100,000,000 to 400,000,000 years. Ami Bouê sometime since published a very complete summary of the older estimates.

[6] New estimates due to Sollas give 100,000,000 to 175,000,000; to Holmes, 210,000,000 to 340,000,000; and to Schmiedel of at least 300,000,000 years.

of the same order of magnitude, and large. For the duration of the diluvium about 1.5 million years was computed. Uranium minerals from the Carboniferous age indicate a lapse of 335 million years and rocks from the pre-Cambrian, the period wherein there is direct evidence of a rich and already much differentiated organic life, a lapse of 1,000 to 1,600 million years.[7] [8]

The values obtained in this manner exceed from fourfold to much more those obtained from other geological methods. They are, indeed, very much greater than most estimates based upon the Kant-Laplace hypothesis as connected with the cooling of the earth from a molten condition to its present temperature. Whether it is possible that a more thorough knowledge of the course and duration of the radioactive processes may reduce the age values deduced from such processes—and Joly has already raised objections against the very high values won through the uranium-lead reactions—or the values obtained from geological evidence come nearer the truth, one thing remains certain: The scanty section of the earth's body, which we know geologically, is old. Gradually we have regained our lost respect for great values. Even the approximately 300,000,000 to 400,000,000 years, which is indicated by the salt method applied to the sedimentation within the earth's surface layers, suffice for the indication of a very high figure for the age of these layers known. However, we must assert very strongly that we are far from able by geological means to set the time of the beginning of the formation of the crust of this earth. Evidently the complete time for the existence of the earth must be very manyfold that of the geologically determined period of the earth's history.[9]

Is this earth, whose age is so many millions of years, as thus read from the rocks within its crust, really growing senile?

And this riddle is well asked. We speak of the stars as growing old along the sequence from the white stars to the yellow, from the yellow to the red; the moon is believed to have rapidly aged and died; the cosmos presses on to a warm death; life on this globe presses on to a cold death.

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[7] How widely the estimates of ages from the uranium and thorium minerals may vary is indicated by the work of L. A. Collins (Amer. Jour. Sci., 5th series, vol. 12, July, 1926). The following ages for pre-Cambrian minerals of Australia were estimated: For a fergusonite, 620; a mackintoshite, 1,475; a pilbarite, about 3,840 million years. However, the last-named mineral is annotated as "altered," so that within it the lead-uranium relationship should not be normal but the range from 620 up to 1,475 million years does not seem very small.

[8] The late Professor Barrell (Bull. Geol. Soc. of Amer., vol. 28, 1917) estimated the time since the beginning of the Cambrian period at 700,000,000 years, basing his conclusions mainly on radioactive data. (Translator's note.)

[9] Nernst, arguing generally from the Kant-Laplace theory, estimates the period of the earth's existence as a hot liquid ball as equivalent to the length of time which has elapsed since the formation of the earth's crust, as obtained from the earliest uranium minerals, i. e., about 1,500 million years.

Yet what shall we understand as the aging of this earth? Where and how will this aging be expressed?

Shall we carry over to the earth without further qualification the physiological ideas and processes of growing old, which in many instances are not exactly qualified or known? May we apply such ideas to an inorganic body like the earth?

Evidently the earth, in its processes, presents no picture of developments equal to organic developments.

The biological changes in the life processes of an organism are bound with the wonderful protoplasm through the highly specialized phenomena of assimilation, dissimilation, organic growth, and reproduction.

The petrologist in discussing the earth's volcanic rocks may indeed speak of magmatic "assimilation"; but the inorganic "assimilation" in the earth's crust, in the earth's body, is nothing more than a "solution" within the molten mass through the addition of a foreign substance within an existing molten substance. Similarly magmatic "differentiation" is not to be compared with organic "dissimilation." It is nothing more than one of the various reactions between the components of the magma according to their relative quantities and relations to each other and the variations in the pressure and temperature of the surroundings.

Though, following the planetesimal theory, we talk of the earth growing to its present size, yet this growth is not taken in the sense of the growth of an organism through the actions and reactions of the latter's protoplasm. The growth of the earth is to be taken merely as a simple increase in bulk through the accretion of cosmic bodies. There was, and is yet to-day, an assimilation of these bodies into the earth's substance through weathering and various transformations; but there is here only an addition to the earth of matter, similar to the substance of the earth, coming to it from outside space.

If we might speak of the moon, as W. H. Pickering expresses it, as a late-born child of the earth, and if the depths of the Pacific Ocean indeed show the womb from which the moon was torn out of mother earth's body, this process of the division of a heavenly body into two is least of all to be taken as an instance of organic reproduction.

In general what then shall we take as an expression of the life of the earth that we may measure its growing old? The life of an organism is bound up with protoplasm and its motion. With what is the life of the earth bound? Neither its existence nor yet its length of existence is to be taken as the sense of its life. If we are to draw a parallel from the life of the organic world, then the life of a star should be evidenced by the changes which occur within it through the motions of its component masses. For the earth this will mean to us alterations through movements of masses upon and within the earth's crust, the evidence for which is documented in the manner and nature in which the rocks of the earth's crust occur.

The mass movements of the earth's crust are manifold. There are the movements of the atmosphere and the hydrosphere and their effects upon the rocks of the earth's surface through weathering, chemical transformations, mechanical transportation, the accumulation of material, the formation of new rocks, the movements of glaciers with their effects upon the earth's surface, etc. The intermixing of the rocks of the lithosphere occurs in great variety—through faulting, the earth's crust breaks into great blocks some of which rise, some sink; through folding, the massive mountains and mountain chains rise between immobile blocks; through warping, the earth's crust is arched up in some places, in others it is depressed. The seas accompany such movements by invading the lands in places and in turn are forced to retreat. Paroxysms of trembling in the earth's crust occurring as earthquakes, and the mad outbursts of volcanoes are bound up with movements of the great blocks of this crust. Finally there are the slight tidal movements within the crust, the tides of the ocean and the slight, restless movement of the earth's axis of rotation. All these movements may be taken as the expression of the life of the earth, that Berget has attractively sketched in his beautiful book, "Life and death of this globe."

An organic body (organism), by virtue of its construction out of protoplasm, possesses the ability to pass through its life processes; but this ability is active only when its protoplasmic cell exists in the proper relations to light and warmth, to water and air, and with the necessary food supply. Similarly at least a very great part of the expression of earth-life is possible only through the determining interaction of its surroundings and the cooperation of cosmical influences. Over all stands the mastery of the eternal laws of cosmical physics.

The motions of the atmosphere and the hydrosphere are developed, widely influenced, and kept in their courses through the cosmical element of the radiation from the sun, the earth's rotation, and the changing position of the earth in its orbit. In their motions, as well as their actions upon the rocks of the earth's crust, the atmosphere and hydrosphere are greatly directed and influenced by the action of gravity. Therewith there is a striving, though often interrupted, within the earth's crust, and indeed throughout the whole earth, toward a position of gravitative equilibrium. The rocks formed under the action of the hydrosphere and atmosphere through the

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transformation of preexisting rocks of the earth's crust, and the repeated overlaying of these upon other regions, alter the local gravitational proportion. Therewith result gravitational readjustments of far-reaching effects. The increased local loading through the heaping up of newly formed rocks creates in that region a subsiding movement beneath which there ensues a compensating sideways thrust. The thrust results in an upward movement of the earth's crust elsewhere. Movements of the earth's crust in one place set in action other readjusting movements elsewhere. These readjustments of the earth's outer shell are more or less bound up with the paroxysms of earthquakes and of volcanic actions. And the volcanic reactions continually make rise new masses from the depths to the earth's surface for the geological action of the atmosphere, water, ice, and organic life in a new cycle.

The building of the long, lofty mountain chains stands in close relationship with the mass movements ensuing from the action of the hydrosphere and the atmosphere. In the uplifted mountain chains, their altitude when rightly oriented relative to prevailing winds richly loaded with moisture results in a great increase of rain. Further the surface offered to weathering is much greater than on a level plain. Because of the increased altitude and consequently increased fall for the water, the movement of waters in their channels is greatly increased, and the latter's carrying power is much augmented. In the neighboring plains, where the movement and consequently transporting power of the water is much diminished, the decomposition products, due to weathering and abrasion, will be heaped up. In gathering places, in geosynclines, this mass of matter thus dragged down from the higher ranges upon sinking sedimentation plains, serves for the formation of thousands of meters of new rocks. Out of these areas, as earth history repeatedly shows, new mountains come into existence while the former highlands are worn in proportion to the abrasive action of the water.

None of these mass movements of the earth's crust occurs and works independently. All these life expressions interlock with each other. They show themselves in the most complicated interrelationships. In all these complicated occurrences, their continual, pulsating work forms the manifested whole of this earth's life, the changing episodes of which the rock-made archives of the earth preserve.

Though the unity and heterogeneity of this earth's life stands clearly before us, the next consideration is veiled in uncertainty: What is the unique actuating impulse which leads to this whole interacting complex of the life-assertions of this earth? What originates the impulse which gives to the earth's body the movements which constitute its life?

The answer seemed simple in the period of the unlimited sway of the laws of Kant and Laplace. The loss of heat by the earth entailed a shrinking of its body; this led through the crumpling movements in the relatively solid shell to a distinction between high and low, between mountains and lowlands. Herein lay the cause of all the complexity of the movements to which the earth's crust bears witness.

An especially fortunate form of reply at one time seemed to have been given, an enlightening explanation of the origin of the high and low places on the earth from which would follow necessarily all those movements which we are considering as the life of the earth. This reply came from Lowthian Green in his happy thought of the tetrahedral remodeling of the spheroidal earth. The corners and the edges of this tetrahedral earth were, as this illuminating theory explained, the necessary high regions which caused, directed, and influenced the movements upon and within the earth's crust. But unfortunately all too numerous and weighty objections can be brought against a theory based upon a loss of heat and the consequent contraction, as well as against one consequent to the laws of the nebular hypothesis relating to the contraction of the earth's crust, especially as connected with the reactions of a hot interior upon the outer crust. Such theories can not be brought into general recognition. Just as there are great objections to the nebular hypothesis in elucidating the relations within the planetary system, so there are to it for the explanation of the movements which constitute the earth's life history.

In our need for an explanation of these events in the developments observed in the earth's crust we readily, perhaps too readily, resort to the phenomena of radioactivity. Out of the energy released from the radioactive processes we could conceive a simple explanation of the phenomena of the earth's life. Are we right in this?

However, it seems that at present we must rest content with our knowledge of these phenomena of the earth's life, their interrelationships, alternations, and sequences.

And now let us get back to to-day's question: Is the earth growing old?

Out of the 400 to 1,600 million years of the earth's history of which we know something, can we detect such changes in the evidence of the earth's life as would lead us to the conclusion that there is a crippling in these activities? Such a crippling would mean "growing old."

So far as the rock records of the earth are legible, the "actuality" principle, enunciated by Hutton and more fundamentally stated by Hoff and Lyell, holds for the processes within the earth's crust throughout all the time of the history of the earth known to us. This principle, which has influenced the thoughts of geologists for nearly 100 years, is taken to hold now only in the sense that never upon the earth's crust have forces been active other than those which are acting at present.

Indeed even the oldest known series of rocks tell us, as do those of to-day, of the chemical and physical weathering of the previously existing rocks, of the transport of the weathering products by water and wind. They tell of the accumulation of these products in the lowlands which then existed in opposition to the highlands. They indicate an atmosphere and a hydrosphere with their movements and as to-day, also, the influence of the cosmical agency in the radiation from the sun. From the manner of juxtaposition of even the oldest known rocks there may be inferred the breaking of the earth's crust into huge blocks and mountain building movements of the same nature as those of later periods, just as in the more recent periods, glowing liquid from the depths was pressed through and out of the earth's crust. In one detail only does the evidence of the earth's earlier life differ from that of the present: The evidence of organic life is not handed down to us in the same manner as it is from later periods. That organic life did exist in the Archeozoic era the presence of lime and carbonaceous deposits demonstrates. But the Archaic life was less developed than in subsequent times and consequently its influence in the building and transformation of rocks was of less importance than later.

Always, throughout all time, the same forces, the same manifestations of the life of our earth have been at work as to-day. But not always have they had the same relative importance. Even to-day they do not work the same in all places nor at the same time. Weathering and denudation are much greater in mountainous regions, in the Alps, for instance, than in the flat lowlands in the north of Germany or on the wide plains of central Russia. Weathering and denudation work quite differently under different climatic conditions, as, for instance, upon the east and west sides of the South American Andes. The accumulation and transport of weathered rock is greater in mountain valleys and on the declivities of high peaks than upon the same base in the plains. The action of glaciers is limited geographically, topographically, and by climatic conditions to certain regions. The motions of the earth's crust through earthquakes and volcanic disturbances occur in some regions very much more than in others. In the same places the destructive and constructive forces change even now with the season and climatic changes.

The same conditions held in the past. The nature and amounts of movements and the results varied at the same time in different regions. The differing composition of rocks formed contemporaneously in different regions shows this as well as the varying amounts of the existing rocks formed in the same time at different places. In the same region the formation of rocks varies in time sequence; that is, the factors leading to the accumulation of rocks have varied in intensity and action in the course of time. In the sequence of the rocks of the earth's crust we find almost endlessly occurring cyclic or rhythmic variations. Some of them are directly the consequences of movements in the scaffolding of the earth as shown in the rock series conditioned by the transgression and regression of the seas. Others document the influences of the rhythmical climatic variations which are in their turn bound up with the motions of the earth's crust. W. Ramsay was able to show this convincingly in his fine study, "Orogenesis and climate."

Rhythms are the most evident, the most striking features found in the developments of the earth's history.

The great massive upheavals of the earth's crust like that of the Scandinavian Peninsula, the subsidings like that of the bottom of France, occur rhythmically. They allow the sea to flood the land and then to recede. The repeated alternations of sea and land are rhythmical. The formation of mountain chains by the foldings of the earth's crust is rhythmical. Volcanic activity occurs rhythmically. The great ice ages of the earth occurred rhythmically and were differentiated rhythmically among themselves.

Rhythm dominates the onward flow of the earth's history; never was there uniformity in its paces.

Do these geological rhythms reoccur at equal lapses of time, or are the intervals becoming longer between rhythms of the same class? Are the expressions of the separate acmes becoming weaker? Is there any increasing insensitiveness of the earth to the actuating forces offering an evidence of old age?

Let us consider the formation of mountain chains through folding.

In the oldest period of the earth's history known to us there is such a widespread folding of the earth's crust known that it is indeed ubiquitous. It amounts to a general wrinkling of the earth's surface. Although it is impossible with any success to apply the methods of geology to determining the times of relative occurrence of the rocks of the Archaic times in regions separated from each other, we can at least conclude from the discordances between the Archaic rock series that the formation of the foldings of that era did not owe their existence either to a temporary process or one general throughout that period. For the subsequent foldings of the Algonkian era, although even here the comparisons are yet uncertain, we can say that in both time and place the foldings are conformable. Then there come three great foldings, well recognized in time, place, and nature, the Caledonian, the Variscian, and the Alpidian. Each one of these three is not—as was assumed in the older interpretations—geologically speaking, the work of one time; rather each one is the result of a great number of different folding phases, which among themselves and at different places were of differing intensities and were separated by periods of relative rest so far as faulting goes. We owe to Stille a striking comparison of the occurrence of separate rhythms, the localities of which are very restricted upon small mobile zones of the earth's surface; in general these places are altered for each rhythm, showing the improbability of a really ubiquitous occurrence of the Archaic foldings.

Expressing the times of the occurence of these mountain formations in customary geological nomenclature, the youngest, the Alpidian, lasted with its 11 or 13 phases and their subphases, from the beginning of the Triassic to the end of the Tertiary, through no particular length of geological time. There is a strengthening of its phases until the older Tertiary and subsequently a decline. In the principal phases the folding was extraordinarily strong. The quiescent periods increased in length toward the Tertiary and then decreased in the more recent Tertiary. From its predecessor, the Variscian folding, it was separated by the geologically short quiescent period of the Triassic and in some places by the upper Dyas and the Triassic.

The Variscian folding period, with its four or five phases, occurred during the Carboniferous age and far into the Dyas, and in certain regions, to the end of it. Its phases, varying greatly in intensity in different regions, are separated from each other, so far as the sedimentation indicates, by relatively long periods of rest from faulting.

The Caledonian folding period was separated from the Variscian by the Devonian age, which saw no folding of notable intensity. In this period there are only two folding phases recognizable, separated by almost the whole Silurian. The later, the true Caledonian folding, was the stronger and the wider spread. The long period of quiescence of the Cambrian and the lower Silurian separates the Caledonian folding from those of the pre-Cambrian, the Algonkian and the Archaic times, which are to be placed in no definite comparable relation with the three later periods.

No geological evidence known up to the present gives a basis for the assumption that the time intervals between the three periods of folding should be increased. The number of folding phases in the three periods increases and the intervening intervals shorten rather than lengthen from period to period.

The intensity of the folding, neglecting the wholly undetermined relations of the Archaic-Algonkian times, has certainly not decreased; it has rather increased. It is difficult to reconstruct the mountains of the remote past out of the worn-down remains and then to estimate the magnitudes of the corresponding foldings. We do indeed have many pictures of highly complicated foldings, in the broader significance of the term, in the Caledonian of Scotland and Scandinavia and in the Variscian Appalachians of North America, but it seems to me idle to look in our Variscian Rhenish mountains for such foldings, for example, as the Simplon Tunnel has revealed in the structure of the Alps. The Variscian foldings in middle Europe were manifested upon a far broader basis than in our Alps. I gather from them the impression that on the whole they are less complicated than the more recent Alpidian.

The Alpidian folding occurred over world-wide areas. Its extent was certainly not less than the Variscian; it is known to be greater than the Caledonian folding.

All of this leads me to the conclusion that the possibility and the intensity of these movements of the earth's crust in the mobile zone or in zones which may become mobile and whence mountains may be born, are certainly not decreasing. In the processes of folding there is nothing that indicates that the earth is becoming senile.

During the geological present the earth is again in a relatively quiet period. The continental blocks stand under the influence of a geocratic period such as once followed the Variscian folding in Western Europe during the upper Carboniferous, the Dyas, and the Triassic. Under the still effective influence of the Alpidian folding, the neighboring regions are subjected to such climatic factors that the movements and geological action of the hydrosphere are still very intensive. The amount of these actions will be quite different when these young mountains have been more and more worn down; for instance, the regional climatic differences will be equalized throughout middle Europe. There will then be a repetition of the picture which prevailed at first in the quiescent periods of the Triassic and the Jurassic. However, it will be only the expression of a temporary mode, not a senile weakening of the atmospheric powers.

Since not confirmed by any geological evidence, the idea has been long given up of a steady decrease of the temperature of the earth from early times until the present, although it influenced geological thought for a long time. The demonstration of early ice ages in the Dyas, in the Devonian, in the pre-Cambrian, forces us to discard it because of the proof by Sartorious von Waltershausen, now three-quarters of a century old, that a rock crust at the earth's surface of only 3 kilometers thickness practically makes the temperature of the earth's surface independent of that within. The temperature of the earth's surface has in no way become permanently lower; instead it shows rythmical changes. The great ice ages of the earth's history stand in close relationship with mountain ranges brought into existence through foldings. For the Dyas and the Diluvian ice periods, at least, the dependence is clear. Apart from orographic and cosmical causes the rhythms of the temperature depend upon the rhythmical feeding into the atmosphere of carbon dioxide of volcanic origin as well as upon the varying need of this gas in the formation of coal and the carbonate rocks. Arrhenius and Frech have noted the rhythm of these carbon-dioxide periods and shown their geological importance. To-day, through the consumption of the coal beds by man in his industries, a new enrichment of the atmosphere with carbon-dioxide is taking place. He also thereby wards off the remote danger of the death of the earth through cold.[10] From the earth we read no sign of danger that the oceans and rivers may become solid ice nor that carbon-dioxide snow will fall, nor yet that the earth, at a temperature of absolute zero, will be covered by a new ocean of liquid oxygen and liquid nitrogen, while only hydrogen and helium will form the last tenuous atmosphere of the dead earth.

The natural deliverer of this incomparably important breath of life constituted by the carbon dioxide of the atmosphere, together with the rich store of the gas dissolved in the waters of the oceans, is vulcanism. Besides the seismical tremblings of the earth's crust volcanic actions give us the most immediate evidence of the earth's life. Their manifestations, the movements of the glowing liquid masses toward the earth's surface, together with the accompanying and subsequent phenomena, are recorded throughout all geological time. They do not, however, occur with equal strength or at equal intervals. So far as the outcropping of the volcanic phenomena of the past is to be dated—and this not in every case with the desired accuracy—the uprising and the eruptions of volcanic masses cluster about the times of the great mountain-building foldings. They were generally closely connected, as is the case even to-day, with the mobile regions where this building of mountains was taking place through foldings, and occurred either near them or within them, or else in regions of active movements of the ground. As an expression of the life of the earth the rhythmical character of the phenomena of vulcanism is convincing. How does the intensity of the volcanic activity of the present

[10] Doctor Abbot has shown that as long as there is anything like the present amount of water vapor in the earth's atmosphere the effect of carbon dioxide just discussed will be nullified by the overwhelmingly greater similar effect of water vapor. (Note by translator.)

compare with that of by-gone times? The number of active volcanoes since 1800 has been 231. The number of submarine outbreaks is unknown. The vulcanism of to-day was exceeded certainly by that of the past only for a few periods of equal shortness. The area of 900 square kilometers forming the surface covered with lava from the Skaptar eruption of 1783 on Iceland, the recent and near-recent lava flows building up the Hawaiian Islands or the Aetna, do not take second place when compared with the many eruptions of the distant past. That the vulcanism of the present period stands in close temporal connection with the Alpidian folding period should in no way be taken as prejudicing its dying out in our comparison of the activities of the geological past.

Into whatever class of geological activity we probe, in no case are we led to the conclusion that evidence from the expressed movements indicates an on-coming senility of the earth. Everywhere rhythmical rising and falling, there is nowhere a continuous decrease of the curve of force. Although these rhythms in the life of the earth are so distinctly recognized, their cause is still to-day an unsolved riddle. Cosmical relations are recognized only in limited amounts and undetermined significance; or are the causes within the earth itself?

Joly only recently estimated the relations between radioactive transformations and geological phenomena. He sketched in bold strokes a picture showing how this secret force of radioactivity could broadly account for these rhythms, the "revolutions" of the building of mountains through folding and the great movements of the masses of the earth's crust. It does not lie within my task to-day to go into his arguments, the only purpose of which would be to emphasize the rhythmical nature of the geological events for the understanding of the geological "life" of the earth which we have been discussing.

If really in the radioactive processes is to be found the "magic" which might be the unique causation factor for these manifestations of the life of our earth, then under the circumstances may we not wholly lay aside the idea of any aging of the earth as interpreted in these pulses of the earth's crust? If the physical relations within the earth's crust, which Joly assumed in the compensating processes relative to the development of radioactive energy, do not occur with the complete balance that Joly assumes, if there would occur a storing up of energy beneath the earth's crust and within the earth's body, then a crippling of the earth's pulses would be rendered impossible. Instead, then, of becoming a crippled earth, of becoming stiff in its actions, may it not rather be going toward the catastrophe of a "Nova"?

I must stop the further spinning of such yarns as to the future of this earth, mindful of what that fine satirist, Roderich, once wrote in the album of a geologist:

Man sagt von deinem Wirken wohl am besten: Du prophezeist uns die Vergangenheit. (The best we can say of your work: You prophesy for us the past.)

The past of the earth, so far as geology unrolls it for us, and the present tell us nothing of an aging of the earth.

Die Erde lebt; sie altert nicht. (The earth lives; it is not growing old.)