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SEVENTY-FIVE YEARS OF AMERICAN GEOLOGY[1]

As we commemorate the seventy-fifth anniversary of the American Association for the Advancement of Science, it is a pleasure to recall that this association sprang from the Association of American Geologists and Naturalists, that that association grew from the Association of American Geologists, and that that association in turn was initiated by a call from the Board of Geologists in control of the Geological Survey of New York. This evolution occupied a decade or more just previous to 1848, the date of the founding of this association. It may be convenient to think of the epoch we commemorate roundly as the latter half of the last century and the first quarter of the present century. I hasten to ask forgiveness beforehand for many shortcomings. The record is too rich to be compassed in an hour. A multitude of events of real importance must be passed without mention and those mentioned must be treated too briefly. I can only jump from peak to peak. I hope I shall have your sanction—or if not your pardon—for two general omissions, all formal attempt to give personal credit—which would require a volume—and all effort to pass judgment on questions about which our profession differs, though I shall endeavor to make clear such differences. One of the leading features of our memorial epoch is the extent to which unsettled questions have been developed and the earnestness with which we are struggling with them.

I. THE INCREASE OF GEOLOGICAL LITERATURE

If we could bring to mind a picture of the best geological library in America in 1848 and could realize at the moment all geologic values it contained and the stage of science it represented and could then also bring to mind and full realization the best geological library in America to-day, the contrast would go far to give a true measure of the progress of our science during the seventy-five years. This can only be done very imperfectly in imagination, but the thought may help toward the reality.

II. PROGRESS IN AREAL EXTENSION; GEOLOGIC SURVEYS

In the 30's and 40's of the last century, the establishment of state geological surveys followed one an-

[1] An address before the Section of Geology and Geography on December 28, 1923, the Seventy-fifth Anniversary of the American Association for the Advancement of Science.

other so rapidly as to be dubbed an epidemic, but yet, in spite of this enthusiasm, at the time this association was inaugurated not more than a third of the United States, and a much smaller fraction of the Continent, was geologically known even in a preliminary way. The recent geologic map of Willis perhaps best shows at a glance the status to-day. The contrast is very great. There has been a grand accomplishment. In its way, it is not likely to be surpassed in the future.

At the outset the leadership in surveys was taken by the states and provinces; there was no organized national survey. National geological work began early, but chiefly by the attachment of geologists to expeditions organized for other purposes. Then followed special surveys of growing importance, but more than one third of our memorial epoch had passed before a comprehensive national survey was established. Even the state surveys of the earlier decades were commonly authorized for short periods only. "Complete" surveys of tens of thousands of square miles, with full reports thereon, were ordered made in four or five years, or some such time, on the basis of a few thousand dollars appropriated to cover expenses. It certainly would not be safe to say that "*complete*" surveys were the result, but heroic things were done in the endeavor to meet the requirement. Later, but tardily, the need for continuous surveys was recognized; the dream of completeness became a thing of the past.

III. Extension of the Geologic Column

Great extension in area has been matched by great extension in depth. At the opening of the epoch we celebrate, the geologic column was made to embrace the "Primary," which was simply the cooled crust of a molten globe, igneous and lifeless, and the "Secondary," "Tertiary," and "Quaternary," which were chiefly series of bedded sediments deposited on the "crust." At that time these were supopsed to be separated by catastrophic disruptions which destroyed all previous life and led to repeopling by newly created life. The great unconformities were interpreted as the relics of sweeping catastrophies, not, as now, merely gaps represented by deposition elsewhere.

As time went on, the breaks in the column were reduced by the recognition of equivalent beds deposited elsewhere. Catastrophic speed and violence were gradually replaced by slow and quiet action. The doctrine called, rather inaccurately, uniformitarianism was brought across the Atlantic and naturalized in part, but given a saner interpretation. Hall, Dana, Logan and other Americans seem to have been more influential by their personal leadership than by their qualified adoption of the imported doctrine. In truth, of course, it was Nature's record in building this continent that led the movement. The American record is unsurpassed as a geologic instructor.

Not only was the upper, more obviously stratigraphic, column thus made longer and more continuous, but there was a significant extension downward. The Cambrian beds had been taken as the definite and logical base of the sedimentary series. In the last half of our epoch, however, terrane after terrane, more or less sedimentary, were found to lie geologically below the Cambrian. The thickness of these sub-added beds is now commonly estimated as rising to an order equal to the whole column above the Cambrian, and, what is equally significant, the lower end is yet to be found. Thus, at the end of our seventy-five year epoch, the stratigraphic column is interpreted as several times as long as at the beginning, with a likelihood that it will grow still further by the filling in of a multitude of small gaps, not at first noticed, and by further extension downward.

Not only has the length of the geologic column grown greatly, but profound changes of view as to its nature have taken place. The sharp division into two parts, a lifeless igneous base and a sedimentary fossiliferous superstructure, has given place to the general concept of continuity with merely minor oscillations in the times and regions of major activity. Life has been traced much below the Cambrian, but its lower record is very imperfect. The recent discoveries of more ample and varied life in the lower Paleozoic, particularly the Cambrian, implies, under current evolutional philosophy, a very great downward extension of life. In the judgment of some biologists and geologists, this extension probably reaches below all the pre-Cambrian terranes as yet recognized, though this pre-Cambrian extension is great. The "Azoic" bottom has retired to depths unknown. This profoundly changes the life aspect of the column.

On the physical side, it is now recognized by field workers on the lower horizons that sediments, pyroclastics and lava-flows—all these being surface deposits—enter into the make-up of six or eight thick terranes below the Cambrian. At the same time, great igneous masses, once supposed to be basal, are now found to be intrusions into these surficial and more or less sedimentary accumulations and hence incidents of the stratigraphic series. In the upper part of the column, on the other hand, similar great batholiths have been found to be intrusive into formations as late as the Mesozoic and Cenozoic, while the surficial lava floods of these later formations sometimes rival those of the pre-Cambrian terranes. Naturally, metamorphism has gone farthest in the older and more deeply buried terranes, especially where greater pressure, heat and time have been brought into cooperation, and this tends to maintain the inherited view, but discounting the changes due to metamorphism, the differences between the upper and lower

parts of the column seem to most geologists much less contrasted than they appeared 75 years ago.

IV. NEW CONCEPTS OF AVAILABLE TIME

The extension of the geologic column and the decline of interpretation by swift catastrophic action, together with the increased acceptance of evolutionary views of the life, led geologists during the last half of the last century to postulate greater and greater lapses of time because they seemed necessary to explain satisfactorily the expanding geologic record. The greatness of this extension drew forth protests from distinguished physicists, astronomers and mathematicians, who urged reasons which seemed to them very cogent why available geologic time was limited to shorter lapses by other cosmic processes on which it was dependent. There arose a memorable contest too well known to need deployment here. It is sufficient to note that the restrictive argument was given great weight during the last half of the last century, and led to strained interpretations of geological phenomena. The recent discoveries of the prodigious energies concealed in the constitution of matter, however, have dissipated these hampering views. Geological interpretation is now free to follow geologic evidence. Not only that: radio-activity has furnished a line of specific evidence that seems to directly imply as high antiquity of the lowermost rocks as perhaps either geologic or biologic interpretation requires.

V. INCREASED KNOWLEDGE OF THE COMBINATIONS OF EARTH SUBSTANCES

Knowledge of the material of the earth has been very greatly increased by the thousands of chemical analyses that have been made, in increasing numbers, as the epoch has progressed. These have been gathered into convenient and suggestive form in Clarke's "Data of geochemistry." In addition to their own inherent value, these form a firm basis for the mineralogic, petrologic and economic phases of geology, all of which are intimately related to the chemical.

One of the earliest and most notable treatises on the composition and mineralogic organization of earth substance was the great work of Dana, supplemented by that of his son. The influence of these works has been more than simply American.

A little before the middle of our memorial epoch, the use of transmitted light through thin slices of rock opened a new vista into the intimate structure of minerals and rocks, and inaugurated a new petrologic era. The far-reaching nature of this illumination is difficult to measure; fortunately, it is so well known that I need not try to emphasize it here. While the initiation of this was foreign rather than American, it was promptly naturalized and America soon began to make returns in kind.

The happy thought of Laue that the systematic arrangement of atoms in the surfaces of crystals might serve as a diffraction grating opened a still more penetrating vista into the structure of crystals and has given a tangible picture of the openness and orderliness of the lattice arrangement of atoms in crystals, and suggests the trend of all probable primary material arrangements in the domain next above that of the molecule.

One of the most significant penetrations into the composition and mode of formation of rocks has been gained by a study of the differentiation of magmas as they are passing by stages into the solid state. The complementary action which presumably takes place when magmas are being generated from mixed material has been recognized but not as yet much developed.

VI. LIGHT ON THE CONSTITUTION OF MATTER

Through the researches of chemists and physicists, geologists are now permitted to participate in a most profound insight into the constitution of matter. This is an opportunity of the utmost importance to geology. Most of our inherited concepts of earth substance took shape from the inherited notion that the ultimate integer of matter was an infinitely hard, incompressible, indivisible atom. Out of this there arose false notions of absolute rigidity and incompressibility in compacted compounds of atoms. We are now presented with a picture of opposite import. The atom is now held to be a revolutional mechanism of a singularly open kind, compressible to an extent whose limit is unknown and at present indeterminable, and withal elastic to a marvelous degree. Its intense revolutions seem to give it gyroscopic stability of an extraordinary degree, while its powerful electric and magnetic fields and polarities seem to give the fixity of attachment which is the essence of rigidity. Thus, the very atoms and the closer combinations of atoms (molecules and crystals) seem to define with great clearness the fundamental structure of earth substance. In these fundamental structural types there is fixity of attachment at a given point, or in a given position or attitude, of one integer to another, accompanied by an elastic factor, which permits yielding within the elastic limits but tends to restore the integers to their previous relations, *i.e.*, the elastico-rigid state. This state of fixed or rigid attachment of the integers to given points or in given positions or attitudes is to be distinguished from indifferent attachment of the adhesive sticky or viscous sort which permits motion proportional to the stress but has no elastic or restorative factor. The atomic studies seem further to make it clear that all these qualities have dynamic sources and hence are variable in proportion to the dynamic agencies that give rise to them. The technical factor "rigidity" seems to be simply the

strength of the fixed attachments, subject to elastic yield to the elastic limit, beyond which the structure either breaks down or is transformed into a new or modified elastico-rigid structure. If heat or other dispersive agencies force the atoms or molecules beyond the limits of these intimate attachments, unfixed attachments of the viscous type seem to ensue. Thus, a clearer vision of the intimate nature of earth-substance offers itself for the acceptance of geologists.

But, important as is this substitution of an open dynamic mechanism in place of the incompressible, indivisible atom of former concepts, this is not the limit of revolutionary things offered geologists for election or rejection. It is now held that all atoms above hydrogen are composite. As some of them are now undergoing spontaneous disintegration, there arises the general question whether others or even all the composite atoms are not subject to transformation into other atoms under some of the present conditions within the cosmos, and whether more or less of these conditions may not exist within the earth. This opens very widely the door of assignable reorganizations already urged by the newer school of diastrophists. Apparently, geologists must now face the possibility, if not the probability, that the atoms within the earth may undergo transformations much more widely than present evidences demonstrate, and that this may include constructive transformations as well as destructive ones.

It is significant that even the atomic transformations, so far as known, do not involve any general catastrophe to the mineral affected. They are brought about by individual actions on the part of the constituent integers, one following another at intervals while the embracing structure remains well organized and, to ordinary sense, unmodified. There seems no ground for doubt that in the disintegration of uranium, thorium and the other spontaneously transforming minerals, the action is idioatomic in the sense that the changes take place atom by atom individually and according to the special nature of each. This is in close analogy to the view held by one school of geologists respecting changes in glaciers, metamorphosing rock undergoing "flow," and elastico-rigid material in general, under conditions favorable for this class of motion or deformation, technically grouped under the term "idiomolecular action." When such idiomolecular transformations pervade massive bodies, the general effect takes on the outward semblance of *flow* and is called "flow," but it is not a miscellaneous, pell-mell movement of all the constituent integers, as is liquid flow; it is really a reconstructive process stimulated by stress and carried out by individual atomic or molecular action. The movement of glaciers is interpreted by one school of glaciologists as due to such idiomolecular reconstruction. So, likewise, one school of metamorphologists interpret "rock flow" as belonging to the same category. At the same time, it has long been known that crystals may be so affected by heat or other agencies that they pass into a fluid state and deform in fluidal fashion attended with viscous resistance, and lose their elastico-rigid properties. So also it is familiar knowledge that crystals may be so stressed as to break down by fracture, granulation or shear. Thus, even before the revolutionary discoveries of the constitution of matter, geologists were face to face with antithetical interpretations of flow and other intimate changes of form and texture. This diversity of interpretation calls into function some of the least familiar, most subtle and most radical considerations which affect the problems of the earth body. These we pass on to the tender mercies of the next epoch.

VII. Dominance of Revolutional Energy over Vibratory Energy

The revolutional insight into the fundamental mechanism of earth substance involves a scarcely less revolutional view of the phases of energy embodied in the earth. Seventy-five years ago the vibratory forms of energy—particularly heat—almost monopolized geologic thought respecting the earth's evolution. Heat inherited from the cosmological state and heat produced by compression were thought to dominate the early history of the earth and to control the state of its interior at all later times. Revolutional energy was little recognized except in problems affected by the rotation of the earth. Now, if the new views of the constitution of matter are accepted, the ratio is profoundly reversed. The revolutional energy embodied in the earth may be safely said to be many hundreds of thousands of times as great as the vibratory energy. More than this, the revolutional energy is found to be an essential factor in the constitution of matter and is thus much more fundamental in its nature. The vibratory energy seems to arise mainly from the inevitable collisions, compressions, frictions, interferences or maladjustments of some kind between the organized mechanisms in the pursuit of their individual courses. It seems to take on the aspect of a derivative form of energy growing incidentally out of conflicts rather than an orderly constitutional form of energy. It is rather significant that the constructional form of energy is so unobtrusive that it has taken an inquiring race all the thousands of years of its history, until yesterday, to discover even its existence. The energies that take form from conflict and interference have always been obvious enough. (There is a text for a sermon here, but it doesn't belong to my story.) The geologic importance of this phase of the new disclosures lies in the fact that revolutional energy is peculiarly the energy of organization, is scarcely less than the organizing factor itself, while vibratory energy is domi-

nantly the energy of disorganization and dissipation. We are, therefore, invited to consider whether continuous organization and reorganization of the earth substance is not one of the greatest of geologic processes, and whether it does not go on without end in the sense that other cosmic processes do. This would mean that the interior heat of the earth is, in part at least, a product of the earth's internal metamorphisms, some of which are exothermic and some endothermic—oftenest perhaps a partition between the two. It would follow from this that there is going on within the earth even now, as for ages past, mutual transformations of revolutional and vibratory activity into one another with a result which is a trend toward equilibrium and nearer an equation than the verge of a catastrophe.

VIII. Contributions of Cosmology to the Constitution of the Earth

While I hold that the origin of the earth is a geological question (however much it may also be a question in several other sciences) and a question of unsurpassed geological moment, I here defer to those who take a more restricted view of the scope of geology and shall dwell only on the phases that lead to inferences of strictly geological aspect.

During the earlier part of our memorial epoch, almost all views of earth genesis postulated some form of concentration of diffuse material by self-gravitation. It was held that the inevitable loss of heat led to increased rotation and this in turn to the separation of planetary matter. The most common view was that the earth passed from a gaseous (or equivalent) state to a liquid state which later crusted over. There remained differences of view as to how far the interior solidified. From any form of a fluidal view there arises logically the doctrine that the earth material segregated into concentric shells in the order of specific gravity, the heavier toward the center, the lighter toward the surface. This should have given a state of perfect isostasy, in a horizontal as well as vertical sense. How the later inequalities arose from such a homogeneous start remains an outstanding problem.

Considered in a broad general way, the working factor in this type of evolution is in the concentrating mass itself; the planets arise simply as its own offspring; they were parthenogenic, as a zoologist would say, or monoecious, as a botanist would say, or, let us say, mono-parental. The evolution, in all its main essentials, sprang from the energy and material of the parent nebula and was essentially a process of concentration, partition and reorganization.

Rather late in our memorial epoch, a dioecious or bi-parental hypothesis of origin was developed, stimulated by the feeling that none of the monoecious hypotheses could meet the combination of the peculiar dynamical features found in the solar system. This dioecious (planetesimal) hypothesis postulated the dynamic cooperation of the sun and a passing star (or its equivalent), the latter contributing the surplus energy and rotatory momentum unassignable to the sun-system alone. This greater energy and momentum took form as a scattered planetesimal condition of the constituent matter from which aggregation into the planets, planetoids and satellites pursued a natural but very slow process, so that the great heat generated by the aggregating process was largely lost as the process went on, while the earth remained relatively cool, the material also remaining highly mixed. This feature is the point of greatest geologic divergence from the preceding views. Such a mixed state of solid particles, at the outset, implies a long series of later reorganizations, segregations and metamorphisms, with little likelihood that these are yet complete. It is quite obvious that the evolution of such a cold mainly solid accretional earth must depart rather radically from that of the older gaseo-molten earth.

IX. Progress in Structural and Diastrophic Views

At the opening of the epoch under review, a single simple structural concept of the earth, as a whole, occupied the field almost exclusively, that of a solid crust floating on a mobile substratum, with a deeper interior which had at least once been molten and either still remained so or had solidified under pressure in part or in whole. It was supposed that some molten matter was intruded into and through the crust; that the primitive atmosphere originally held and later precipitated its overburden of waters upon the crust as it cooled and formed a universal ocean. Out of this almost ideal symmetry it was held that progressive cooling gave rise to deformation, one of the first effects of which was the emergence of land, and following this emergence, the era of erosion and deposit began.

In the first decades of our epoch, the main battle of views lay between catastrophic modes of action and modes that came to be called, with some inaccuracy, uniformitarian. At first catastrophism seems to have been more declared than uniformitarianism, but as time went on geologists in increasing numbers turned to the latter view and catastrophism slowly lost its dominance, but has never yet entirely disappeared.

The doctrine of the permanency of continents and ocean basins arose rather early in our epoch and, under the leadership of Dana, became a widely accepted American doctrine. It is to be noted, however, that there has been some retrogression from this view in recent years, notably in the acceptance of the rather free reversals in land and sea postulated by

the Neumayr-Suess school, and the revived postulation of the shifting of continents and the wandering of the poles.

It was perfectly logical that views of diastrophism built upon the concept of a cooling, molten globe should take on certain distinct features, such as shallowness of deformation, since only a relatively thin crust could reasonably be supposed to be involved in the effects of surface cooling. So, too, starting with a molten state of the whole substance in which viscous coherence was the prevailing phase of molecular aggregation, it was natural that viscousness should be extended to the solid state when evidence to the contrary was not outstanding.

On the other hand, the concepts of diastrophism built on the accretional theory, having to deal mainly with mixed heterogeneous materials, at the start—and later with the only partially assorted products brought about by changes in these—naturally assumed greater depth of diastrophism, for it is to be presumed that as the internal stresses were increased by accessions and progress in concentration, they would give rise to further though less diastrophism, whatever their depth. Logically, therefore, no specific limit to the depth of diastrophism is postulated. Under this concept there is naturally also a larger recognition of the elastico-rigid state, as distinguished from the visco-solid state. The deeper internal deformations are referred more largely to glacier-like flow or rock-flow of the type that attends metamorphic reorganization.

The contest between views of diastrophism based on the concept of a visco-solid state and on the concept of an elastico-solid state is another of those subtle deep-lying issues which this epoch passes on to the next.

X. Discoveries that have changed the Aspect of Diastrophism

The discovery that radioactivity is a persistent source of heat and that there are enough radioactive heaters in a thin outer shell to compensate for all the known radiation of heat from the earth's surface has put a new aspect on the doctrine of secular cooling as a source of diastrophism. It raises the serious question whether there has been any material reduction in the earth's temperature since Proterozoic times.

The transmission through the earth-body of seismic waves along paths that traverse depths equal to half of its radius and more, is accepted by most seismologists as indicating that a solid-elastic state prevails at least to these depths, *i.e.*, prevails in seven eighths of the volume of the earth-body. As to the central one eighth, the status is less sure and it remains for improved instruments and increased skill to test the deeper penetrations, if indeed they really succeed in traversing these longer and deeper chords. Recent investigations of the body tides and nutations imply a very effective elastic solidity of the earth-body, as a whole, and so presumably of its central one eighth. These discoveries relative to the state of the main mass are held to bear decisively on the vital question whether the material involved in diastrophism is elastically solid (elastico-rigid) or viscously solid. A viscous adhesion of the molecules to one another with no elastic throw-back is held by one school at least to be fatal to the transmission of the second set of preliminary seismic waves in the manner and at the velocities recorded. So also, the increasing density of the interior as depth increases in itself tends to retard the velocity of the waves. And yet, in spite of all increases of density and all viscousness, the velocity of the waves increases notably with increase of depth in the outer portion and less notably below, but when correction is made for the probable increase of density, the record continues to imply increase of elastic solidity as far as the record is interpretable.

The special theories of diastrophism are such a host that I must pass them without even mention.

XI. Progress in Views of Vulcanism

The concept of vulcanism most prevalent at the birth of our association placed its seat and source in the postulated molten mass beneath the "crust." The concept was a natural derivative from the gaseo-molten cosmology then prevalent. Since an actual fluidal connection between the volcanic neck and the molten interior was commonly held, and since this should logically have been made manifest by tidal oscillations and simultaneous eruptions in adjacent volcanoes, much effort was made to detect the indicated movements, but the results were disappointing. An unexpected degree of independence was found, though minor sympathetic effects assignable to common body stresses have been detected. The trend of recent opinion has hence set toward the view that volcanic action is local and arises from special local causes. It is worthy of note that this trend has been led by inquirers who favor the gaseo-molten theory of earth genesis, while such local origin and independence is the logical inference under the accretional theory, a notable case of convergence.

XII. Advances in Views of Metamorphism

In the early stages of our memorial period, it was supposed that nearly all rocks below the Cambrian were igneous, and metamorphic changes in these received scant attention. Metamorphism at that stage was little more than a transformation of sediments and the sediments were relatively limited. In late

years, both the range and the importance of metamorphism have greatly increased.

This holds true measurably without regard to views of the primitive state of the earth material, but under the view that the earth grew up slowly by accessions of all kinds of matter in a solid state, metamorphism logically rises to a place of commanding importance. On such mixed solid material metamorphic action should have begun at once, wherever it took place, thus preceding vulcanism—and should equally have followed it. If the earth was solid throughout its known eras, metamorphism should have continued with more or less, but probably declining activity, to the present day.

Since metamorphic changes have an endothermic as well as an exothermic phase, metamorphism plays a radical part in problems of the earth's internal temperature. The status of the internal temperature of the earth is thus made to depend on the progressive consumption as well as production of heat, and not so much on inherited heat.

Through the density and stress changes attending metamorphism, it becomes a factor in diastrophism. Reorganization in the depths of the earth, as well as in its shell, is held by a growing school of geologists to be a source of diastrophism.

XIII. Progress in Erosional and Sedimentary Geology

However the deformations of the earth were caused and renewed at intervals, they were prerequisites to the erosion and deposition that have taken place, and hence have been given precedence here. The successive diastrophisms determined the special phases of stratigraphic work, while they influenced also the course of life evolution.

The early interpretations of stratigraphic processes were strongly tinged with catastrophism. There was great freedom in postulating not only rises and falls of the crust, but great debacles of strangely fantastic types. But these excessive liberties with the laws of nature were rather individual than representative of the rising school of American geologists.

It is historically worth while to note that alternations of relative quiescence and disturbance and the rhythmical play of erosion and deposition were early recognized and emphasized.

About the middle of our memorial epoch, the very important doctrine of base-leveling was given form and started on its career by Powell and Gilbert. This doctrine, carried into fuller detail and application by others later, has powerfully affected the interpretation of the larger aspects of denudation and deposition, as also of life progress, and has had an indirect influence on problems of megadiastrophism.

An adequate appreciation of subaerial deposits belongs almost wholly to recent years, as also the distinctive functions of epicontinental and abyssal seas. The facility with which deposition on slopes gives elusive suggestion of great crustal sinking has been urged but is yet to be fully realized and used as a check on extravagant assignments of depression.

Recently, two tenets whose mutual incompatibility does not seem to have been generally recognized, have made notable progress: (1) the doctrine of isostasy, which, in its very nature, tends to keep light segments in the high places and heavy segments in the low places—a special kind of permanency, especially in a solid earth—and (2) the postulation of great reversals of land and sea, involving eversions of the heavy oceanic segments and submersions of the lighter continental segments—an imported mode of interpretation following Neumayr and Suess. Ancestrally, the first is the offspring of a "floating crust," the second of the catastrophism of the earlier days, but both have been modified to escape the burden of their inheritances. Both must be reckoned among the notable movements in American geology which pass on into the next epoch.

XIV. Progress in Correlation by the Life Record

It is scarcely possible for those who have not lived through the whole of our memorial epoch to realize the profundity of the change between its beginning and end in the interpretation of the life record. Well into the early years of the epoch it was taught in our standard text-books that successive creations of life followed successive catastrophies which detroyed all existing life. I was taught specifically, and with some followed successive catastrophies which destroyed all life was destroyed; not a single species passed from the Paleozoic to the Mesozoic. I was taught that there were similar complete destructions later. Perhaps this tells the status of geological *knowledge* as well as geologic thought at the beginning of our epoch as pointedly as anything can. The doctrine of continuous life development—which of course meant also continous conditions congenial to life—had to face as stiff an opposition as ever stood in the way of a scientific concept. And yet none has ever won a more signal triumph in the scientific world or wrought a more profound reversal of interpretation. This issue in the American geological world was fought out mainly in the middle third of the 75 years we celebrate.

It was fortunate indeed for American science that the states which led in geologic mapping and correlation were seated on geologic terranes built with more than usual fullness and symmetry, especially

New York. It was equally fortunate that their fossil records were clear and decisive. The influence of New York and the adjacent regions and of the able geologists and paleontologists who worked these fields was a boon to our science of the first order. It was likewise fortunate that the Paleozoic series of the adjacent interior had an unsurpassed symmetry and fullness of development and that its correlation fell into like able hands. By reason of its inherent superiority and of the personal ability of its workers, the American system of correlation and classification has had a development of its own, save that the larger groupings, assumed to represent worldwide stages, have largely been adapted from the earlier European classifications. In most respects the American continent is better suited than most other continents to serve as a historical standard, both because of the greatness of its terranes and the steadiness of its growth. From the very first, a commanding series of paleontological contributions came from the students of the Paleozoic series of the eastern region, and later a singularly brilliant series of contributions were poured in by the workers on the later terranes of the great West. The record of American paleontology and stratigraphy is one which may well give eminent satisfaction to the people of our continent.

XV. Progress in Hydrospheric Geology

The evolution of the much branched tree of life implies continuity in the conditions hospitable to life, not only in general, but in special adaptation to each independent branch of life after it left its parent branch. This implies an evolution of the land suited to the support of land life and an evolution of the ocean suited to support the marine life. At no time since an existing branch started its independent evolution can we rationally suppose that its requisite environment has been wholly destroyed. Thus suitable physical continuity is implied by organic evolution. Catastrophism had a fair field so long as new creations were available to repeople the devastated regions, but it at once became hampered as soon as the concept of continuity of life was accepted. And yet it is one of the seeming paradoxes of the history of geology that catastrophism, particularly in the hidden depths of the sea, is freely called into service by one school of geologists to explain the geographic gaps in certain regional successions of life, while to another school it seems to be one of the historical idiosyncrasies of the current epoch that tenets which have a catastrophic aspect linger almost solely in the dark shadows of the deep seas.

In the early part of our epoch the sea was simply the sea. There was little distinction of parts or of functions; it rose and fell; it came and went; and little thought was given to the how or the why. But in time both the dynamics and the deposits of the sea began to be scrutinized. Continental shelves and epicontinental seas were differentiated from the abyssal oceans; their respective deposits were discriminated. It came to be recognized that the continental shelves and the beds of the epicontinental seas are *parts of the continents,* not properly parts of the ocean basins. This recognition gives to the continental terranes about one third of the shell of the earth and to the sub-oceanic segments about two thirds. This gives a new aspect to the working factors of the elevation-depression land-sea problem. The geologic records of the later ages—which alone are fairly complete—seem to show that the continents have gone up together and the ocean basins have gone down together—an indication of earth dynamics of no little moment.

At the opening of the association's history, there was scarcely any dissent from the view that the waters of the ocean were precipitated from the supposed hot moist atmosphere as soon as the radiation of primitive heat permitted it, and that water action on the rock surface then began and has continued ever since. At the start the levelness of the cooled crust was supposed to have given rise to a universal ocean, but as inequalities arose the waters were gathered into the deeper basins, the land appeared, disintegration and solution took place, the solutes were carried to the ocean, and the ocean grew more and more saline as time went on. On the basis of this concept, its most typical salt, sodium chloride, has been held to give data for an estimate of the earth's age.

It was only late in our epoch that these tenets were called in question on the ground that the whole mass of the ocean could not have been held in the air as vapor under the kinetic theory of gases. In harmony with this was the postulate that the hydrosphere has grown gradually by accretion through the ages. This rivalry of views is one of the late issues of our epoch, and the battle of the waters and of the brininess of the great deep is another of the conflicts of geological thought that must pass on into the next epoch.

XVI. Advances in Atmospheric Geology

In the early days of our epoch, the vast hot vaporous atmosphere of the older view was a fruitful theme for geologic eloquence. It is almost a pity that the kinetic theory of gases has pushed this flow of eloquence off the stage. It was later seen that the steady evolution of life of types intimately dependent on a certain range of temperature and on an atmosphere suitable for breathing imposed severe restrictions on postulates respecting the early atmospheres and climates. It also came to be seen that mechanical restrictions had been imposed from the beginning by the limited ability of the earth's gravity to hold gases of such molecular activities as those that constitute the

atmosphere. These were among the considerations that led to the later view that the atmosphere gathered gradually; partly from without and partly from within, but always under the joint control of gravity and its own molecular activity. The logic of the kinetic theory of gases leads to the conclusion that the atmosphere grades upward from its intensely collisional state at the bottom into a much more open state in which outward vaulting and return of the molecules is more characteristic than direct to-and-fro collision. In turn, this vaulting or krenal atmosphere is held to pass into a still more attenuated state in which satellite-like revolutions of molecules become characteristic, forming an orbital ultra-atmosphere. This reaches to the limit of the earth's sphere of control. The new picture is that of an envelope of three intergrading phases enwrapping the planet. Thus enwrapped, the earth revolves through the outlying ultra-atmospheres of the sun, giving rise to interchanges between the ultra-atmospheres of the earth and of the sun. This interchange works constantly toward equilibrium between the two atmospheres. This last concept implies atmospheric persistence and measurable constancy—save for relatively small oscillations—throughout the known part of geologic history. This view has but lately come upon the stage and adds another to the list of issues that pass on into the next epoch.

XVII. The Trends of Views on Geologic Climates

As previously noted, the inherited view of the origin of the earth implied a hot moist atmosphere thick with perpetual clouds, forming a dull sultry climate. This was commonly supposed to have continued until the luxuriant vegetation of the Carboniferous period "purified" the air of its supposed excess of carbon-dioxide and permitted the appearance of air-breathing life. What was then regarded as the first appearance of annual rings in the trunks of trees was held to be telling evidence of a passage from a dull uniform cloudy climate into one of diverse seasons glorified by sunshine. The growing evidences of the past 75 years, however, have forced very radical departures from this familiar view. Glacial deposits have been found as far back as the Proterozoic, and arid stages at least as far back as the Cambrian. In Carboniferous times it would seem that the sunshine was strong enough to give rise to protective palisade cells in the upper layer of the leaves. Air-breathing animals are now known to have flourished earlier than the Carboniferous.

Between the ancient glacial stages, warm climates extending far within the polar circles are implied by fossil evidence. These apparently continued longer, even in the polar regions, than the glacial stages. The evidence thus seems to many geologists, probably to most, to indicate that cold climates have alternated with warm climates, and dry climates with wet climates, from the earliest well-recorded times to the present. Some would press the picture further and postulate an approximately uniform chain of oscillating swings of climate from one limit to the opposite, forming a climatic rhythm running from the beginning of the legible geologic record to the present. Some connect the climatic rhythm with the diastrophic and other rhythms which they interpret as marking the earth's progress. But others question some of these tenets.

Climatic explanations are as plenty as blackberries in the woods; we can not stop to even count them. For the glacial phase, they are certainly enough to make glad the heart of the protagonist of the method of multiple working hypotheses, but it is not so clear that they shed luster upon it.

XVIII. The Progress of Prognosis

One can not well recall the great climatic descensus from a hot wet beginning to a cold dry end—that held the stage in the early part of our epoch—without seeing how inevitable was the forecast of a further descent to a final winter and a universal desert. And one can not wonder that such eloquence as was left over from the dramatic beginning was poured forth in prophecy of the dismal end lying just a little in front of us.

In strong contrast is the later prognosis which forecasts a future of merely oscillating conditions, like those of the past, extending on to limits we dare not set, to lapses perhaps as great as the past. At least this view sees no signs of a definite decline to an early end. A final winter seems no more foreshadowed by the recent glacial stages than it was by the Proterozoic glaciations. The aridities of to-day seem no more definitely to imply a universal desert than did the arid state of India in Cambrian times, or the wide-ranging Permo-Triassic aridities in their day. Probably an end must come. But if 60,000 suns can live long enough to gather into a globular cluster by a mode which perhaps took ten billion years or some such time, we may feel with some confidence that our sun will do its part to keep the earth alive for eras in the future not unlike those in the past. At least one of the new rival views that we hand over to the future permits us to think that man's future career is chiefly a matter of his own making. We may, then, rationally regard the study of the earth's existing resources, as well as the development of man's capacities to use them in making the most of himself, as one of the potential factors in his own destiny.

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