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# SOME FUNDAMENTAL CONCEPTS OF EARTH HISTORY.

JAMES H. LEES.

We have been accustomed to think, most of us, that in the early days of the world's geologic history Nature manifested herself in forms different from those with which we are familiar; that God, the supreme Power of the universe, employed other types of energy than those by means of which He works today. And these conceptions have been fostered and influenced very largely, consciously or unconsciously, by our religious and theological training. For we each have a theology, whether we recognize and admit it or not, and we are governed in our thinking to a large extent by this theology and it is very likely to color our outlook upon life and our interpretations of the phenomena of the outside world. We have accepted the science of three thousand years ago because of a certain imputed authority, and have given it precedence, in the theological domain at least, over the science of today. Our religious instruction has been distinctive in the teaching that the methods which God used in creating this world were entirely apart from those by which He perpetuated it. The science of geology was founded upon this concept. The world is today peopled with certain groups of animal and plant life. In the rocks are found entombed the remains of other types differing widely from each other and from modern forms. These facts were accounted for in early days by the hypothesis of a series of creative fiats and destructive cataclysms whereby new and successively higher orders of life were alternately deployed and as autocratically swept off the stage, as it were in a moment of time. Here again theology has guided science and we have investigated natural phenomena in the light of a pseudo-scientific interpretation which we have read into certain Biblical passages. Our scientific forbears at first failed to realize that the laws of development and decay operated as perfectly and inexorably in the beginning as now, that the perpetuation or the extermination of any form of life depends upon its ability to adapt itself to external conditions and also upon what I may call its adherence to standard. It is the plainer, simpler, more mobile types which have persisted from the past. The bizarre, the ultra-radical as well as the ultra-conservative, have disappeared, or, what is just as fatal to real progress, have failed to keep pace with the march of the race, have fallen hopelessly behind in the onward sweep of life toward higher and higher development.

The trend of modern scientific thought has been away from the cataclysmic toward a more uniformitarian point of view. We are coming to understand that present forms of life differ from those existent during earlier periods not because they belong to a distinct creation but because they have progressed during the ages, have developed those traits and characters which fitted them to compete with untoward conditions and unfavoring circumstances.

If we turn to inanimate nature the same rule of uniformity holds good. The rock foundations of the continent to the profoundest depths yet penetrated bear every evidence of formation by the same agencies and under control of the same laws as those now operative. The only differences are those of location and degree. There was a time when, according to the most modern and reasonable theory of earth history, the upbuilding of the earth's mass by accretion from outside sources was the dominant activity. At other and successive periods volcanic forces have raged with tremendous violence and enormous volumes of liquid rock have poured over the surface or have been thrust into the solid body of the earth. During still other periods, and these have been the dominant ones of the earth's later history, the quiet processes of erosion of the lands and deposition in the seas have been uppermost in importance. These latter processes have given us our sandstones, the beds of shale which enclose our coals and the limestones which form such an important resource for constructional purposes. To them we owe in large measure our vast resources of iron, of rock salt, of gypsum and of other minerals. And these processes are today as active as ever they were. The mud banks and sand bars at the mouths of our great rivers, the limy clays and beds of shell and coral in the quiet, shallow off-shore reaches of the modern oceans, these will as surely consolidate into solid rock as have similar deposits of the past.

It is my purpose to outline briefly the progress of the ideas which have been held successively by students of natural history regarding the origin of the earth and the operation of natural phenomena.

From the beginning of man's history as a thinking being he has been impressed by the outstanding forces of Nature and the more obtrusive features of the earth's surface. Storm and flood, thunder and lightning, volcano and earthquake inspired him with fear and led him to invest them with supernatural origin and power, while on the other hand the pleasant shady vale or the bubbling spring suggested to his facile imagination the presence of harmless sprites and reveling nymphs. Monotheism has displaced these manifold and ill-assorted divinities by one Supreme Ruler and an orderly and neverfailing body of law. But it has always been the curse of science, popular as well as technical, that from the observed body of fact and experience unwarranted conclusions have been drawn and fantastic hypotheses have been formulated. There is always the tendency to devise the extraordinary, rather than the ordinary explanation for natural phenomena. On the other hand it must be recognized that this tendency to speculate when it has been backed up by solid fact and proven law, has been the source of all advanced ideas regarding the past history of our world and the method of operation of the forces which have been and are shaping it.

While, then, the laity among the Greeks and Romans were content to ascribe such forces to supernatural causes their philosophers, from Herodotus and Aristotle to Strabo and Pliny, were coming to appreciate the natural causes of physical phenomena. Thus Herodotus, 500 years before Christ, attributed the Vale of Tempe to an earthquake, rather than to the work of Hercules, and Strabo, about the beginning of the Christian era, never alludes to the legendary mode of its origin, as if there could be no reasonable doubt. Aristotle (384-322 B. C.), who wrote extensively on scientific subjects, discussed earthquakes and volcanoes as due to internal fire and wind, an explanation which was accepted for centuries. While some of the attempted explanations of these thinkers were crude and fantastic yet in many cases they show accurate observation and acute reasoning. Seneca (-65 A. D.) remarks that "Though the processes below ground are more hidden from us than those on the surface of the earth, they are none the less equally governed by invariable laws." The fact that fossil shells have been found far from the present seas and at considerable altitudes above sea level has led to much speculation. The Greek and Roman scholars are positive in their opinion that these record the former presence of the sea—a conclusion which might well have been accepted by their successors of the Middle Ages and later. How such changes of level were effected they could not explain, any more than they could tell how the mountains and the valleys, the rivers and the plains attained their present forms. Indeed it was not until the last century that the true explanation for these features was found—again, the most reasonable and natural explanation, lying ready to hand when some observer should be clear minded enough to grasp it. But before the fall of the Roman empire the operation of certain well defined natural laws had been appreciated and it is noteworthy that the development of the scientific spirit in investigating Nature was unhindered by theological preconceptions or popular misconceptions. If the same tolerance had been manifest in Christian Europe the history of scientific research would have been far different than it actually has been.

During the Middle Ages the Arabs endeavored to enlarge the bounds of natural science and one of them, Avicenna (980-1037), states with admirable clearness that "Mountains may arise from two causes, either from uplifting of the ground, such as takes place in earthquakes, or from the effect of running water and wind."

By the time of the revival of learning the Church had obtained such a hold on the minds of men and on their methods of study that they were allowed to express no opinion on the age of the earth or its geologic history which was counter to the words of the first chapter of Genesis. This effectively disposed of the notion that the sea had once overspread the lands and that in it had lived animals whose remains are now entombed in the rocks. For had not the Creator separated land and sea before animal life was called into being? Neither was there any place for the heresy that the fossiliferous rocks, though perhaps several thousand feet thick, had accumulated during immense periods, for there was no escaping the dogma that the world had been created out of nothing about 6,000 years ago.

So to escape martyrdom and the irrefutable facts of Nature at the same time there was adopted the expedient that these fossils never represented living creatures, but were mere sports of nature, *lusus naturae, lapides sui generis, lapides figurati.* Those who could not accept this hypothesis had recourse to Noah's flood, although the impossibility of this explanation is equaled only by that of the other. But the "Diluvialists" formed an important theologico-scientific school during the 16th, 17th and 18th centuries, although they were combated by such men as Leonardo da Vinci (1452-1519), the sculptor-engineer, Nicolas Steno the Dane (1631-1687), who was among the first to see that the earth's strata constitute a chronological record, and Robert Hooke the Englishman (1635-1703), who argued against the insufficiency of the Noachian Deluge in length, just as some other scholars had come to question its universality.

During this period there were devised a number of cosmogonies, whose chief aim was to harmonize natural events with theological interpretations and whose chief characteristic seems to have been their disregard for natural phenomena. The limitations under which their authors labored, both as to their knowledge of Nature and as to the time within which they must compress the history they treated, resulted in many ludicrous suppositions, such as the one already mentioned, that the immense thicknesses of fossiliferous rocks were formed during the Flood.

There is a group of writers who deserve special mention because their theories carry the first foreshadowings of the truly scientific attempts to explain origins and forces. These men were Descartes (1596-1650), Leibnitz (1646-1716) and Buffon (1707-1788) who all held that the planets were originally glowing bodies like the sun. Buffon went further and conceived of the planets as having formed a part of the sun's mass, whence they were separated by the shock of a comet. While these men were limited by lack of data regarding the composition and mechanics of the heavenly bodies, their honest efforts to really use such knowledge as they had must command our admiration. Buffon indeed looked forward to the time when the oceans would erode away and cover the lands and when the planet would become gradually refrigerated and unfit for human occupancy.

During the latter part of the 18th century there were probably no scholars who influenced geological thought as profoundly though in totally divergent directions as did the German Werner (1749-1817) and the Scotchman Hutton (1726-1797), founders respectively of the schools of Neptunists and Plutonists. Werner and his school revived the old idea that the entire earth had been covered to the summits of the mountains by a universal ocean, and believed that from this ocean all the rocks had been deposited by chemical precipitation; hence the geological formations were universal in extent and uniform in character. At a suitable time this universal ocean conveniently disappeared but it had to be recalled in order to deposit some other formations which had been discovered out of their natural order. Then it again vanished like a well trained servant. The Neptunists also insisted on the aqueous origin of the vast systems of rocks which are now known to be and many of which were then claimed by other investigators to be of volcanic or igneous origin.

On the other hand it was one of the fundamental doctrines of Hutton and the Plutonists that the internal heat of the globe has frequently forced great masses of molten rock into higher formations or onto the surface of the earth. However, Hutton realized that large bodies of rocks are of sedimentary origin. While Werner scouted the idea of the importance of earthquake and volcanic phenomena, Hutton saw in them and in their allied forces a sufficient agent for the tilting of the strata and the elevation of the dry lands above the oceans. Unlike his predecessors Hutton attributed volcanic activity to the internal heat of the globe rather than to the combustion of inflammable substance, such as coal, bitumens, pyrite, &c. It was Hutton's clear eye, too, which saw more than anyone before him had seen the importance of running water as a land sculptor. What we today accept as commonplace was by Hutton's contemporaries rejected with scorn or quietly ignored.

Previous to the early years of the 19th century geologists almost to a man had been Catastrophists—whether Diluvialists or Vulcanists—concerned in explaining all striking and unfamiliar phenomena, all well marked stages in earth history, by some great convulsion of Nature, by the intervention of some agent or force not now evident and of which modern science knows nothing. But Hutton taught that we have no right to appeal, in formulating the history of the earth, to any causes or forces which are not in operation at present. In other words the dominant idea in his philosophy was that the present is the key to the past. He thus laid the foundation for the school of Uniformitarianism, of which Lyell (1797-1875) rising to prominence a few years later, became the chief exponent. This school, carrying to its logical conclusion the statement of Hutton that "no powers are to be employed that are not natural to the globe, no action to be admitted of except those of which we know the principle, and no extraordinary events to be alleged in order to explain a common experience," denied that there was any reason to suppose that geological agents have ever varied in their activity, or in their potency to modify the features of the earth.

While they served to break the shackles with which Catastrophism had bound the science, the Uniformist doctrines have been displaced in large part by the principles of Evolution. The Evolutionist, although he holds on the one hand to the permanence of the laws and forces of Nature through all the earth's history, also holds on the other hand that these forces have acted with varying intensity during different periods of that history. Thus there has been an interplay of laws and agents which has resulted in exceeding diversity of events and resultant forms.

It may be said here that by the time Buffon published his *Epoques de la Nature* in 1778, Geology was becoming freed from the thrall of theological dogma; hence he felt at liberty to ascribe long periods of time to the development of the earth—that is, long as compared with the brief time previously alloted. He estimated from his experiments with cast-iron globes that the world began about 75,000 years ago and would come to an end 93,000 years hence. While these figures seem small to the modern geologist they represent a great advance beyond the limitations of earlier writers, and may be said to mark the beginning of an intelligent attempt to estimate the duration of geologic time.

Undoubtedly the theory of earth origin which more than any other since the beginning of the 19th century has influenced geologic thought, is that of La Place, known as the Laplacian or Nebular Hypothesis. Pierre Simon, Marquis de La Place, was born in 1749 of very poor farmer parents and died in 1827. He was one of the most brilliant of mathematicians and astronomers and through his studies of celestial mechanics was able to formulate more clearly than any other scholar of his own or previous time a theory of the origin of the solar system. This was published in 1796 as a footnote to his *Exposition du systeme du monde*. According to this hypothesis the material of the solar

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system was originally in an extremely heated gaseous spheroid extending far beyond the present orbit of Neptune. This spheroid contracted and rotated as a result of loss of heat. In time an equatorial ring of gaseous matter was left behind in the orbit now occupied by Neptune. After further shrinkage other rings were formed where the other planets now revolve. As these rings cooled they parted and collected into spheroids which gradually condensed into the planets. Most of them while still gaseous gave off secondary rings which evolved into satellites. In those cases where cooling progressed far enough the masses liquified and at length their surfaces hardened into rock. A modification of the theory suggested that owing to pressure solidification would begin at the center, while on the contrary other students urged that the temperature at the center would be too high for the original gas ever to liquify.

Now it will be conceded that there are many features of the solar system which seem to harmonize beautifully with this theory. It is certainly true also that the earth's interior is hot and that vast quantities of molten rock have been thrust forth from within. And it is also true that most of the oldest known rocks are igneous or derived from igneous rocks. But on the other hand there have developed, especially in recent years, a number of serious objections.

(1) Lord Kelvin computed that the density of the nebula when it was expanded forty times beyond the orbit of the earth (Neptune's orbit has a radius thirty times that of the earth) would be 1/570,000,000 that of common air. It is difficult to understand how such a diffuse body could maintain such an exceedingly high temperature as postulated, and why its substance would not have cooled to solid particles long before these could become aggregated.

(2) It has been urged that definite rings might not be formed but that the equatorial matter would separate particle by particle.

(3) Mathematical calculations show difficulties in the way of a ring forming into a spheroid so simply as the theory demands. The earth ring would have a cross section of about twenty-five miles and its center of gravity would be at the center of the sun. Such a ring of gas with its exceedingly low gravitative force and with the high temperatures necessary to keep all the earth substances in gaseous form could not hold together by its own

gravitative control the atmospheric constituents, nor the waters of the ocean, nor probably even the much heavier rock substances of the future earth.

(4) In any rotating system the momentum of rotation remains constant through all changes of state. As the nebula contracted it rotated faster and hence assuming the present momentum of the solar system, the sun should today have an equatorial velocity of 270 miles per second. Its actual velocity is about one and one-third miles per second. There seems to be no agent competent to have caused this enormous retardation.

(5) If the mass of the solar system be theoretically converted into a gaseous spheroid as postulated by La Place and be given all its present momentum, by the time the Neptunian ring is ready to be separated the nebula will be found to have less than $\frac{1}{200}$ of the momentum necessary for that separation. In like manner at the Jupiter stage the momentum of the nebula will be only $\frac{1}{140}$ of the necessary value, at the earth stage $\frac{1}{1800}$ and at the Mercury stage $\frac{1}{1200}$. Reversing the statement—at the time the Neptunian ring was ready to be formed there would be required for separation a momentum 200 times as great as the actual momentum at that stage. In the Jovian stage the needed momentum would exceed that available by 140 times; in the earth stage by 1800 times; in the Mercury stage by 1200 times. These figures not only reveal a serious weakness but they show alarming discrepancies among themselves.

(6) Directly in line with these facts is the demonstration that if, assuming again the original nebula, the whole mass remained together until the rate of its rotation became sufficient to force the separation of a ring, it would not acquire this rotation until it had shrunk well within the orbit of the innermost planet.

(7) If again we assume the system to have developed to the stage when Jupiter's ring was ready to be left behind we can see that Jupiter's momentum must be proportioned to that of the nebular material inside his ring as the masses and velocities and radii of the two bodies were proportional. Now the mass of Jupiter and his satellites is about $\frac{1}{1000}$ that of the system exclusive of the planets outside his orbit. But computations by Sir George Darwin show that Jupiter and his moons carry 96 per cent of the whole momentum of the solar nebula at that stage.

Other planets show similar disproportions between masses and momenta, some of them even greater than this one. The planetary system as a whole carries 1/745 of the mass of the entire solar system but it contains over 97 per cent of the total momentum. Tidal reaction between the central and outlying bodies might help this difficulty slightly but it is entirely inadequate to fully meet the case.

(8) It would seem that the rings should have a certain symmetry and regularity in masses. But this does not hold good, as has always been recognized. The masses of the planets from outermost to innermost, taking the earth as unity, are 17, 14.6, 94.8, 317.7, 0.1073, 1, 0.82, 0.0476.

(9) The rings should have been circular when formed and no great divergence should result during later evolution. Most of the planets satisfy this law fairly well, but the orbits of the planetoids are neither circular nor concentric, but are singularly interlooped.

(10) If we consider the evolution of the satellites from their primaries we will see that the former should revolve in the same direction as the rotation of the master spheres, from the very mode of their origin, and that these master spheres should rotate in less time than the revolutions of their respective satellites. But Phobos, the inner satellite of Mars, revolves around that planet more than three times while the planet rotates once, and the little bodies which form the inner border of Saturn's inner ring revolve in about half the time of Saturn's rotation.

(11) As additional evidence of the same kind may be cited the discovery that Saturn has one moon and Jupiter two which revolve in retrograde direction. The necessity of uniformity of motion under the Laplacian hypothesis was so patent that it was taught that a single exception would prove fatal to the hypothesis.

It must be remembered that La Place propounded his theory at a time when less was known of the heavenly bodies and their mechanics, and also of the laws of gases, than is known now. For many years the theory seemed to fit the observed facts, astronomic, physical and geologic. It would be hard to overestimate its value to advancing science, substituting as it did something specific and tangible and reasonable for the wild speculations which had preceded it. Some of the facts of astronomy and physics which recent research has marshalled against the theory have been stated above. It may be added here that the Nebular Hypothesis provided an immense atmosphere during the early stages of the earth's evolution with gradual diminution until presumably its rarity would allow the total drying up and freezing of the earth. As it has been expressed, "Our recent icy stage was but an October frost; December was yet to come." But recent studies have shown the presence of glacial epochs almost from the beginnings of known geologic history as written in the stratified rocks. Furthermore, evidences of dry periods far back in the past have come to light and have still further disturbed the regularity of the supposed course of events. Again, the granitic masses which were once supposed to represent the very rock foundations of the earth's crust have proved to be later intrusions and not the original crust at all. The globe itself seems to be adding its testimony to the insufficiency of the old theory of its origin.

Some years since, while Dr. T. C. Chamberlin was engaged in a study of the glacial deposits of Wisconsin, of which state he was State Geologist, he became interested in an investigation of the causes of glacial periods. This led him gradually backward to the broader theme of the origin of the earth and the sufficiency of the Laplacian Hypothesis. After he became president of the Univeristy of Wisconsin and since he has been head of the department of geology at the University of Chicago he continued his researches, with the coöperation of Dr. F. R. Moulton, the able astronomer and mathematician. The discrepancies which were discovered as a result of their computations and which have been outlined above weakened their faith in the older view and after several attempts to patch it up or to use some other existing hypotheses, such as the meteoritic of Lockyer and of Darwin, they found it necessary to set about the more difficult constructive task of formulating a new hypothesis which would avoid the pitfalls that had wrecked the old one and which would fit observed facts and demonstrated laws. Their progressive results were subjected constantly to the most rigorous mathematical scrutiny and the completed hypothesis—the Planetesimal Hypothesis—seems to meet the most exacting demands of modern science. A brief outline of this hypothesis must suffice here.

It is postulated that the solar system originated from the slight disruption of an ancestral sun by the distant approach of another star. This resulted in the throwing out of a part of the sun's mass into two opposite, spirally curved arms—a spiral nebula was formed. Now it seems to be a well established fact that such approaches are not uncommon events, as celestial events go, and are recorded by the flashing out of new stars. It is true, too, that the spiral nebula is the predominant form in the heavens. When it is realized that only $\frac{1}{745}$ of the solar system's mass is contained in the planetary bodies it will be realized how comparatively insignificant may have been the event which caused the initiation of the system, especially in consideration of the enormous volumes of matter which are constantly being shot out from the sun under ordinary conditions and apparently without any external stimulus.

Reasoning from the analogy of observed spiral nebulæ it is assumed that the matter contained in the two arms was embraced partly in knots or masses of more aggregated matter, between which were immense spaces more sparsely occupied. As the sun-substance was shot forth it must have expanded enormously and before long much of it passed from the gaseous state through the liquid to the solid, though of course it remained in an extremely finely divided state. The spectra of the spiral nebulæ show that they are in this finely divided, chiefly solid condition. Perhaps the larger knots, even in their most expanded and cooled state, had gaseous centers. The smaller knots doubtless were composed of solid particles.

The attraction of the passing star had imparted a rotatory motion to the arms of the nebula, hence the whole mass swept around its center of gravity, the knots exerting a secondary pull of their own, the more scattered matter controlled directly by the central parental body. Some of the matter shot out was doubtless drawn back into the sun but the remainder proceeded in its evolution to form the planetary system. The knots served as the nuclei about which revolved a great swarm of matter. most of which was in time gathered into closer relationship to form planets, planetoids or satellites. The knots also acted as harvesters of the celestial reaping grounds, if I may use the figure, and drew in such of the scattered particles, the planetesimals, which had been revolving directly around the sun, as came within their spheres of attraction and as they were competent to hold. In the case of the larger planets these doubtless included even the lightest gases, such as hydrogen and helium, but the smaller planets such as the earth could hold only the heavier atmospheric gases, and these only after the temperatures had fallen to those of their present surfaces. The smallest planets, Mercury and Mars, and the planetoids and satellites never were able to hold atmospheric gases or water vapor. Some smaller knots in the vicinity of the larger ones were within their spheres of control and so became satellite knots. From their smaller gathering power they would always remain relatively small. As a result of the nature of their origin the different knots would have irregular spacings and masses. Hence their growth would be unequal and in ultimate character they would be different.

It seems probable that the largest of the planets, Jupiter, has always been very hot. Indeed he is held by some astronomers to be self-luminous, a miniature sun. In the case of the earth knot the smaller size permitted rapid and probably complete cooling so that the juvenile earth was not very hot, either inside or outside. Probably the core was never liquified, either from its original condensation or from later accretions of planetesimal matter. Whatever tendency there was in this direction because of friction or compression would be antagonized by the increasing pressure of overlying rock.

The atmosphere of the earth is thought to have been derived, first from gases entrapped in the planetesimal matter and later released; second from gaseous matter which had been revolving about the growing earth—"the irreducible gaseous residium of the knot"; and third from matter which came in with planetesimals or as planetesimals. Its evolution began early and in a minor way is continuing at the present day.

The hydrosphere, the water of the earth, was somewhat later in forming. Molecules of water-vapor have a greater velocity than do those of the atmospheric gases and hence would not condense into water until after an atmosphere had been well developed. If, as computation shows to be probable, the earth-knot had 30 or 40 per cent of the present mass of the earth, it no doubt held water-vapor from the first, and so the hydrosphere would begin its development early in the planet's evolution. In the very nature of things the young earth probably had arid regions and periods as well as humid ones.

Probably it was not long after this that volcanic action began on the growing earth. With the continual infall of material there was a parallel tendency to readjustment, reassortment, and consequent condensation. This would cause increased pressure and pressure generates heat. The heat at the center moved outward into regions of lower pressure and here the melting points of some substances were reached. The tendency was for these fused masses to ascend and hence in time the surface was reached. In many cases the lava so formed cooled as great masses within the porous outer zone. In other cases it welled quietly out upon the surface, and in yet others, where gases were confined within the molten rock, violently explosive eruptions took place. The climax of vulcanism seems to have been reached during Archean time, at the very beginning of observable geologic history. Since then the processes of weathering, erosion and sedimentation have become more and more predominant, although there have been repeated outbursts of volcanic activity such as those which gave us the trap rocks and granites of New England and the great lava flows of the Columbia river basin. But most of the post-Archean rocks are sedimentary deposits formed by the agency of wind and water.

It is probable that radio-activity was a contributing factor in initiating and perpetuating volcanic activity, just as electricity and magnetism were influential in helping on the growth of the earth knot.

It was inevitable that there should be irregularities in the surface of the young sphere, both from the infall of planetesimals and from volcanic activity and deformative movements. In the hollows thus formed the hydrosphere first appeared at the surface. As more and more water-vapor condensed and the hydrosphere grew the lakelets increased in size and numbers until the oceans of today were developed. The material which underlay these water bodies and which fell into them was less subject to weathering processes than the material which formed the land areas and as a result the land masses came to have a lower specific gravity than the suboceanic masses. This resulted in progressive compression and depression of the ocean basin and corresponding laying bare and crowding of the land masses. Crumpling and distortion were attendant upon these events and the irregularities of the continents were continually aggravated. Lines of weakness developed and here, as we might expect, volcanic and earthquake activity are in evidence.

Conditions favorable for the maintenance of life no doubt ensued long before the earth attained its full growth, but we have no means of knowing when or whence or how or where that life was initiated, except that doubtless it was in the water, and the first forms were plantlike in nature. By the time the first available legible record was made in the oldest exposed sedimentary rocks, both animal and plant life were highly developed and widely deployed. A great lapse of time must be represented by this development, a period, it may be, equal to or greater than all subsequent time.

By way of summary, then, it may be stated that the Planetesimal Hypothesis provides for the beginning of the solar system by a spiral nebula, from the arms of which have developed the planetary bodies, while the central part has become, or remained, the sun. Limiting our attention to the earth we may trace first the growth of the lithosphere, the solid part, by accretions of planetesimals, then the development of the atmosphere, and a little later of the hydrosphere, by release and closer indrawing and capture of their component elements. The oceans have always occupied essentially their present basins and have merely overlapped more or less the continental margins and from time to time have transgressed the interiors of the great land masses. Unlike the Laplacian Hypothesis this one does not demand symmetry and uniformity either in the spacing and masses and motions of the planetary bodies or in the progress of their development and history, but provides latitude for all observed and probable variations. The occurrence of arid and glacial conditions on the earth is thus not only allowable, but is a probable, an almost necessary feature of actual reactions and interactions between lithosphere, hydrosphere and atmosphere. The hypothesis seems to meet the necessities of the solar system and so far no critical objections have been advanced against it, although it has been abundantly discussed before the learned societies of the United States.

In concluding this outline of the progress of thought regarding geologic history I am reminded of Tennyson's beautiful and expressive lines:

"There rolls the deep where grew the tree.
O earth what changes has thou seen!
There where the long street roars hath been
The stillness of the central sea.

"The hills are shadows, and they flow
From form to form and nothing stands;
They melt like mists, the solid lands,
Like clouds they shape themselves and go."

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DES MOINES