Journal of the Minnesota Academy of Science

Volume 3 | Number 2 Article 3

1887

The Field of Geology and Its Promise for the Future

W. J. McGee

ground in an old woodpecker's hole. On rapping on the stub with my gun the bird pushed out its head. The young were of all sizes, showing that the eggs had been incubated from the first laying. The eggs contained large embryos.

May 8, 1888.

[*Paper Y.*]

THE FIELD OF GEOLOGY AND ITS PROMISE FOR THE FUTURE.— *W. J. McGee.*

I.

The legitimate field of Geology is now fairly defined, and so fully occupied that it is possible to scan its expanse and discern the tracts yet untrodden by the pioneer. From a survey of the field it appears that many of these lacunae are interesting, and that one is especially noteworthy.

The primitive geologic classification is based immediately upon phenomena—upon those products of the forces operating naturally upon the earth with which it is the province of the science to deal; but in most cases the processes may be readily inferred from the products, and the phenomena may thus be classified as well by the agencies they represent as by their individual characteristics. So the empiric or formal laws expressing the external relations of the phenomena give place to natural or physical laws expressing their essential relations in terms of the operations by which they are produced; and the ultimate geologic classification thus becomes genetic, or a classification by processes rather than products.

Now the various processes with which the geologist has to deal fall naturally into two principal and antagonistic categories, which are supplemented and modified by five subordinate categories; and these categories of processes clearly define the province of geology.

The initial geologic movements (so far as may be inferred from the present condition of the rocks of the earth) were distortion or displacement of the solid or solidifying terrestrial crust in such manner as to produce irregularities in the surface of the globe. These are the movements involved in mountain growth and in the development of continents; they have been in operation from the earliest eons recognized by the geologist to the present time; and their tendency is ever to deform the geoid and produce irregularity of the terrestrial surface. Such movements have been collectively designated displacement or diastrophism; but in the present connection at least they may be grouped as *deformation*, and the quality of the movement may be characterized as *diastatic*. The movements are partly vertical (though there is always a horizontal element) and are most easily measured from a fixed datum plane, such as sea level, and they are therefore commonly separated into *elevation* and *depression*.

The second great category of movements comprises the various processes of aqueous erosion and deposition initiated by the primary deformation of the terrestrial surface. By these processes mountains and continents are degraded, and sea and lakes are filled with their debris; these processes, too, have been in active operation from the dawn of geologic history to the present; and they ever tend to restore the geoid by obliterating the irregularities of the terrestrial surface produced by diastatic movement. The processes may be collectively called *gradation*; and the antagonistic operations comprehended under the term are designated respectively *degradation* and *deposition*.

A subordinate class of processes by which the rocks of the earth are formed or affected is the extravasation of lavas and other volcanic matter from beneath the surface, and the outflow of subterranean waters containing minerals in solution, together with the consequent collapse of cavities and other movements within the crust of the earth. These processes have been in operation throughout geologic time, though perhaps with diminishing activity; they have added materially to the superficial strata of the earth; and they have modified the geoid not only by addition without but by commensurate loss within and consequent deformation or structural alteration. The operations are commonly comprehended under the name *extravasation*; and, like the other primary categories, this comprises two subordinate classes of processes of antagonistic tendency, which, simply for the purpose of fixing their relations, may be called *efflux* and *collapse*. The vibratory movements of *seismism* probably result from both deformation and vulcanism under certain conditions.

The second subordinate category of processes by which the rocks themselves and the operations of the second great category of geologic processes are modified, comprises the chemic and chemico-mechanical alterations in constitution and structure of the earth's strata brought about by the action of percolating water, air and other gases, the rise of the isogeotherms beneath areas of deposition, the heat of deformation, etc. These processes have affected the rocks ever since the solidification of the planet, but probably with progressively diminishing intensity; by them the rocks exposed to degradation are disintegrated, decomposed and softened, and degradation is thereby accelerated; by them the soft sediments are first lithified and then (sometimes) subsequently metamorphosed; and by them the chemic complexity and structural heterogeneity of the terrestrial crust have been largely produced. The various processes are processes of *alteration*; and they comprehend *lithifaction* and its antithesis (*decomposition* and *disintegration* combined) in its various phases, or rock formation and rock destruction.

There is another subordinate category of processes which are intimately allied to the second great category, viz: *glaciation*. Only two clearly defined periods of extensive glaciation (both late Tertiary or Quaternary) have been recognized, though others have been suggested; in general the tendency is to obliterate surface irregularity both by grinding down elevations and filling up depressions, and thus to perfect the geoid; but glaciation may also accentuate pre-existing irregularities of surface, certainly by moraine-building and probably by basin-cutting, and must therefore be set apart as a unique agency in the modification of the external configuration of the globe. The general process comprises *glacial construction* and *glacial destruction*.

The fourth subordinate category includes the effects of aerial circulation directly upon the land and indirectly through wave and current action. The processes have been in operation throughout geologic time, but so indolently that little traces of their products are found save on the present surface; in general the tendency is to reduce elevations and fill depressions, and thus to merge into gradation; but there is also a tendency to build dunes, beaches and banks, and thus to produce certain minor irregularities of the earth's surface as well as to perpetuate others. The general process may be called *eolation*; and its subordinate processes are, like those of the other categories, antagonistic.

There is a final category which is in part allied to alteration, but is in part unique, viz: the chemic, mechanical and dynamic action of organic life. Ever since the terrestrial crust became so stable as to retain a definite record of the successive stages of world-growth, life has existed, and by its traces has furnished the accepted geologic chronology; at first the organisms were simple and lowly and affected the rocks chemically through the processes of growth and decay as do the lower plants and animals of the present; later, certain organisms came also to contribute largely of their own bodily substance to the growing strata; and still later the highest organisms, with man at their head, have come to interfere with gradation, alteration and eolation by dynamic action, and thus directly or indirectly to modify the various inter-related geologic processes—indeed it is probable that in populous plains, at least, the several natural processes combined are less potent factors in geologic development than human action alone. The vital forces are too varied in action to be conveniently grouped and comprehensively named.

This simple classification of processes appears to traverse the entire domain of geologic science, whether empiric or philosophic, and sets forth the various parts in true relation. It is summarized in the accompanying table.

CLASSIFICATION OF GEOLOGIC PROCESSES.

Principal Categories.	1. Deformation,	E evation. Depression.
	2. Gradation,	Deposition. Degradation.
Subordinate Categories.	1. Extravasation,	Efflux. Collapse.
	2. Alteration,	Lithifaction. Delithifaction.
	3. Glaciation,	Glacial construction. Glacial destruction.
	4. Eolation,	Eolic construction. Eolic destruction.
	5. Vital action.	Various constructive and destructive processes.

It is interesting to note in passing that the first subordinate category is intimately connected with the first principal category of movements, and that both tend to produce departures from the simple geoidal form, or *heteromorphism*. Play is thus given to the operations of the second principal and the last four subordinate categories, which are also intimately related and combined and tend to produce *heterogeneity* in the external shell of the earth. The joint result is *differentiation* of the earth's exterior—the antithesis of those processes of *concentration* and *segregation* by which the planet was originally formed. The passage from the stage of segregation to that of differentiation represents the senescence of the planet; these stages define the provinces of the astronomer and geologist respectively; and the latter defines in like manner that portion of the field of knowledge within which the inductive method of reasoning is alone applicable, by reason of the ever increasing complexity of the phenomena.

The domain of geology being thus outlined, it remains to indicate those fields which have been well covered by investigation and those which yet remain untrodden; and the first principal category, which defines the least-known field, may be passed for the present.

Geology found birth with the study of the sedimentary rocks and their contained fossils; the extravasated rocks soon after received attention, and at a comparatively early period the metamorphic strata and other rocks produced by the alteration of sediments and extravasated materials, etc., came under investigation; and so the lines of pioneer research were directed toward the genetic classification of rocks. Great progress has been made along these lines, and most of the rocks of the explored earth have been classified with a greater or less degree of refinement. The sedimentary strata are generally classified either by their own sequence or by the degree of biotic development of their contained fossils, or chronologically; some of the extravasated rocks and many of those produced by alteration are simply classified by their extrinsic characters, or petrographically; while certain other rocks of both kinds are classified by their constituents, or mineralogically. The clastic rocks—the products of deposition—especially have received careful scrutiny; out of their study has grown the greater part of geologic literature; surveys and commissions have been endowed for the purpose of investigating them; national and international conventions have been established to discuss them; and their relation to the arts and to the welfare of the race have been pointed out repeatedly. This field of geology has been carefully covered; and though its economic importance is such that it cannot be abandoned and must even be tilled more deeply than ever as the years go on, it may be questioned whether it is not exhausted to comparative barrenness unless new and more fruitful methods are devised.

The phenomena of degradation were brought into prominence by Lyell, and have ever since maintained an important place in geologic literature. Within the last decade, however, a novel and important cognate idea has been developed: it is now perceived that the processes of degradation are governed by definite laws and leave a legible record of their operation in the configuration of the surfaces upon which they have acted, and consequently that geologic history can be interpreted from the hills produced by degradation as well as from the strata produced by deposition in contiguous areas. This discovery, simple as it seems, marks an era in the progress of geologic science, if not indeed the birth of a new science. Already the subject of "geomorphology" as it is called by the director of the national geologic survey, or "systematic geography," as the physical geographer of Harvard proposes to term it, has attracted much attention among the foremost students of this country, and nearly as much abroad. Thus this field, although long worked, is to-day one of the most promising in the entire domain of geology.

Those phenomena of extravasation which trench upon stratigraphy, petrography, and mineralogy have been carefully studied and their significance and formal relations set forth as clearly as present classifications permit; but while the still more interesting physical relations have long been under investigation in various parts of the earth by a score of vulcanologists, the great problems of vulcanism and seismism remain in large part unsolved. These problems cannot, however, be separated from those of deformation, and this field of research is thus narrowed, though it promises rich reward to profound workers.

By reason of the impetus given by early studies, petrography and mineralogy have been carried well forward, and great progress has been made in ascertaining the genesis and relations of the elements of the terrestrial crust. Various rocks and minerals have been discovered in nearly all portions of the earth, their relations to each other and to the arts have been comprehensively studied, and elaborate systems of classification have been devised for them; the ores have been tested and applied to the uses of man in all countries; and most of the mines of the world have been extensively exploited. Yet the progress in this field of rock formation has thus far been chiefly in the direction of differentiation and endless multiplication of details; and the need of the hour is for concentration and for the development of a philosophic idea by which the complex subject may be simplified as the even more complex subject of biology was simplified by the idea of natural selection. This field of geology is promising both to the daily drudge who digs for base metal and to the inspired searcher who delves more deeply for the golden grains of knowledge.

It is remarkable that the class of geologic processes and agencies most intimately related to the leading industry of the world, and even with all the higher forms of life upon the globe, i. e., the decomposition of rocks, the formation of subsoils and soils, etc., should have received so little attention. The entire field of agricultural geology remains practically untrodden, and no man dreams whither its unexplored paths may lead.

Although the glacial deposits of the world, and particularly those of America, have been elaborately studied, and although this study has contributed more than one important chapter to the history of the earth's development, the field remains fertile and yields rich returns for labor expended upon it. But little is yet known of the destructive action of ice; for the glacial mill is veiled from curious eyes, save perhaps its outer portals, and the areas of greatest grinding are unexplored or inaccessible; the fact that the question as to the glacial excavation of the Great Lakes is still mooted and so far from settlement that no conservative geologist speaks upon it with confidence, well illustrates the paucity of knowledge concerning the primary process of glaciation; and so this field is one of the most promising within the domain of the science to the intrepid explorer. Equally promising however, is the general field of inquiry concerning the causes and conditions of glacial climate, where the physicist and astronomer meet the geologist on common ground, and where more than one sturdy pioneer has already gone down beneath the gloom of uncertainty into the treacherous morass of ill-founded speculation.

The direct action of the winds has never been an important process in geology, save, perhaps, in limited areas, and the subject promises little to the investigator; the indirect action of the winds through the waves and currents of inland seas has just been studied by American geologists so exhaustively as apparently to leave little for their successors in this field; but the indirect effects of aerial circulation upon geologic phenomena produced through climate, oceanic currents, etc., affords a fit field for further study.

Science never lifted the veil of the unknown upon more enchanting vision than when she vivified the fossils entombed in the rocks and thus opened a vivid panorama of the earth's life stages, stretching from the present back through unreckoned ages to the infancy of the organic world; and though paleontology has revolutionized cosmology within two generations, its field is fertile as ever and responds abundantly to intelligent cultivation. The influence of physical environment upon the organism has been carefully examined, and an essential factor in the development of life has thereby been brought to light; but, although the coals, limestones, hydrocarbons, etc., have been separately studied, the general reciprocal influence of the organism upon the physical environment, and thus upon the general process of differentiation of the external shell of the earth, has never been comprehensively investigated. This will eventually prove one of the most fruitful fields of geologic research.

Recurring now to the first principal category of processes, viz., deformation, the most interesting and one of the most extensive of the partially explored fields of geologic research is found. The structure of mountains has long been attentively regarded, and many profound speculations concerning their origin have been indulged in; and the origin of continents and ocean basins has been considered by every student of the general geologic history of the globe. Here the domain of the physicist and astronomer on the one hand and that of the geologist on the other, overlap; and the ablest minds of the generation have sought to solve the problems presented by the phenomena. Here the physicist contributes principles and makes deductions of great suggestiveness and often of high value to the geologist; and here the geologist is an agnostic, assails the deductions of the physicist, and, too frequently for the good repute of physical science as applied to geologic research, breaks them down. But the geologist is equally an agnostic with respect to his own conclusions of higher rank than mere generalizations; and he assails every inference of his fellows, and unless he be rash indeed, guards his own course at every step and feels his way cautiously through the tangled maze of ambiguous testimony recorded in the crumpled strata of the mountains. Yet substantial progress is made during each decade in the subjugation of this refractory territory.

Within about a decade an inference of the highest moment has been made by American geologists concerning diastatic movement, viz: that certain orogenic movements are consequent upon gradational transfer of matter; that the earth is in a condition of isostacy, and that as the rains bear detritus from the mountains into the seas, the unloaded mountains rise and the loaded sea bottoms sink; and thus that a part of the deformation of the outer shell of the earth is consequent upon the processes of gradation. At first blush it might appear that the great problem of earth movement is solved by this discovery; but consideration shows that these consequent diastatic movements are but the indirect result of antecedent diastatic movements for which no adequate cause has yet been assigned. It is evident that if diastatic movement were dependent solely upon transfer of sediments it would progressively diminish with lapse of time, that the mechanism of mountain building and continent growth would soon be clogged by increasing friction, and that the terrestrial surface would be quickly graded so completely that further movement would cease; but the rocks record diastatic activity throughout geologic time, now increasing, now diminishing, but on the average probably increasing rather than diminishing, and perhaps as potent to-day as during any past time. So deformation is separable into two classes of movements, that depending upon transfer of sediments, which may be designated *consequent*; and that for which cause has not yet been assigned (unless the "contraction" theory be accepted), which may be called *antecedent*. Discriminated upon a different basis they fall into two classes approximately but not exactly coinciding with these, namely, *orogenic*, or mountain making movements, and *epeirogenic*,* or continent building movements.

The first of these classes of diastatic movement may be set aside as at least partially explained, though many details remain to be elaborated; and this part of the field is yet promising to the student. But it is the remaining portion of the field of geology defined by deformation which, above all others, appears to afford promise for the future, and especially to the systematic student who seeks to dig deeper than his fellows;

*A term proposed by Gilbert.

and here the most profound of the remaining mysteries of geology is found.

II.

It is only within a decade that diastatic movements of the consequent class have been separated from the primary class; even yet there are geologists who do not recognize the distinction; and so most of the hypotheses thus far framed to explain the deformation of the terrestrial shell rest on the implicit or explicit assumption that all diastatic movements belong to the class here called antecedent.

The primitive hypothesis ascribed the corrugations of the terrestrial crust to more rapid contraction of the interior of the earth than the exterior shell, accompanying secular cooling. The common conception as to the mechanism of this process was familiarly illustrated by likening the corrugated globe to a withered apple—the inequalities of the terrestrial surface corresponding to the wrinkles on the apple's skin; and to the surprise of a majority of geologists this hypothesis has been prominently advocated within a year or two. It appears, however, quite untenable: Fisher and others have shown that the postulated cause is far from commensurate with the observed effect—that even upon the most liberal estimates of radial contraction due to secular cooling, the concomitant tangential contraction would not produce a tithe of the observed corrugation of the terrestrial crust; Dutton maintains that equitable contraction of a spheroidal segment would not produce corrugations such as those characterizing the earth's skin; Taylor, Alexander Winchell and others have pointed out that any corrugations resulting from secular contraction of the terrestrial crust in combination with stresses resulting from precession, nutation, retardation of axial rotation, etc., would tend to assume certain definite directions, and that these directions do not coincide with those of the mountain ranges actually existing nearly enough to give countenance to the hypothesis; Reade and others have recently discovered that tangential contraction due to secular cooling must have been confined to a limited shell (even thinner than the strata actually known to be corrugated); and it might be shown that the concentration of montanic corrugation along certain lines, leaving vast intervening areas quite undisturbed, does not agree with the hypothesis and could not occur in accordance with it under any conditions of rigidity and internal friction of the rocks which it is reasonable to assume—the arches are too long and rest too heavily upon the terrestrial nucleus to convey crushing strains to their extremities without greater compression about their keystones. The "contraction hypothesis" must therefore be rejected, at least as a quantitatively adequate cause of terrestrial deformation.

There is an alternative hypothesis. A dozen geologists have shown that lines of mountain growth commonly coincide with zones of rapid deposition during former times, and that in these zones the deposition was accompanied by depression (thus foreshadowing the later conception of consequent diastatic movement); they have shown further that in consequence of the combined sinking and thickening of the crust the surfaces of equal temperature within the earth—the isogeotherms—unquestionably rose through the sediments until strata formed at the temperature of the sea bottom were heated to hypogeal temperatures; and they inferred that the consequent expansion of the sediments developed stresses whereby further heat was generated, and that the rocks were thus corrugated, flexed and sometimes metamorphosed. This hypothesis has had currency for a generation. It has been commonly questioned, however, whether the assumed cause is commensurate with the observed effect, whether the expansion of sedimentary beds by local rise of isogeotherms from time to time and from place to place is sufficient to explain the extensive and profound corrugation observed in the mountains of the earth, the shortening of the Alpine arc by 120.000 metres as measured by Heim, and the shortening of the Appalachian arc by 60 miles as estimated by Claypole. Quite recently, however, Reade has pointed out what the early advocates of the hypothesis had overlooked, viz: that since the strata are confined in two directions, any expansion due to rise of temperature must take place all in one direction, and that a given rise of temperature would produce thrice the elevation and perhaps thrice the corrugation inferred by the older geologists; and the hypothesis has thus been rendered more acceptable.

Singularly, Reade and all of his predecessors, save J. Herschel, practically neglect the most important factor in the series of movements contemplated in the hypothesis; and even Herschel's case is hardly the general one: lines of sedimentation are the margins of continents; in each case the sediments are laid down not upon a horizontal surface but upon a seawardly sloping bottom; moreover the sediments do not form a horizontal surface, but take a certain seaward slope determined by bottom slope, marine currents, wave action, etc. Thus the mass of sediments is collectively in the condition of the mass of snow upon a roof or upon a mountain side, i. e., in a condition of potential instability or *inequipotentiality*. If the mass is stable in either case, it is because the friction among the particles exceeds the attraction of gravitation upon the particles; and it is obvious that if particle friction were reduced by augmentation of temperature or by alteration of constitution, or if the efficiency of gravitation were increased by addition to the mass, the point of stability might be passed, when the mass would move in the direction of slope. It is equally obvious that if an inequipotential mass expand, the resulting movement will not take place equally in all directions but in the direction of least resistance, which is that of the slope. Now every deposit of sediments fringing the continents is in a condition of inequipotentiality, and any movement due to rise of isogeotherms must take place in a single direction; and the movement will not be limited to that due to expansion, since other factors co-operate. But under the classification tabulated above, any such movements fall into the consequent class, and hence the hypothesis utterly fails as an explanation of the obscure antecedent deformation by which active geologic processes were initiated early in the history of the earth, and by which these processes have ever since been maintained. It cannot be too strongly emphasized that without continents zones of deposition could not be formed, and that continents could not have come into being without antecedent deformation. The case is simple. Either (1) the primeval earth was highly rugose and gradation and consequent deformation have always been employed in reducing the rugosity, or else (2) a general deforming force of unknown value has always been in operation—either the earth is a clock once wound up and ever since running down, or else it is a prime motor whose mechanism may be obscure but whose energy is ever renewed within itself. To the working geologist, constrained by the inexorable logic of facts, there is but one choice between these alternatives—the primeval earth was less rugose than the present, and diastatic movement has not declined with the ages; and the grander earth movements are in progress to-day and apparently as active as at any time in the past.

Thus it appears (1) that while the problem of consequent diastatic movement has been at least partially solved, no attempt has been made to explain antecedent deformation except by the untenable "contraction hypothesis;" and (2) that the antecedent movements are now and ever have been important factors in developing continents and mountains and initiating the various geologic processes whose products represent the material phenomena of the terrestrial crust. The source of these mysterious movements may be sought; and to this end the quagmire of speculation must be skirted.

Pratt and others have shown that a plumb-line suspended over the sea-shore is generally deflected seaward, despite the less density of water than land, thus indicating much greater density of the submarine portion of the earth than of its subaerial portion; and Fisher and others have shown that when the plumb-line is suspended at the base of a mountain range it may be deflected away from it despite the great density of the superficial mountain rocks, proving the mean density of the mountain range to be less than that of the adjacent plain. The discovery of this relation and the American induction of consequent deformation led to the development of Dutton's doctrine of isostacy, according to which the entire terrestrial shell is in a state of hydrostatic equilibrium—the continents floating higher than the sea bottoms because lighter, and the mountain ranges overlooking the adjacent plains, like icebergs the ocean, because their roots are less dense than the medium they penetrate.

A qualitatively adequate cause for the relation is not far to seek, and has indeed been suggested by Faye: Deep sea soundings have shown that the deeper waters of the ocean are cold, the mean temperature of the ocean bottom being much lower than that of the surface either of water or land. Now, water is a good conductor and also a ready conveyor of heat; and it is evident that the ocean bottoms are subjected to more rapid refrigeration than the land, that the terrestrial shell is chilled to the greater depth beneath the sea, and that the cooler suboceanic rocks are, *ceteris paribus*, denser than those forming the continents. And this explanation of the observed inequality in density of the earth's shell is at the same time an explanation of antecedent deformation; for it is evident that with the progress of secular refrigeration there is a constant tendency to depress and condense the ocean floor and to relatively uplift and lighten the continents.

It is true that the existing difference in temperature appears inadequate alone to explain either the difference in density or the inequality in altitude between ocean bottom and land surface, and that the difference in rate of secular cooling similarly appears inadequate alone to explain the aggregate of epeirogenic movement; and herein lies the supposed weakness of Faye's hypothesis. Be it noted, however, that the cause has not only been in operation throughout geologic time, but has produced cumulative and thereby greatly multiplied effects. The direct and indirect consequences of an initial inequality in temperature of the earth's crust are complex and far-reaching, though none the less obvious. If a slight irregularity in a shoal sea bottom, sufficient to deepen the waters on the one hand and expose the rocks on the other hand, be given, it is evident (1) that the sea bottom will be chilled and the exposed rocks warmed, producing (2) contractional shortening of the sea bottom radius and deepening of the basin, together with expansional elongation of the land radius and elevation of the nascent land, and at the same time (3) condensation of the sea bottom strata and lightening of the land strata accompanied by further sinking of the former and rise of the latter in isostatic adjustment. It is equally evident that these movements will be followed by (4) desiccation, oxidation, disintegration, and relief from pressure, and thus further lightening, of the land strata; and eventually by (5) erosion of the exposed rocks and deposition of their detritus in less compact condition about the land periphery, thereby farther diminishing the mean density of the growing land, and consequently (6) still further elevation of the land and relative depression of the sea basin. It is evident also (7) that each of these consequent movements must co-operate with the initial one in deforming the earth's shell, (8) that each additional deformation must (within certain distant limits) increase the difference in rate of refrigeration both directly and through differentiation and consequent levitation of the nascent land, to be followed in turn by (9) renewed deformation. Whether these cumulative tendencies are quantitavely adequate to produce the observed difference in density and altitude of ocean basins and continents and the sum of the antecedent deformation of the earth cannot be determined at least until the researches of Woodward upon the rates and effects of secular of cooling of the earth have borne fruit; but certainly there is here a veritable, and as viewed from the standpoint of the geologist apparently a sufficient cause of antecedent diastatic movement.

If the cause be adequate, world-history becomes simple and intelligible. While yet the planet was young and its surface approximately homomorphic and homogeneous, slight warping of the primeval surface occurred, and low islands emerged, either synchronously or independently, to form the continental nuclei; for under the hypothesis this slight initial cause sufficed to set the entire process of earth-differentiation in operation. The sun beat upon the low islands and checked the chilling of the rocks, which thus rose higher and higher, while the neighboring seas grew deeper and deeper; anon the rain fell upon the rocks, triturated them, and carried their debris to the perimeters of the infant continents which they absolutely depressed though always less than their own thickness by reason of their relative lightness, and as the sediment-choked sea shoaled, the continents grew; then the isogeotherms rose under the continental margins, and the sediments were still further lifted by consequent deformation; with the heating from below the strata expanded laterally as well as horizontally, and so slipped seaward on the sloping bottoms and crumpled their perimeters which thus rose still further above sea level and formed mountain ranges overlooking the sea on the one hand and the original continental nuclei on the other; and thus the continents expanded and the derived rocks being ever lighter than the original, they have maintained approximately their original positions, while the continent-building movement has never ceased to operate. With increase in area, the continents were separated into tracts within which the geologic processes varied in activity, some of the nuclei merged and the land masses became asymmetric; some were temporarily submerged, and others may have become lost; the shores were shifted through long distances with the successive oscillations of the growing land; and as the land area increased, isostatic stresses were developed which affected the entire globe and perhaps gave birth to new continents or brought death to old. At the same time great mountain ranges were upheaved and great valleys excavated, particularly about the continental margin, and consequent diastatic movement supervened; in the interior of the continents the primitive rocks were slowly degraded, modified in density and conductivity, and here, too, consequent deformation progressed; and various subordinate movements occurred, which need not be considered here. But in general the continents grew peripherally, their margins were the zones of activity while their centers were more stable, and the general process was one of differentiation and levitation; while the ocean floor simultaneously shrunk and sank, the general tendency was toward condensation and conservation of the primitive terrestrial shell.

The details of world growth cannot b- set forth in a page. It is enough to here portray, in few and simple lines, a hypothetic conception of the general process, chiefly to show that while the unequal cooling of land and sea bottom may be altogether inadequate to produce directly the grand inequalities of the earth's surface, the cause has operated cumulatively and in conjunction with the most potent agencies of geology throughout the whole of geologic time, and may be amply adequate to produce indirectly the obscure antecedent stresses (for which adequate cause has not hitherto been assigned) by which the terrestrial motor has ever been kept in motion and to initiate the consequent movements by which the mountains and the lesser valleys have been developed. Thus may a mite be contributed toward the elucidation of the great remaining mystery of geology.

June 11, 1888.

[*Paper Z.*]

A CHECK-LIST OF THE PALAEOZOIC FOSSILS OF WISCONSIN, MINNESOTA, IOWA, DAKOTA AND NEBRASKA.—*Bruno Bierbauer.*

It is the object of the following list to enumerate as far as possible all the described fossils of the Palaeozoic formations of Minnesota, Wisconsin, Iowa, Nebraska and the Dakotas. In none of the states named, with the exception of Wisconsin, has a complete list been made of the known fossils within its borders. The descriptions of the forms enumerated in this list are scattered through the publications of various scientific societies throughout the world, the reports of many scientific surveys, home and foreign periodicals, etc., so the work of collating was a very tedious one. In the preparation of the list the compiler received valuable aid from Messrs. E. O. Ulrich, Charles R. Keyes, W. H. Scofield and Professor C. W. Hall, and to the first named of these gentlemen are especial thanks due for access to manuscript lists and compilations not elsewhere obtainable.

In the classification it will be seen that no one authority has been followed. The general outline is that of Nicholson and Lydeker; special groups are arranged according to the plan of some one especially eminent in their study. The Crinoidea are classed closely after Wachsmuth and Springer's revision, the Blastoidea after Etheridge and Carpenter, the Cystids after Zittel, and the Bryozoa after Ulrich. The list is designed to be what it is named, *a check-list.*