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CATASTROPHISM AND EVOLUTION.[1]

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WE have come together to-day to do honor to this young, strong institution. We are here that we may make the human circuit complete, and feel the current of a common pride glow from brain to brain. In celebrating the honest, manly growth of the Sheffield Scientific School, among the feelings which animate us veneration for antiquity finds no place. It is denied us to look back into the real past, for the brief lapse of thirty years compasses the life of the school. That short period, however, has amply sufficed to develop, with positive distinctness, the motive and animus of the institution. Its peculiar character is fixed. Reverence for natural truth and the deep, earnest, scientific methods of searching after it are what is taught here; so that we who have passed beyond these doors are gladly welcomed among that resolute band of nature-workers who both propel and guide the great plowshare of science on through the virgin sod of the unknown.

It is centuries too late to define or establish the value of science. Its numberless applications, which find daily expression in the material appointments of life, and serve to refine, to elevate, to render more admirable the mechanism of civilization, have long since put that question at rest. Let us hope that as a means of clearing away the endless rubbish of false ideas from the human intellect, for the lifting of man out of the dominion of ignorance, scientific method and scientific education are acknowledged to be adequate, if not supreme. We may congratulate ourselves, for that victory is won. At last modern society admits that a knowledge of the laws which govern the cognizable universe, and the possession of the only methods which can advance

[1] An address delivered at the Sheffield Scientific School at Yale College, New Haven, June 26, 1877.

that sort of knowledge, presupposes, nay, even develops, an intellect both vital and broad. If in America Science as a mode of education has won her way to the front, it is due, in prominent measure, to the honest training of the Sheffield Scientific School, and time will render this institution its unfailing reward.

Honored by the invitation to address you to-day, I have chosen to present a contribution to the theory of catastrophism and its connection with evolution, feeling that, however slight this contribution may be, as my own it is a direct outgrowth of this school, and that if I turn from the far greater and more attractive achievements of others, from the wealth of literary and philosophic materials which press forward for utterance, and bring here something which I have reached myself, it will afford you a more intimate interest. I have hoped, too, that other graduates might feel as I have, and that year by year men might stand here, fresh from the battle-field of life, out of the very heat of the strife, to tell us of their struggles, and hang the shields they have won along the walls of this temple of science. I ask you then to listen to a plain statement of my views of catastrophism and the evolution of environment.

The earliest geological induction of primeval man is the doctrine of terrestrial catastrophe. This ancient belief has its roots in the actual experience of man, who himself has been witness of certain terrible and destructive exhibitions of sudden, unusual telluric energy. Here in America our own species has seen the vast, massive eruptions of Pliocene basalt, the destructive invasion of northern lands by the slow-marching ice of the glacial period, has struggled with the hardly conceivable floods which marked the recession of the frozen age, has felt the solid earth shudder beneath its feet and the very continent change its configuration. Yet these phenomena are no longer repeated; nothing comparable with them ever now breaks the geologic calm.

Catastrophism is therefore the survival of a terrible impression burned in upon the very substance of human memory. The doctrine was also arrived at in very early times by our modern method of reasoning from marine fossils observed to be entombed in rocky beds far removed from the present seas, — beds which compel the natural inference that they are sea bottoms upheaved. This induction is poetically touched in the Rig Vedas, is stated in scientific method with surprising frequency among the Greeks, and recurs in the writings of most earth-students ever since.

Plutarch in his Morals gives a vivid account of an interview

between an Egyptian priest and wise Solon, who, in the open-mindedness of a truly great man searching after immemorial knowledge, had come to sit at his feet to listen. Calmly and with the few broad touches of a master, in that simple eloquence which comes of really knowing, the priest tells him of the catastrophes of submergence and upheaval which the earth's surface has suffered; and his method was identically ours of to-day. What a picture! Solon the wise, inheritor of the Hellenic culture, master of the polished learning of his country and his day, sitting within the shades of that hoary temple, listening devoutly to the words of one who spoke as out of the dark vault of the past and told how the solid continents were things of a time, born but lately from the womb of the sea.

When complete evidence of the antiquity of man in California and the catastrophes he has survived come to be generally understood, there will cease to be any wonder that a theory of the destructive in nature is an early, deeply rooted archaic belief, most powerful in its effect on the imagination. Catastrophe, speaking historically, is both an awful memory of mankind and a very early piece of pure scientific induction. After it came to be woven into the Sanskrit, Hebrew, and Mohammedan cosmogonies, its perpetuation was a matter of course.

From the believers in catastrophe there is, however, a totally different class of minds, whose dominant characteristic is a positive refusal to look further than the present, or to conceive conditions which their senses have never reported. They lack the very mechanism of imagination. They suffer from a species of intellectual near-sightedness too lamentably common among all grades and professions of men. They are bounded — I might almost say imprisoned — by the evident facts and ideas of their own to-day and their own environment. With that sort of detective sharpness of vision which is often characteristic of those who cannot see far beyond their noses, these men have most ably accumulated an impressive array of geological facts relating to the existing operation of natural laws. They have saturated themselves with the present *modus operandi* of geological energy, and culminating in Lyell have founded the British School of Uniformitarianism.

Men are born either catastrophists or uniformitarians. You may divide the race into imaginative people who believe in all sorts of impending crises, — physical, social, political, — and others who anchor their very souls *in statu quo*. There are men

who build arks straight through their natural lives, ready for the first sprinkle, and there are others who do not watch Old Probabilities or even own an umbrella. This fundamental differentiation expresses itself in geology by means of the two historic sects of catastrophists and uniformitarians. Catastrophism, I doubt not, was the only school among the Pliocene Californians after their families and the familiar fauna and flora of their environment had been swept out of existence by basalts and floods. As understood by archaic man, by the Orientals, the early Egyptians, the Greeks, the Arabs, and indeed until modified within the century by the growing belief in derivative genesis, or by the unbroken continuity of organic life from its first introduction on the planet, catastrophism was briefly this: —

The pre-human history of the planet has been variously estimated in time, from two days — the period assigned by the Koran — to an indefinite extension of ages. The globe having cooled from a condition of igneous fluidity received upon its surface of congealed primitive rock the condensed aerial waters, which formed at first a general oceanic envelope, swathing the whole earth. Out of this universal sea emerged continents; and as soon as the temperature and atmospheric conditions were suitable, low organisms, both of the vegetable and animal kingdoms, were created, and the complex machinery of life set in successful motion.

The great obvious changes in the rocky crust were referred to a few processes: the subaerial decay of continents, delivery of land-detritus by streams into the sea, the spreading out of these comminuted materials upon a pelagic floor, and lastly upheaval, by which oceanic beds were lifted up into subsequent land masses. All these processes are held to have been more rapid in the past than now. Suddenness, world-wide destructiveness, are the characteristics of geological changes, as believed in by orthodox catastrophists. Periods of calm, like the present, suddenly terminated by brief catastrophic epochs, form the groundwork of this school. Successive faunas and floras were created only to be extinguished by general cataclysms.

From all these tenets the modern uniformitarian school dissents only so far as to hold that the processes have not necessarily been more rapidly accomplished than at the rate we witness to-day. The facts of one school are the facts of the other. Both read the record of upheaval and subsidence, of corrugation and crumpling of the great mountain chains alike. One meas-

ures the rate of past geological action by the phenomena of to-day; the other asserts that the present furnishes absolutely no key. This irreconcilable difference finds its most pronounced expression when applied to the past history of life on the planet. If catastrophes extirpated all life at oft-repeated intervals from the time of its earliest introduction, then creation must necessarily have been as often repeated. If this is the case, it is plain that the Creator took pains each time to improve on the lately obliterated forms. If, on the other hand, the uniformitarian biologists are correct in their belief of the descent of all animal life from one or a few primeval types, then catastrophes of a universally destructive character cannot have occurred, and the changes which are proven to have taken place in the earth's surface may have been as moderate and harmless as they maintain. The uniformitarians reject the idea of a rapid and destructive rate of geological revolution in the past, first, because the present course of nature offers no parallel suddenness of action; and, secondly, because they conceive that nature never moves by leaps. They derive great comfort from quoting the well-known saying of Aristotle, that "Nature never does with her greater what she can do with her less." They are especially fond of objecting to catastrophes on account of the vast force necessitated. I confess that this seems to me a singularly fallacious view. Absolutely identical expenditures of energy are required to elevate a continent or depress an ocean basin given distances, whether the operation is instantaneous or infinitely slow. No geologist will hesitate a moment to admit that the question between the schools is not one of geological result, for both read the results alike. I am sure no student of energy will object to my statement that the result requires identical energy, whether employed after the uniformitarian or the catastrophic method. If, as I assert, geological result and the energy to produce it are identical, whichever school is correct, then the only issue between the contestants reduces itself simply and solely to the one question of rate of geological change. In that view, uniformitarianism is the harmless, undestructive rate of to-day prolonged backward into the deep past. This is the belief hinted at by Aristotle and Pythagoras, fought for by Goethe, Lamarck, and Geoffroy St. Hilaire, held to by Hutton, Lyell, and most British geologists, accepted with a lover's credulity by nearly all evolutionists, and finally trumpeted about by the army of scientific fashion followers who would gladly die rather than be caught wearing an obsolete mode or believing in any penultimate thing.

On the other hand, catastrophism of the orthodox sort is the belief in recurrent, abrupt accelerations of geologic rate of crust change, so violent in their rapidity as to destroy all life on the globe. This idea, the mere survival of a prehistoric terror, backed up by breaks in the palæontological record and protected within those safe cities of refuge, the cosmogonies, was fully credited by so recent a great *savant* as Cuvier, and still counts among its soldiers a few of the cast-iron intellects of to-day.

Sweeping catastrophism is an error of the past. Radical uniformitarianism, however, persists, and probably controls the faith of a majority of geologists and biologists. A single extract from so late and so important a book as Croll's Climate and Time will serve to show how strong men still believe in what may be called homœopathic dynamics. Speaking of uniformitarianism, Croll says: "This philosophic school teaches, and that truly, that the great changes undergone by the earth's crust must have been produced, not by convulsions and cataclysms of nature, but by those ordinary agencies that we see at work every day around us, such as rain, snow, frost, ice, and chemical action, etc."

Having reduced the antagonism of the two schools to a question of rate of transference of energy, a single illustration will serve to render clear how, the amount of energy remaining the same, this difference of rate may make the difference between uniformity and catastrophe. Suppose two railway trains of equal weight, each traveling at the rate of fifty miles an hour. On one steam is suddenly shut from the cylinder. The train gradually lessens and lessens its speed, finally coming to rest. It has required a given definite amount of resistance, a numerically expressible amount of work to overcome the motion of the train. The other train at full speed dashes against a bridge pier and is utterly wrecked. The weight, speed, and momentum of the trains are identical, and precisely equal resistance has been expended in bringing them to a stop. In one case the rate of resistance was slow, and acted merely as friction, quite harmlessly to life and after the uniformitarian mode. In the other the rate of resistance was fatally rapid, and its result catastrophe.

Remembering distinctly that uniformitarianism claims one dynamic rate past and present, let us turn to the broader geological features of North America and try to unravel the past enough to test the tenets of the two schools by actual fact. Beneath our America lies buried another distinct continent, — an archæan America. Its original coast-lines we may never be

able fully to survey, but its great features, the lofty chains of the mountains which made its bones, were very nearly coextensive with our existing systems, the Appalachians and Cordilleras. The cañon-cutting rivers of the present Western mountains have dug out the peaks and flanks of those underlying, primeval uplifts and developed an astonishing topography: peaks rising in a single sweep thirty thousand feet from their bases, precipices lifting bold, solid fronts ten thousand feet into the air, and profound mountain valleys. The work of erosion which has been carried on by torrents of the Quaternary age — that is to say, within the human period — brings to light buried primeval chains far loftier than any of the present heights of the globe. Man's enthusiastic hand may clear away the shallow dust or rubbish from an Oriental city, and lay bare the stratified graves of perished communities: it is only a mountain torrent which can dig through thousands of feet of solid rock and let in the light of day on the time-stained features of a long-buried continent.

Archæan America was made up of what was originally ocean beds lifted into the air and locally crumpled into vast mountain chains, which were eroded by torrents into true subaerial mountain peaks. This conversion of sea strata into the early continent is the first record of a series of oscillations in which land and sea successively occupied the area of America. In pre-Cambrian time the continent we are considering sank, leaving some of its mountain tops as islands, and the neighboring oceans flowed over it, their bottoms emerging and becoming continents. This is the second of the recorded oscillations of the first magnitude.

After Archæ-America had began to sink and its bounding land masses to emerge, the conditions on the two sides of the ocean began to show characteristic difference of behavior, — difference in the rate of subsidence, — that very difference of rate which uniformitarianism denies.

Palæ-Pacifis and Palæ-Atlantis were land areas which I conceive to be of continental magnitude, from the vast volumes of sediment brought down by their rivers and poured into the Palæ-American Ocean. American geologists have found the record along the eastern margin of that ocean, namely, the present Appalachian region, so legible that they are agreed as to its main features. There is no plea of illegibility here. The total sediment which fringed the shore of Palæ-Atlantis was about forty-five thousand feet in maximum, but the original ocean, when strata began to gather, was not forty-five thousand feet deep.

That depth and the full accumulation of beds were arrived at by successive subsidences of the sea bottom. The Primordial or earliest Palæozoic along the eastern shore shows evidence of shallow water, which deepened by the occasional sinking of the sea floor. This periodic subsidence went on through the whole Palæozoic time, influencing the Appalachian region, and during the whole coal-bearing period affecting the sea bottom as far as Kansas. Shallow-water evidences are common up to the Carboniferous, after which successive low-level land areas repeatedly occupied the east half of the present Mississippi basin.

This immensely long history of periodic but general subsidence was broken in the northeast by several sudden uplifts, in which the sea strata were so disturbed and inclined that the succeeding beds rested on them unconformably, and in one instance the Green Mountain range was upheaved. The general law on the east side of the Palæ-American Ocean has been the continual in-pouring of sediment from Palæ-Atlantis, subsidence of sea bottom, repeated a great number of times, and only locally varied by dislocation and uplifts. A very limited but not unimportant chapter has just been added to the American rock record by the geological exploration of the fortieth parallel; it is the mode of deposition of the Palæozoic rock in the Western United States.

Passing now to the western side of the ocean, we have again the same enormous thickness of thirty or forty thousand feet of Palæozoic beds, but from bottom to top no evidence of disturbance, only uniform proof of deep oceanic deposition. In other words, the two sides differ: one went down by gradual and successive subsidence; the other at once sank so as to form a profound ocean, which, from beginning to end of the vast Palæozoic age, received in its quiet depth the dust of a continent and the débris of an ocean life. I do not say that the western ocean bottom never suffered further subsidence. I only assert that between the two sides the difference of rate was simply immense.

In keeping with the minor and slight movements of subsidence in the east are the changes in the materials of the gathering strata, which are found to vary continually. Here again the contrast between the east and west is marked. All the Palæozoic series in the west consist in the main of a few broad changes between quartzitic and limestone beds, both giving evidence of deep-sea deposition. By way of illustrating these changes of material, let us consider the condition of sedimentation at the west during the Carboniferous age. There we have seven thousand

feet of limestone, for the most part quite free from land-detritus, accumulated with all the evenness and regularity which the most ardent uniformitarian could ask, suddenly followed by an equal amount of pure land-detritus almost free from lime. This sudden change of sediment simply means a sudden physical change, either a cosmical one which recorded itself as a cycle of climate productive of great erosion, or a terrestrial change resulting in such great disturbance of distant land and sea areas as to cause new climate or new avenues of drainage, or some remote coast disturbance which brought about a revolution of oceanic currents. In either case the sudden change, both at the beginning and end of the quartzite period, and the vast scale of the deposit, means a change of rate in the current operation of nature, and an enormous change of rate. The abrupt passage from a period in which little or no land-detritus has entered a sea for millions of years to one when it pours in with relatively marvelous rapidity is certainly not uniformitarian. This phenomenon of sudden change in the broad petrographical features of a composite group of strata is equally true of each sudden break, of which the western Palæozoic has six. Recall that the bottom of all this ocean was a former continent, that along the east the continent went down gradually, by considerable steps it is true, but still by periodic and, perhaps, gradual subsidences. If the uniformitarians can derive any comfort from Eastern America, — and I suppose they justly may, — they are welcome to it. The rate of subsidence in the east, although not unlikely to have been catastrophic as regards the life of the disturbed region, looked at broadly may be called uniformitarian. That on the west was distinctly catastrophic in the widest dynamic sense.

Let us pass now to a remarkable chapter of events which closed the Palæozoic ages. What is now the eastern half of the Mississippi basin had through the coal period often extended itself as a land mass as far west as the Mississippi River, and had as often suffered subsidence and resubmergence. To the west, however, still stretched the open ocean, which, since the beginning of the Cambrian, had, with a single exception, never been invaded by land. At the close of the Palæozoic the two bordering land areas of Atlantis and Pacifis, since the beginning of the Cambrian permanent and perhaps extended continents, began to sink. They rapidly went down, and at last completely disappeared, their places being taken by the present Atlantic and Pacific oceans, while the sea floor of the American ocean, which had

been for the most part permanent oceanic area ever since the submergence of the archæan America, emerged and became the new continent of America, which has lasted with local vicissitudes up to the present. The east and west were, indeed, separated by a mediterranean sea, the sole relic of the American ocean, which now occupied a narrow north and south depression.

In that mediterranean sea, we may say that the conditions have been uniformitarian; that is to say, in the great post-Palæozoic catastrophe that ocean was spared. It remained a body of deep water, its bottom undisturbed by folds or dislocations, and there is no evidence of a cessation of sediments; yet the species which lived there throughout the vast length of the coal period were completely extinguished, and entirely new forms made their appearance. Although spared from the actual physical catastrophe, the effect of the general disturbance of that whole quarter of the globe was thoroughly catastrophic, and exerted a fatal influence upon life far beyond the actual theatre of upheaval.

Passing over the Mesozoic age, which in detail offers much instructive material as to rate of change, we pause only to notice a catastrophe which marked the close of that division of time.

In a quasi-uniformitarian way, 20,000 or 30,000 feet of sediment had accumulated in the Pacific and 14,000 in the mediterranean sea, when these regions, which, during their reception of sediment, had been areas of subsidence, suddenly upheaved, the doming up of the middle of the continent quite obliterating the mediterranean sea and uniting the two land masses into one.

The catastrophe which removed this sea resulted in the folding up of mountain ranges 20,000 and 40,000 feet in height, thereby essentially changing the whole climate of the continent. Of the land life of the Mesozoic age we have abundant remains. Thanks to the palæontologists, the wonderful reptilian and avian fauna of the Mesozoic age is now familiar to us all. But after the catastrophe and the change of climate which must necessarily have ensued, this fauna totally perished. The rate of this post-Cretaceous change was, in other words, catastrophic.

During the Tertiary, fresh-water lakes of wide extent occupied the western half of the continent. Such was the character of the great post-Cretaceous uplift that there were left broad, deep continental basins above the level of the sea. Into these the early Tertiary rivers found their way, creating extended lakes in which accumulated strata rivaling in importance the deposits

of the great oceans. The whole history of the Tertiary is that of the accumulation of thick sedimentary series in fresh-water lakes, accompanied by gradual and periodic subsidence, carried on smoothly and uniformly up to a certain point, and then interrupted by a sudden, mountain-building upheaval, which drained the lakes and created new basins. The five minor catastrophes which have taken place in the western half of America during the Tertiary age have never resulted in those broader changes which mark the close of the Archæan, the Palæozoic, and the Mesozoic ages. They never broke the grander outline of the continent. They were, however, of such an important scale as to very greatly vary the conditions of half the continent. I may cite the latest important movement, which took place probably within the human epoch, certainly at the close of the great Pliocene lake period of the west. The whole region of the great plains, as far north as we are acquainted with their geology, and southward to the borders of the Gulf, was occupied by a broad lake which existed through the Pliocene period, having always a subtropical climate. In that lake, beds 1000 to 1200 feet thick had accumulated, when suddenly the level floor was tilted, causing a difference of height of 7000 feet between the south and west shores, making the great inclined surface of the present plains, and utterly changing the climate of the whole region. Not a species survived.

I have thus hastily mentioned a few of the most important geological crust changes in America whose rates are demonstrably catastrophic. Besides surface changes involving subsidence, upheaval, faulting, and corrugation, all of which may be executed on a scale or at a rate productive of destruction of life, catastrophes may be brought about by sudden great changes of climate or by intense volcanic energy. In the latter field there are obviously no catastrophes of the first order. Geological maps of the globe have progressed far enough to demonstrate that considerable areas are, and always have been, free from actual ejection of volcanic materials. On the contrary, numerous great regions, notably the western third of our own continent and the shores of the Pacific, were once literally deluged with volcanic fires. An examination of the ejected rock shows that modern eruptions, by which the volcanic cones of the present period are slowly built up from slight overflows piling one upon another, are not the method of the great Miocene and Pliocene volcanic periods. There were then outbursts hundreds of miles in extent, in

which the crust yawned and enormous volumes of lava rolled out, overwhelming neighboring lands. Volcanoes proper are only isolated chimneys, imposing indeed, but insignificant when compared with the gulfs of molten matter which were thrown up in the great massive eruptions. Between the past and present volcanic phenomena there is not only a difference of degree but of kind. It is easy to read the mild exhibition of existing volcanoes as a uniformitarian operation, namely, the growth of cones by slight accretions; but such reasoning is positively forbidden in the past.

If poor, puny little Vesuvius could immortalize itself by burying the towns at its feet, if the feeble energy of a Lisbon earthquake could record itself on the grave-stones of thousands of men, then the volcanic period in Western America was truly catastrophic. Modern vulcanism is but the faint, flickering survival of what was once a world-wide and immense exhibition of telluric energy, one whose distortions and dislocations of the crust, whose deluges of molten stone, emissions of mineral dust, heated waters, and noxious gases could not have failed to exert destructive effect on the life of considerable portions of the globe. It cannot be explained away upon any theory of slow, gradual action. The simple field facts are ample proof of the intensity and suddenness of Tertiary vulcanism.

Of climate catastrophes we have the record of at least one. When the theory of a glacial period came to be generally accepted, and the destructive effects of the invasion of even middle latitudes by polar ice were realized, especially when the devastating effects of the floods which were characteristic of the recession of the ice came to be studied, uniformitarianism pure and simple received a fatal blow. I am aware that British students believe themselves justified in taking uniformitarian views of the bowlder-till, but they have yet to encounter phenomena of the scale of our Quaternary exhibitions.

A most interesting comparison of the character and rate of stream erosion may be obtained by studying in the western Cordilleras, the river work of three distinct periods. The geologist there finds preserved and wonderfully well exposed, first, Pliocene Tertiary river valleys, with their bowlders, gravels, and sands still lying undisturbed in the ancient beds; secondly, the system of profound cañons, from 2000 to 5000 feet deep, which score the flanks of the great mountain chains, and form such a fascinating object of study, and not less of wonder, because the

gorges were altogether carved out since the beginning of the glacial period; thirdly, the modern rivers, mere echoes of their parent streams of the early Quaternary age. As between these three, the early Quaternary rivers stand out vastly the most powerful and extensive. The present rivers are utterly incapable, with infinite time, to perform the work of glacial torrents. So, too, the Pliocene streams, although of very great volume, were powerless to wear their way down into solid rock thousands of feet, at the rapid rate of the early Quaternary floods. Between these three systems of rivers is all the difference which separates a modern (uniformitarian) stream and a terrible catastrophic engine, the expression of a climate in which struggle for existence must have been something absolutely inconceivable when considered from the water precipitations, floods, torrents, and erosions of to-day.

Uniformitarians are fond of saying that give our present rivers time, plenty of time, and they can perform the feats of the past. It is mere nonsense in the case of the cañons of the Cordilleras. They could never have been carved by the pigmy rivers of this climate to the end of infinite time. And, as if the sections and profiles of the cañons were not enough to convince the most skeptical student, there are left hundreds of dry river-beds, within whose broad valleys, flanked by old steep banks and eloquent with proofs of once-powerful streams, there is not water enough to quench the thirst even of a uniformitarian. Those extinct rivers, dead from drought, in connection with the great cañon system, present perfectly overwhelming evidence that the general deposition of aerial water, the consequent floods and torrents, forming as they all do the distinct expression of a sharply-defined cycle of climate, as compared either with the water phenomena of the immediately preceding Pliocene age or with our own succeeding condition, constitute an age of water catastrophe whose destructive power we only now begin distantly to suspect.

I have given you what in my belief are sound geological conclusions, the want of time alone causing me to waive the slow production of proofs. I believe I am fully prepared to sustain the assertions, first, that the rate of physical change progressing to-day in all departments of terrestrial action is inadequate to produce the grander features of American geological history; secondly, that in the past, at intervals, the dynamic rate has been so sharply accelerated as to bring about exceptional results; thirdly, that these results have been catastrophic in their effect

upon the life of America and the bounding oceans. I have called the revolutions in the American area catastrophic because any disturbances of land or sea, of the described scale, intensity, and rapidity, could not fail to have a disastrous effect on much of the organic world. The uniformitarian school would accept these crust changes with unruffled calmness; they would read the record exactly as a catastrophist might, only they would assume unlimited time and their inch-by-inch process. The analogy of the present, they say, is against any acceleration of rate in the past, and besides, the geological record is a very imperfect document which does not disprove our view. In plain language, they start with a gratuitous assumption (vast time), fortify it by an analogy of unknown relevancy (the present rate), and serenely appeal to the absence of evidence against them as proof in their favor. The courage of opinion has rarely exceeded this specimen of logic. If such a piece of reasoning were uttered from a pulpit against evolution, biology would at once take to her favorite sport of knuckle-rapping the clergy in the manner we are all of us accustomed to witness. In forbidding us to look for past rates of change differing from the present, the British uniformitarians have tied the hands of the science. By preaching so eternally from the text of "imperfection of the geological record," they have put blinders on the profession. A few more such doctrines will reduce the science to a corpse, around which teleologists and biologists might hold any sort of funeral dance their fancy dictated. Now, because the record is not altogether made out is no proof whatever that it never will be. There was once a discovery of a very small piece of evidence, the Rosetta Stone, which served as a key to a vast amount of previously illegible material. Geology, if not strangled in its own house, will, in my belief, go on and dig up enough Rosetta Stones to translate the strata into a precise language of energy and time.

As yet we have no means, beyond mere homotaxial comparison, for relating the crust movement of distant regions. I do not, however, despair of our being able to correlate the movements and revolutions of different continents. At present, old-fashioned catastrophes, involving repeated world-wide destruction of all life, such cataclysms as Cuvier believed in, and which occasioned the revolt of the biologists of his time, are justly repudiated. On the other hand, the mild affirmations of the uniformitarians, that existing rates of change and indefinite time

are ample to account for the past, are flatly and emphatically contradicted by American facts. With our present light, geological history seems to be a dovetailing together of the two ideas. The ages have had their periods of geological serenity, when change progressed in the still, unnoticeable way, and life through vast lapses of time followed the stately flow of years, drifting on by insensible gradations through higher and higher forms, and then all at once a part of the earth suffered short, sharp, destructive revolution, as unheralded as an earthquake or volcanic eruptions. The sciences are as independent as bodily organs; they are the vitals of human knowledge. A fallacy lodged in one produces functional disturbance of the others. It was the error of universal and extreme catastrophes which so violated the conceptions of Lamarck, Goethe, and St. Hilaire as to draw out their earnest protest, and as usual they urged the pendulum past the golden mean of truth over to the counter error of extreme uniformitarianism. This later error has been confidently built in as one of the corner-stones of the imposing structure of evolution. I believe the crumbling, valueless nature of this foundation will yet make itself felt in the ruin of just so much as the builders have rested upon it.

If the vicissitudes of our planet have been as marked by catastrophes as I believe, how does that law affect our conceptions of the development of life and the hypothesis of evolution? Man, whatever the drift of life or philosophy, returns with restless eagerness, with pathetic anxiety, to the enigma of his own origin, his own nature, his own destiny. With reverence, with levity, with faith, with doubt, with courage, with cowardice, by every avenue of approach, in every age, the same old problem is confronted. We pour out our passionate questionings, and hearken lest mute nature may this time answer. But nature yields only one syllable of reply at a time.

Darwin, who in his day has caught the one syllable from nature's lips, advances always with caution, and although he practically rejects does not positively deny the existence of sudden great changes in the earth's history. Huxley, permeated in every fibre by belief in evolution, feels that even to-day catastrophism is not yet wholly out of the possibilities. It is only lesser men who bang all the doors, shut out all doubts, and flaunt their little sign, "Omniscience on draught here." It must be said, however, that biology, as a whole, denies catastrophism in order to save evolution. It is the common mistake of biologists to as-

sume that catastrophes rest for their proof on breaks in the palæontological record, meaning by that the observed gaps of life or the absence of connecting links of fossils between older and newer sets of successive strata. There never was a more serious error. Catastrophes are far more surely proved by the observed mechanical rupture, displacement, engulfment, crumpling, and crushing of the rocky surface of the globe. Granted that the evidence would have been slightly less perfect had there been no life till the present period, still the reading would have been amply conclusive. The palæontological record is as imperfect as Darwin pleads, but the dynamic record is vitiated by no such ambiguity.

It is the business of geology to work out the changes of the past configuration of the globe and its climate; to produce a series of maps of the successive stages of the continents and ocean basins, but it is also its business to investigate and fix the rates of change. Geology is not sòlely a science of ancient configuration. It is also a history of the varying rates and mode of action of terrestrial energy. The development of inorganic environment can and must be solved regardless of biology. It must be based on sound physical principles, and established by irrefragable proof. The evolution of environment, a distinct branch of geology which must soon take form, will, I do not hesitate to assert, be found to depend on a few broad laws, and neither the uniformitarianism of Lyell and Hutton, Darwin and Haeckel, nor the universal catastrophism of Cuvier and the majority of teleologists, will be numbered among these laws. In the dominant philosophy of the modern biologist there is no admission of a middle ground between these two theories, which I, for one, am led to reject. Huxley alone, among prominent evolutionists, opens the door for union of the residua of truth in the two schools, fusing them in his proposed evolutional geology. Looking back over a trail of thirty thousand miles of geological travel, and after as close a research as I am capable, I am impelled to say that his far-sighted view precisely satisfies my interpretation of the broad facts of the American continent.

The admission of even modified catastrophe, namely, suddenly-destructive, but not all-destructive change, is, of course, a downright rejection of strict uniformitarianism. I comprehend the importance of the position, how far-reaching and radical the logical consequences of this belief must be. If true, it is nothing less than an ignited bomb-shell thrown into the camp of

the biologists, who have tranquilly built upon uniformitarianism, and the supposed imperfection of the geological record. I quote a few of their characteristic utterances. Lamarck, in his Philosophie Geologique, 1809, says, "The kinds or species of organisms are of unequal age, developed one after another, and show only a relative and temporary persistence. Species arise out of varieties. . . . In the first beginning only the very simplest and lowest animals and plants came into existence; those of a more complex organization only at a later period. The course of the earth's development and that of its organic inhabitants was continuous, not interrupted by violent revolutions. . . . The simplest animals and the simplest plants, which stand at the lowest point in the scale of organization, have originated and still originate by spontaneous generation." Darwin [1] says: "We must be cautious in attempting to correlate as strictly contemporaneous two formations, which include few identical species, by the general succession of their forms of life. As species are produced and exterminated by slowly acting and still acting causes, and not by miraculous acts of creation and by catastrophes. . . . And again, for my part, following out Lyell's metaphor, I look at the natural geological record as a history of the world imperfectly, kept and written in a changing dialect; of this history we possess the last volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved; and of each page only here and there a few lines. Each word of the slowly changing language in which the history is written, being more or less different in the successive chapters, may represent the apparently abruptly changed forms of life entombed in our consecutive but widely separated formations. On this view, the difficulties above discussed are greatly diminished, or even disappear."

It is unnecessary to repeat here the well-known views of Lyell. How far biologists have learned to lean on his uniformitarian conclusions may be seen from the following quotation from Haeckel,[2] "He [Lyell] demonstrated that those changes of the earth's surface which are still taking place before our eyes are perfectly sufficient to explain everything we know of the development of the earth's crust in general, and that it is superfluous and useless to seek for mysterious causes in inexplicable revolutions. He showed that we need only have recourse to the hypothesis of

[1] Origin of Species, p. 522.

[2] History of Creation, vol. i., pages 127–129.

exceedingly long periods of time, in order to explain the formation of the crust of the earth in the simplest and most natural manner, by the means of the very same causes which are still active. Many geologists had previously imagined that the highest chains of mountains which rise on the surface of the earth could owe their origin only to enormous revolutions transforming a great part of the earth's surface, especially to colossal volcanic eruptions. Such chains of mountains as those of the Alps or the Cordilleras were believed to have arisen direct from the fiery fluid of the interior of the earth through an enormous chasm in the broken crust. Lyell, on the other hand, showed that we can explain the formation of such enormous chains of mountains quite naturally by the same slow and imperceptible risings and depressions of the earth's surface which are still continually taking place, and the causes of which are by no means miraculous. Although these depressions and risings may perhaps amount only to a few inches, or at most a few feet, in the course of a century, still in the course of some millions of years they are perfectly sufficient to raise up the highest chains of mountains without the aid of mysterious and incomprehensible revolutions. . . . We have long known, even from the structure of the stratified crust of the earth alone, that its origin and the formation of neptunic rocks from water must have taken at least several millions of years. From a strictly philosophical point of view, it makes no difference whether we hypothetically assume for this process ten millions or ten thousand billions of years. Before us and behind us lies eternity." This is even bolder than Hutton, who says: "I take things as I find them at present; and from these I reason as regards that which must have been. . . . A theory, therefore, which is limited to the actual constitution of this earth, cannot be allowed to proceed one step beyond the present order of things."

The successive hypotheses which, linked together, form the chain of evolution are, first, the nebular hypothesis; second, spontaneous generation; third, natural selection. It is only with the last that geology has intimate relation. The general theory of a derivative genesis or the descent of all organisms by the various modes of reproduction from one or a few primitive types which came into existence by spontaneous generation was believed long before the Darwinian theory was advanced. Darwin's great contribution was the modus operandi of derivative genesis. It was a mode of accounting for the in-

finite branching out and differentiation of the complex forms of life from the primitive germs. His theory is natural selection, or the survival of the fittest, a doctrine which, left where Darwin leaves it, has its very roots in uniformitarianism.

Analyzed into its component parts, natural selection resolves, as is well known, into two laws, hereditivity and adaptivity: first, the power on the part of organisms to transmit to offspring their own complex structure down to the minutest details; and, secondly, the power by slight alterations on the part of all individuals to vary slightly in order to bring themselves into harmony with a changed environment. When we bring geology into contact with Darwinism, it is evident that hereditivity is out of the dómain of our inquiry; it is not the engine of change, it is the conservator of the past; but the companion law of adaptivity, or the accommodation to circumstances, is one which depends half upon the organism and half upon the environment; half upon the vital interior, half upon the pressure which the environment brings to bear upon it. Now, environment, as conclusively shown by biologists, is a twofold thing, a series of complicated relationships with contemporaneous life, but, besides, with the general inorganic surrounding, involving climate and position upon the globe. Preoccupied with the strictly biological environment, namely, the intricate relation of dependence of any species upon some of its surrounding species, biologists have signally failed to study the power and influence of the inorganic or geologic environment. The actual limits of the influence of physical conditions on life are practically unknown. In America more than in Europe this branch of inquiry has begun to attract notice, but it is yet in its swaddling-clothes. It has lain little and weak from inanition, while the favorite child, Natural Selection, has been fed into a plethoric, overgrown monster. Darwin, Wallace, Haeckel, and the other devoted students of natural selection have brought to light the most astonishingly complex struggle for existence, everywhere progressing — the fiercest battle for life and for subsistence, for standing-room, for breath. Some species gain, others lose, some go down to annihilation. In this battle they seea dequate cause for all the great, highly organized products of the millions of years since life began. From their logic, you and I are conquerors who have mounted to manhood by treading out the life of infinite generations. We are what we are because this brain and this body form the most effective fighting-machine the dice-box of ages has thrown.

From their conclusions and philosophy let us turn, but with no revolt of prejudice, no rebound of a happier intuition, for this is a question of science. Those who defend the stronghold of natural selection are impregnable to the assaults of feeling. They are dislodged only by the solid projectiles of fact, and to facts cast in the mold of nature they count it no dishonor to surrender. If, as I have said, the evolution and power of environment have been singularly neglected studies, if biologists have allowed the splendor of their achievements within the province of life to blind them to the working of that other and no less important side of the problem, what then is the general relation in time and space of the inorganic environment to life?

Let us first acknowledge frankly that the present and later parts of the Quaternary period are uniformitarian; that the changes going on in organic life now do obey the great law of survival of the fittest, and that if the uniformitarians were true in making of the past a mere infinite projection of the present, then the biologists would have based their theories on a solid foundation, and my protest would have no weight. Let us go further and cordially admit that in all periods of uniformity the progress of life would adjust itself to its surroundings, and the war of competitive extermination become the dominant engine of change and development. This is giving full credit to the greatness of the biological result, and simply asserts that they who achieved it are sound as far as the analogy of present uniformity may be permitted to go. But uniformity has not been the sole law; it has, as we have seen, been often broken by catastrophes, — that is, by accelerated rate of change. Rapid physical change has been, it seems to me, the more important of the two conditions of the past, the one whose influence will at last prove to have been the dominant one in life change.

Has environment, with all the catastrophic changes, been merely passive as regards life? It has either had no effect, or has restrained the progress of evolution, or has advanced it, or its influence has been as varied as its own history, — now by the development of favoring conditions accelerating vital progress, now suddenly exterminating on a vast scale, again urging evolution forward, again leaving lapses of calm in which species took the matter into their own hands and worked out their own destiny. It is only through rapid movements of the crusts and sudden climatic changes, due either to terrestrial or cosmical causes, that environment can have seriously interfered with the evolution of

life. These effects would, I conceive be, first, extermination; secondly, destruction of the biological equilibrium, thus violating natural selection; and thirdly, rapid morphological change on the part of plastic species. When catastrophic change burst in upon the ages of uniformity, and sounded in the ear of every living thing the words "change or die," plasticity became the sole principle of salvation. Plasticity, then, is that quality which, in suddenly enforced physical change, is the key to survival and prosperity. And the survival of the plastic, that is of the rapidly and healthily modifiable during periods when terrestrial revolution offers to species the rigorous dilemma of prodigious change or certain death, is a widely different principle from the survival of the fittest in a general biological battle during terrestrial uniformity. In one case it is an accommodation between the individual organism and inorganic environment, in which the most yielding and plastic lives. In the other it is a Malthusian death struggle, in which only the victor survives. At the end of a period of uniformitarian conditions, the Malthusian conqueror, being the fittest, would have won the prize of survival and ascendency. Suppose now an interval of accelerated change. At the end only the most plastic would have deviated from their late forms and reached the point of successful adaptation, which is survival in health. Whatever change takes place by natural selection in uniformitarian ages, according to Darwin, advances by spontaneous, aimless sporting and the survival of those varieties best adapted to surrounding conditions, and of these conditions the biological relations are by far the most important of all. By that means, and by that alone, it is asserted, species came into existence, and inferentially all the other forms from first to last. This is the gospel of chance.

If the out-door facts of American geology shall be admitted to bear me out in my assertion of catastrophes, and if the epochs of maximum vital change do, as I hold, coincide with the epochs of catastrophes, then that coincidence should be directly determinable in the field. I confidently assert that no American geologist will be able to disprove the law that in the past every one of the great breaks in the column of life coincide with datum points of catastrophe. It remains to be determined how far this coincidence is the expression of environmental cause, responded to in terms of vital effect.

From a comparison of the list and character of geological changes in America with those mysterious lines across which no

species march, I feel warranted in harboring the belief that catastrophe was an integral part of the cause ; changed life, the effect. Biologists are accustomed to explain the cause of a great gap like that which divides the Palæozoic and Mesozoic life by an admission that the Palæozoic forms ceased to live, but that the succeeding changed forms at the beginning of the Mesozoic were not the local progeny, greatly modified by catastrophic change, but merely immigrants from some other conveniently assumed country. They succeed in rendering this highly probable, if not certain, in many instances. But they are estopped from always advancing this migration theory. Greek art was fond of decorating the friezes of its sacred edifices with the spirited form of the horse. Times change ; around the new temple of evolution the proudest ornament is that strange procession of fossil horse skeletons, among whose captivating splint-bones and general anatomy may be descried the profiles of Huxley and Marsh. Those two authorities, whose knowledge we may not dispute, assert that the American genealogy of the horse is the most perfect demonstrative proof of derivative genesis ever presented. Descent they consider proved, but the fossil jaws are utterly silent as to what the cause of the evolution may have been.

I have studied the country from which these bones came, and am able to make this suggestive geological commentary. Between each two successive forms of the horse there was a catastrophe which seriously altered the climate and configuration of the whole region in which these animals lived. Huxley and Marsh assert that the bones prove descent. My own work proves that each new modification succeeded a catastrophe. And the almost universality of such coincidences is to my mind warrant for the anticipation that not very far in the future it may be seen that the evolution of environment has been the major cause of the evolution of life ; that a mere Malthusian struggle was not the author and finisher of evolution ; but that He who brought to bear that mysterious energy we call life upon primeval matter bestowed at the same time a power of development by change, arranging that the interaction of energy and matter which make up environment should, from time to time, burst in upon the current of life and sweep it onward and upward to ever higher and better manifestations. Moments of great catastrophe, thus translated into the language of life, become moments of creation, when out of plastic organisms something newer and nobler is called into being.