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Uniformitarianism and Catastrophism

Uniformitarianism assumes the principle that the past history of the earth is uniform with the present in terms of the physical laws governing the natural order, the physical processes occurring both within the earth and on its surface, and the general scale and intensity of these processes. It asserts further that our only means of interpreting the history of the earth is to do so by analogy with events and processes in the present.

Catastrophism assumes the principle that conditions on the earth during the past were so different from those existing in the present that no comparison is possible, that earthquakes, volcanic eruptions, and the elevation of mountains and floods occurred during the past on a scale many times greater than that of any similar events observable in the modern world, and that geological events in the past were often so violent and catastrophic, that they sometimes destroyed all the species living in particular districts.

The questions raised by the conflicting assumptions of uniformitarianism and catastrophism apply most directly to the interpretation of geological history, but are not restricted to it. These questions arise in science whenever there is need to interpret natural events occurring at a distance in space or time. In these circumstances the separation of the events or processes from the observing scientist requires him either to interpret them by analogy with events and processes closer at hand and more directly observable, or, to assume that the distant events are the result of processes unknown to him and are, therefore, impossible to interpret. If a scientist attempts to interpret distant events by analogy, he is assuming the uniformity of the natural order through space and time.

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The terms "catastrophism" and "uniformitarianism" were introduced in 1837 by William Whewell in his *History of the Inductive Sciences* to describe the two leading schools of theoretical geology at that time. Catastrophism, which was the older theoretical viewpoint, was in England widely accepted and defended by the older generation of geologists, but its leading exponents were then on the Continent. Leopold von Buch, the German geologist, had presented a theory of craters of elevation to account for the form of volcanic mountains. He supposed that such volcanoes as Teneriffe in the Canary Islands had not been built up gradually by many repeated volcanic eruptions carried on over an immense period of time, but by an upheaval of the surrounding rock strata, and that this upheaval had been essentially a single event, catastrophic in nature, and without parallel in the modern world. Von Buch presented this theory in 1824 after a visit to the Canary Islands, and in 1829 Léonce Élie de Beaumont published his theory of the sudden and simultaneous elevation of mountain chains. He had been struck by the fact that a number of ranges of mountains tended to be composed of rocks of similar geological age and showed similarities of structure. For instance, de Beaumont suggested that the Pyrenees had been uplifted in a single sudden upthrow (*en un seul jet*) and that this elevation had occurred at the same time as that of the Alps. Von Buch and de Beaumont suggested that in the geological past there had occurred events on such an enormous scale as to be catastrophic in nature and without counterpart in the modern experience of man. Their view of the history of the world was that while conditions on the earth's surface in modern times, that is, since the appearance of man on earth, had been relatively orderly and calm, undisturbed by any great changes which might destroy a significant portion of life on earth, this stable and reliable condition of the earth's surface was of relatively recent appearance. During the geological past, they assumed that, while there may have been long periods of calm conditions, the earth had also been subjected repeatedly to enormous changes, great shakings of the surface of the whole earth, which had resulted in the throwing up of mountain ranges, vast floods, subsidences, and other catastrophes.

In assuming the extraordinary and catastrophic nature of the earth's history, von Buch and de Beaumont were part of a tradition of geological thinking which extended back to the seventeenth century and was deeply influenced by the account of the Creation in Genesis. Genesis takes for granted that the condition of the world at the time of its creation was different from its present state, and this assumption was accepted unquestioningly by late seventeenth- and early eighteenth-century writers on the origin of the world. Even if one leaves aside extravagant and uncritical writers like Thomas Burnet whose *Sacred Theory of the Earth* (1681-89) was an imaginative but completely uncritical account of the origin and history of the earth, the ideas of a cautious and disciplined scientist like John Ray nonetheless take for granted that the account in Genesis did reflect the actual events which occurred at the origin of the world and, furthermore, that the present world was temporary and would disappear in a great conflagration at the day of judgment. In the early eighteenth century, it became generally recognized that the fossils found in rocks were the actual remains of once living animals. For geologists in Italy fossils demonstrated that the Italian rock strata had been laid down beneath the sea, because the well preserved fossil shells in the Italian strata were recognizably similar to the shells species living in the Mediterranean. For geologists in England and in northern Europe, however, the recognition of fossils as the remains of once living animals posed the difficulty that they belonged to species without counterparts in the north Atlantic, or in other parts of the world, for that matter. Thus the fossils of the English strata suggested the existence of multitudes of species in the past which had since died out. The disappearance of such multitudes of species also suggested that they must have been destroyed by some great catastrophic event on the earth's surface.

Of the geological theories put forward during the eighteenth century, perhaps the most influential was

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that of Abraham Gottlob Werner. As a professor at the School of Mines at Frêyburg, Werner became expert in the recognition of rocks and minerals.

In 1793 Peter Simon Pallas, as a result of his study of the two principal mountain ranges of Siberia, decided that the characteristic structure of mountain ranges was a central core of granite with schistose rocks containing no fossils along the flanks of the granite, and with fossil-bearing limestone rocks lying outside and above the schistose. Pallas' observations on the structure of mountain ranges, and those of Horace Bénédict de Saussure on the Alps, appear to have been used by Werner in the development of his theory of the earth. Werner assumed that the granite represented the original surface of the earth formed when the earth had cooled from a molten mass. He thought that the schistose rocks had been deposited from the universal ocean, which, in the first stages of the earth's history, had covered the whole surface of the earth and had been as deep as the mountains are high. The schistose rocks had been chemical precipitates from the

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primordial ocean, but at a later stage mechanical sediments had been deposited from this ocean, giving rise to the strata of limestone, shale, and sandstone.

Werner's assumption that granite represented the original surface of the earth and was consequently the oldest rock, was challenged in 1795 by James Hutton in his *Theory of the Earth with Proofs and Illustrations.* Hutton had been impressed by the fact that the stratified rocks were sediments which, to his mind, must have been laid down beneath the sea. These sediments, laid down originally as soft sand, mud, or marl, had somehow been consolidated into solid rock and had then been raised from the sea bottom to form dry land and even hills and mountains. The force which produced both the consolidation of sediments into rock and their elevation into hills and mountains was heat. Hutton was evidently impressed by the discovery of specific and latent heats by his friend Joseph Black, the physicist. Hutton considered heat as a force inherent in matter, moreover, as a repulsive force, derived ultimately from the sun. It might assume the form of specific heat; in which case it influenced the volume of matter, or, latent heat, which determined the fluidity of matter, or light, or electricity. Heat which was so diverse in its form and its effects, existed abundantly within the earth and acted both to consolidate sediments into rock and to elevate them. In 1788 Hutton discovered in Glen Tilt in the highlands of Scotland, a dyke of granite, which had clearly intruded into the surrounding schistose strata. Not only had the granite intruded into the stratified rock, but it had intruded in a molten condition because the strata in the vicinity of the dyke were much altered, as if by heat. Hutton was greatly excited by this discovery because it meant that the granite was not the oldest rock and did not represent the primordial surface of the earth. Instead, it represented a later intrusion, and the oldest rocks discoverable were stratified rocks which had themselves originated as sediments. However, these sediments represented the detritus of some preexisting land. Hutton was aware that the whole surface of the land was subject to relentless forces of erosion and was being worn down steadily by rain and running water. The wearing down of the land was necessary to create the sediments which were deposited on the sea bottom. These sediments accumulated over immense periods of time, were then in turn hardened into rock by heat, and elevated from the sea to form hills and mountains. Hutton saw this process of the wearing down of land, the deposition of sediments and their re-elevation extending indefinitely into the past and continuing indefinitely into the future. He saw the present surface of the earth, not as fixed and unchang ing, but as intermediate stage in a continuous process.

Hutton's theory reflects the calm inquiring rational spirit of the eighteenth-century Enlightenment; Hutton possessed the same temper of mind as David Hume, the philosopher, or Adam Smith, the economist. His theory was attacked immediately as being dangerous to religion, and the force of this criticism was sharpened by the political consequences of the French Revolution. In Great Britain the French Revolution was felt to endanger the whole fabric of social order, of which the Christian religion was the essential foundation. Hutton's theory left no place for the Mosaic account of Creation and of the Flood. It assumed that the earth and the physical order of nature were eternal and unchanging. At the same time that Hutton's theory was being attacked on religious and scientific grounds, liberal political ideas had become unpopular in Britain, and a repressively reactionary tone dominated politics. At Edinburgh where Hutton's friends continued to support his theory after his death in 1797, Robert Jameson, professor of natural history at the University of Edinburgh, was one of the most vigorous exponents of the Wernerian theory. Consequently, the controversy between the Wernerians and Huttonians raged with a special vigor at Edinburgh between 1800 and 1810. Hutton's friends, several of whom were associated with the *Edinburgh Review,* tended to be liberal in their outlook, whereas the Wernerians were Tories, and these political associations tended to deepen and embitter the scientific controversy.

The Wernerian-Huttonian controversy at Edinburgh did have the effect of convincing geologists of the dangers of theoretical controversy. Thus, when the Geological Society of London was founded in 1807, its members decided to avoid theoretical discussion in favor of a broad program of geological field studies. Geological evidence, which could not be interpreted in terms of the Huttonian theory, was also accumulating. In 1811 Alexandre Brongniart and Georges Cuvier published their description of the Tertiary strata of the Paris basin. Among these strata Cuvier and Brongniart found a repeated alternation of fresh water and marine sediments. Such an alternation required either repeated incursion of the sea over the land, or repeated subsidences and re-elevations of the land. Hutton's theory provided for neither contingency. At the same time, Cuvier and Brongniart had described a whole series of sediments unknown to Werner. In 1812 Cuvier also published the first edition of his *Recherches sur les ossemens fossiles* (1812-26) based upon his reconstruction of fossil animals during the preceding fifteen years. This work presented to the scientific world a succession of populations of animals, all extinct, and

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sometimes both larger in size and more numerous in species than the animals of modern times. Cuvier asserted that each successive assemblage of fossil species of animals had been destroyed by a geological catastrophe, such as might occur when the sea rose to cover the land. He did not hesitate to extend the consequences of his observations made in the Paris basin to the whole world. Cuvier was as skillful a politician as an anatomist, and his theory of successive catastrophes, the most recent of which was the flood described in the Bible, appealed strongly to the religions because it allowed the numerous and striking recent discoveries in paleontology to be reconciled, however uncritically, to the biblical account of creation. After 1815 Cuvier's catastrophism was perhaps keyed to the intellectual tone of the Bourbon restoration, but it was also popular in the English-speaking world. An English translation by Robert Kerr was published at Edinburgh in 1815 and again in many subsequent editions.

Perhaps paleontology tended to strengthen the plausibility of catastrophism by the fact that the discovery of so many large and remarkable fossil animals suggested that catastrophic events on earth must have been needed to bring about their disappearance. In 1812 the skeleton of a remarkable fossil reptile, seventeen feet long, was found in the blue Lias formation at Lyme Regis on the coast of Dorsetshire. This reptile, which had paddle-like appendages to equip it for swimming, and which in some respects resembled a fish, in 1816 was named Ichthyosaurus. In 1820 another large swimming reptile, also from the blue Lias, and with a remarkably long neck was described by William Daniel Conybeare and was named Plesiosaurus. This was followed by the discovery of the enormous Megalosaurus by the Reverend William Buckland in the Stonefield slate, and of the Iguanodon by Gideon Mantell in Sussex. In 1825, in the third edition of his *Recherches...*, Cuvier described the Pterodactyls, a group of fossil flying reptiles. These discoveries all exerted a profound effect on both the scientific and popular imagination and presented a vivid picture of the abundance, diversity, and enormous size and strangeness of past forms of life.

One of the points which had been at issue between the Huttonians and Wernerians had been the question of the origin of basalt. Werner had considered that basalt had been formed by crystallization from water, whereas Hutton and such French geologists as Jean

Étienne Guettard and Nicholas Desmarest considered it a volcanic rock. The volcanic origin of basalt was generally accepted in Britain after 1813 when the Reverend William Buckland and the Reverend William Daniel Conybeare visited the Giant's Causeway in Ireland, where they found clear evidence that that particularly famous basalt formation had resulted from a volcanic outflow.

In general, British geologists tended to abandon Werner's idea that rock strata had been formed by crystallization or deposition from a universal ocean, and had accepted the Huttonian idea that the strata had been laid down beneath the sea and had subsequently been elevated. However, in accepting the concept of movements of the land they necessarily accepted the occurrence of catastrophes during the history of the earth, because they could not conceive how elevations sufficient to create the existing hills and mountains could occur without catastrophes. In 1814 the English geologist Thomas Webster published a description of the geology of the Isle of Wight in which he showed that the chalk strata forming the central range of hills in the island were vertical or very steeply inclined and that they formed one side of an anticlinal fold, the opposite side of which, he discovered on the south shore of the Isle of Wight. Webster showed that the strata must once have been continuous in a great arch extending across the whole Isle of Wight and that most of this arch had since been removed. The chalk strata which had formed this arch had been formed as horizontal beds of sediment in the sea, so that their upraising to form the arch had required their uplift, bending, and disturbance on a great scale. This kind of disturbance was explicable to Webster only by some enormous convulsion of a kind entirely different from anything experienced in modern times. The basic assumptions of geologists in the 1820's, whether Huttonian or Wernerian, was stated by William Whewell in 1831:

> In the dislocation of provinces, in the elevation of hills from the bottom of the sea, in the comminution and dispersion of vast tracts of the hardest rock, in the obliteration and renewal of a whole creation they seemed to themselves to see... the manifestation of powers more energetic and extensive than those which belonged to the common course

of every day nature.... They spoke of a break in the continuity of nature's operations; of the present state of things as permanent and tranquil, the past having been progressive and violent

(William Whewell, review of Lyell's *Principles of Geology, British Critic,* 9 [1831], 190).

During the 1820's the evidence for convulsive and catastrophic changes in the history of the earth seemed so compelling and universal that the revival of James Hutton's concept of a continuous process shaping the earth's surface indefinitely through time is a development requiring some explanation. Two factors seemed to have played a role. The first may have been an increasing interest in the study of volcanic activity in different parts of the world.

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Beginning in 1797 Leopold von Buch (1774-1852) made extensive studies in the Alps where he determined that their structure showed that they had been uplifted. From his further observations on the Alban Hills and Vesuvius in Italy and on Etna in Sicily he became convinced of the vast extent and power of volcanic activity, and of its capacity to uplift whole areas of country. In 1802 he visited the Auvergne district of France where he found a series of volcanoes of different ages, all of which were connected with an underlying platform of granite. He decided that the mass of trachyte forming the Puy-de-Dôme was simply granite which had been softened and pushed up as a protuberance. The other *Puys,* which possessed the conical forms and craters characteristic of volcanoes, had been formed by the ordinary process of volcanic eruption. After a visit to Norway, where he observed granite veins extending into an overlying fossil-bearing limestone which was highly altered along the lines of contact, von Buch travelled to Madeira and the Canary Islands. There he saw the results of volcanic activity on a still larger scale and studied the way in which the islands had been formed as a result of volcanic action. He concluded that most oceanic islands were the products of volcanic activity.

When von Buch studied the form of volcanoes he noted that they were both conical in form and stratified, with the strata sloping away on all sides from the crater's summit. He decided that this structure was not the result of accumulated lava flows, because the lava emerged in small streams which did not form continuous sheets over the whole surface of the mountain. When he compared his observations in the Canary Islands with those he had made in central France, von Buch decided that each volcano had resulted originally from a dome-shaped extrusion of molten rock from the interior of the earth. If this extrusion broke through to the surface, it solidified while retaining its form and gave rise to a dome-shaped mountain such as the Puy-de-Dôme in Auvergne. More often, however, the extrusion might burst like a bubble at the summit and collapse inward, thereby forming a cone-shaped volcano of typical form with a crater marking the site of explosion. In this theory each volcanic mountain was the product of a single violent eruption instead of the accumulated product of a long series of eruptions extended over a great period of time. Von Buch called the interior molten mass, whose extrusion from the interior of the earth had given rise to the volcano, a “Crater of Elevation.” He thought that their extrusion uplifted the rock strata of the surrounding country in a catastrophic manner.

On his return to Europe, von Buch again studied the Alps for a number of years and decided that they had been formed by a process of upheaval from below, the upheaving force being volcanic rocks which could not find their way to the surface because of the thickness of the overlying rock strata.

In 1822 William Daniel Conybeare suggested that volcanic activity sustained over a long period might be able to produce a large scale elevation of the land. Volcanoes were studied by Charles Daubeny, and by George Poulett Scrope and both studied the area of extinct volcanoes in the Auvergne district of France as well as those in Italy and Sicily.

The other factor which may have played a role in extending the time scale of earth history was the development of paleontology, which had also seemed to support catastrophism by requiring the extinction of so many successive assemblages of animals and plants.

However, the succession of floras and faunas revealed by paleontology also required greatly lengthened periods of time. In addition, the detailed study of the fossil animals and plants found together in a single bed frequently suggested the existence of conditions analogous to those of the present. For instance, in the Tilgate Forest bed, studied by Gideon Mantell in 1822 and subsequent years, there was a collection of the bones of turtles, one or more species of crocodiles, freshwater shells, and the remains of various plants including tree ferns and large weeds. There were successive layers of clay and sand, such as might have been laid down in a modern river delta, and the animals and plants were comparable to those which might live in a river delta in a modern tropical country. These fossils, therefore, suggested that conditions on the earth's surface at a very remote period of time had been comparable with those of modern times, although the climate and latitude of Great Britain had then been much warmer. In 1824 Charles Lyell gave a reverse kind of analogy when he compared the plants and animals living in modern freshwater lakes in Scotland with the fossil animals and plants found in freshwater marls of the Paris basin, and found the assemblage of species very similar in both instances.

From 1820 to 1828 Charles Lyell was first a law student and later a practicing barrister, but through the whole time, he was an enthusiastic amateur geologist and naturalist. He travelled frequently and extensively. In 1818 he had toured Switzerland and northern Italy. In 1820 he returned to Switzerland and this time went as far south in Italy as Rome. He made frequent excursions on horseback through southern England, and in 1823 spent many weeks in Paris where he became acquainted with the Parisian geologists and studied the geology of the Paris basin. In 1824 he spent an extended period in Scotland. These travels gave him a broader experience of landscape, geography, and

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geology than many of his contemporaries had. In 1828 Lyell travelled with Roderick Murchison through the Auvergne district of France, then southward to Nice and along the coast into Italy. At Padua, Murchison turned back, but Lyell went on south through Italy to Naples and made a tour of Sicily. One of his chief geological discoveries during this journey was that the Tertiary beds of the Paris basin formed only the earliest part of the succession of Tertiary formations, and that in Italy and Sicily there were three series of Tertiary strata, each successively younger than those of the Paris basin. Ultimately he named them the Eocene, Miocene, and older and newer Pliocene formations, of which the Eocene represented the beds of the Paris basin. Taken together, the whole series of Tertiary strata were at least equal in total depth to the succession of secondary strata in England. In southern Italy and Sicily Lyell found that the newer Pliocene strata contained fossil shells, almost entirely belonging to species still living in the Mediterranean. He also found that these strata which were close to the active volcanoes of Vesuvius and Etna appeared to have been uplifted by volcanic activity. He became convinced that volcanic activity and earthquakes were both the causes of and manifestations of uplift.

In a letter to Roderick Murchison written as he was returning northward, Lyell expressed the geological conviction to which his tour had led him:

That no causes whatever have from the earliest time to which we can look back, to the present, ever acted but those now acting and that they never acted with different degrees of energy from that which they now exert

(*Life, Letters and Journals of Sir Charles Lyell Bart,* ed. K. M. Lyell, 2 vols., London [1881], I, 234).

He was stating the central principle of what was to be known as uniformitarianism. As a principle, it was the outgrowth of Lyell's geological experience, but it must be emphasized that it was not, and is not, a demonstrable scientific conclusion. Instead, it is a statement of faith and a working hypothesis which is, nonetheless, a hypothesis indispensable to the progress of geology as a science. Lyell assumed that gradual causes acting through long periods of time might exert large-scale effects. His further assumption, that all geological effects are the result of gradual causes acting over large periods, required him to study relentlessly the existing processes going on both in the earth and over its surface, to pursue their consequences, and to estimate their rates. His principle of uniformity required Lyell always to attempt to *explain* geological phenomena and never to abandon this attempt to seek explanation by dismissing phenomena as the result of catastrophic events of unknown origin and magnitude. Lyell assumed that the order of nature and the physical laws of nature remained constant through time. He saw, too, that our only possibility of attaining knowledge of the geological past was by analogy with modern conditions. The geologist had to assume that conditions in the past were comparable to those of the present and that processes going on in the past were comparable to processes going on at the present time, or else he would have to abandon all hope of acquiring any knowledge of the past.

Furthermore, Lyell's principle of uniformity opened up to the geologist a multitude of questions for investigation because the whole present order of nature, existing both over the earth's surface and within its interior, became relevant to his purpose. Hence, the geologist must seek to learn what is going on at the present in order to understand what has gone on in the past. Catastrophism, on the other hand, removes the necessity for investigating modern processes because events in the past are considered to have no counterparts in the present. The explosion which occurred at the time of emergence of a "Crater of Elevation" occurred only once and is not to be understood from the study of modern volcanic activity. The effect of catastrophic explanations in each instance in which they were used and in which they are used today, is to close off further investigation. Lyell stressed that an enlarged view of the existing order of nature was the primary requisite for a geologist, and the chief means of attaining this enlarged view was travel. He wrote:

To travel is of first, second, and third importance to those who desire to originate just and comprehensive views concerning the structure of our globe

(Lyell, *Principles of Geology,* 11th ed., 2 vols., London [1872], 1, 69).

During his lifetime Lyell upheld the principle of uniformity in eleven successive editions of his *Principles of Geology,* published between 1830 and 1872, and in other books and memoirs. With unequalled insight, he interpreted a vast range of geological data in terms of processes observable in the modern world. Of even more far-reaching significance was his influence on Charles Darwin. During the voyage of the H. M. S. Beagle, 1831-36, Darwin came to appreciate the great value of the approach to geology embodied in Lyell's *Principles.* He then applied the same principles to the interpretation of the geological history of species and considered what would be the effect of a modern process, namely, natural selection, if it had continued to act through an indefinite period of past time. Darwin's theory of the origin of species by natural

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selection may be considered an application of Lyell's principles of uniformity to the living world.

Towards the end of Lyell's life uniformitarianism was attacked by the physicist, Lord Kelvin, who in 1865 argued that if the earth had been formed originally as a hot molten body which had later cooled but which also continued to lose heat by radiation, its age could be calculated by extrapolating backward from its present rate of heat loss. Kelvin assumed that there was no source of heat within the earth, other than that which was present there when the earth was formed. On his assumptions he showed that the age of the earth could not be greater than 100,000,000 years and was probably much less. This short and restricted time span for the age of the earth would not allow sufficient time for the extremely slow gradual geological processes, as viewed by Lyell, to bring about the actual geological changes which had occurred. The history of the earth if thus compressed in time would necessarily become violent and catastrophic. This concept of the earth's severely limited age would not allow time, either, for the slow process of evolution of living species by natural selection, as viewed by Charles Darwin.

In the face of Kelvin's calculations, geologists tended to retreat from their advocacy of uniformitarianism after Lyell's death in 1875. In 1897 Sir Archibald Geikie wrote that uniformitarianism “in its extreme form is probably held by few geologists in any country.” By “its extreme form” Geikie meant chiefly a uniformitarianism which would rule out events on a catastrophic level in volcanic activity and mountain building during the geological past. However, with the discovery of radioactivity, it was pointed out by Ernest Rutherford in 1904 that the radioactive elements did provide a steady source of heat within the earth. The assumptions on which Kelvin had based his estimates of the age of the earth were, therefore, invalid and his calculations meaningless. Geologists did not, however, recover immediately their confidence in uniformitarianism, and in many instances they continued to believe that volcanic activity and mountain building had gone on during particular periods of the geological past on a scale, and with an intensity, unparalleled in the present. In recent years, however, radioactive methods of dating rocks have shown that instances of supposed catastrophic volcanic activity and mountain building have, in fact, occurred over long periods of geological time. There is, therefore, little reason to believe that they ever involved systematic volcanic eruptions or earthquakes of magnitude greater than those which occur on earth today. The principle of uniformitarianism may be considered vindicated by modern science.

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[See also Continuity and Discontinuity; Evolutionism;Religion and Science; Uniformitarianism in Linguistics.]

Comments