18th and 19th Century Geology

Debates about the age of the earth

and the processes of change

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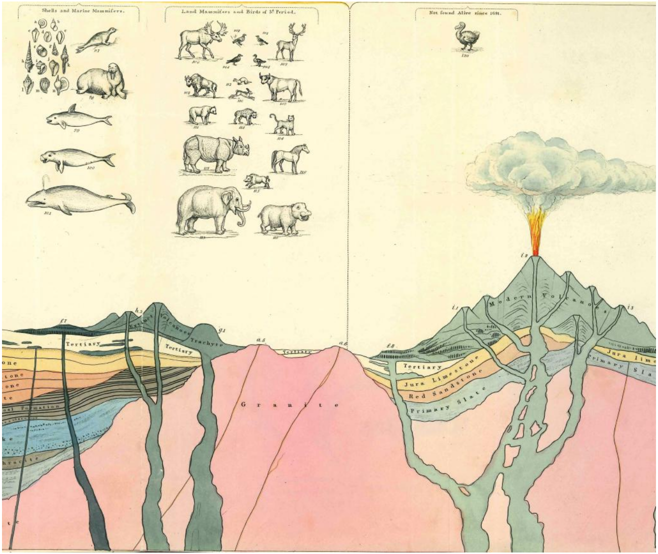
The age of the earth

The age of the earth was a central question for 17th–19th century naturalists. Aristotle had argued for a very old, essentially eternal, earth, but Protestant thinkers had taken a much more literal reading of the Bible and argued for a rather young earth. In the 1640s, Archbishop James Ussher of Armagh, Ireland, had used the Bible to calculate that the Biblical creation started on 23rd October, 4004 BC. Enlightenment thinkers, such as Buffon, had argued that the earth was tens of thousands of years old – and were rebuked by the Church for these views.

By the mid 1700s, naturalists were broadly convinced that the earth was what they considered to be very old, and that geological strata could be used to set out a *relative chronology* for the production of various types of minerals, and so on. Georges Cuvier and other comparative anatomists demonstrated that fossils could also be used to set up *relative chronologies*. There was a growing sense that the earth was *old*.



W. Buckland, *Geology and Mineralogy Considered with Reference to Natural Theology* (1837)

History and development

One of the major debates in 18th and 19th century geology was whether or not the change that the earth has undergone throughout time should be categorized as historical or developmental.

History

Historical change is characterized by chance events and contingency. In a historical process, past states do not predict future states and the only way to know what has happened in the past is through "archival" research.

Development

Developmental change is characterized by lawlike behavior or patterns. In this case, it is sufficient to know the law, or the pattern, to predict – with varying accuracy – the outcome.

Uniformitarianism and catastrophism

One of the central debates in the 18th and 19th centuries concerned the rate of change in geological processes.

Catastrophism

Catastrophists took the position that there had been periods in the earth's past in which change had taken place at a massively accelerated rate – that there had been extensive flooding, or volcanic activity, unlike anything now ocuring.

Uniformitarianism

Uniformitarianists argued that the same causes are in operation now as were operating in the past. They claimed that the processes that formed the geological formations that we see are still active at present – glacial advance and retreat, volcanoes, periodic flooding, the rising and lowering of the sea bed, and so on.

Types of rocks and mineral

Sedimentary

Sedimentary rocks are composed of compacted or cemented sediment. The composition of the original sediment is easily recognised in the resulting rock: *sandstone*, *mudstone*, and *limestone*.

Metamorphic

Metamorphic rocks are sedimentary rocks that have been exposed to sufficient heat and pressure to change their chemical and physical structure: *schist*, *marble*, *slate*, and *gneiss*.

Igneous

Igneous rocks are the result of cooled and crystallized magma, or volcanic flows: *granite*, *basalt*, *diorite*, and *obsidian*.

Neptunism and plutonism (or vulcanism)

From the earliest times it was clear that some rocks were clearly igneous and others clearly sedimentary, but there were ongoing debates about which rocks were which, and the significance of these types of rocks.

Neptunism

We call those theorists neptunists who argued that sedimentary rocks were the most important and ancient of the rocks – who viewed the most important changes as having to do with sediment in ancient waters.

Plutonism (Volcanism)

We can use plutonist (*volcanist*) for those theorists who argued that the most important and ancient rocks are igneous – that the most significant changes have to do with heat.

Geology in the 17th century

In the 1600s, many naturalists in Protestant countries worked with the theory of a very short timespan for the history of the earth – as determined from a strict reading of the Bible. Naturalists from Catholic countries, on the other hand, had a tendency to take a less literal reading of the religious texts.

Thomas Burnet (1635?–1715) argued that the earth was a dead star that was cooling over time. He claimed that Noah's flood was the result of the earth collapsing as it cooled. William Whiston (1667–1752) argued that the flood was the result of a comet striking the earth. They were both trying to come up with *naturalist explanations* of a spiritual or religious story.

Nicholas Steno (1638–1686) and Robert Hook (1635–1703) believed that fossils were the remains of living organisms, and argued that finds of marine fossils in mountain ranges meant that there had been large scale changes on the surface of the earth – changes which had been *catastrophic*.

Mining schools

In the 18th and 19th centuries, mining schools were an important institutional nexus for geological studies on the European continent, and later in the US, Japan, and various colonial counties. These centers trained a large number of engineers and geologists and a number of important geologists taught in these schools.

- Royal Hungarian Mining Academy, Schemnitz (1760), École de Mines, Paris (1783), Freiberg Academy, Saxony (1765), Columbia School of Mines, NY (1864).

The first American school of geologists were largely trained at Freiberg and then established mining schools in the States.

In Britain, on the other hand, mining schools only developed starting from 1851 – before which mining was largely a private enterprise and separate from theoretical geology.

École des Mines de Paris

École Nationale Supérieure des Mines de Paris

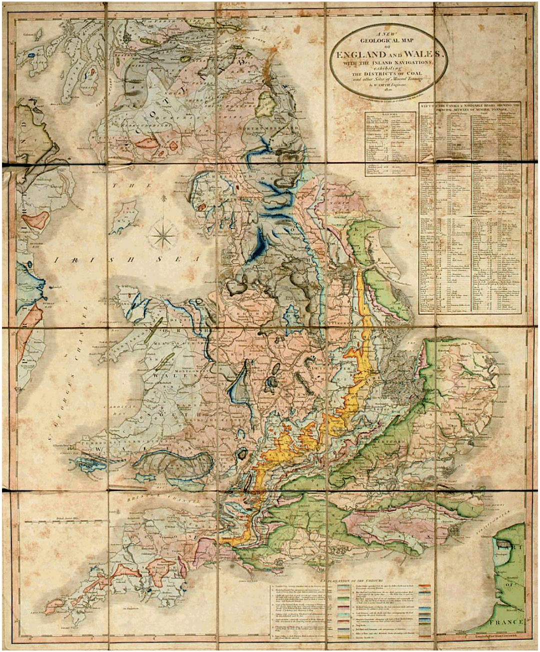
Geological surveys

Another important institutional setting for geology in the 18th and 19th centuries was the geological survey. These were usually organized research expeditions, employing a number of specialists and engaged in research for some 5–10 years.

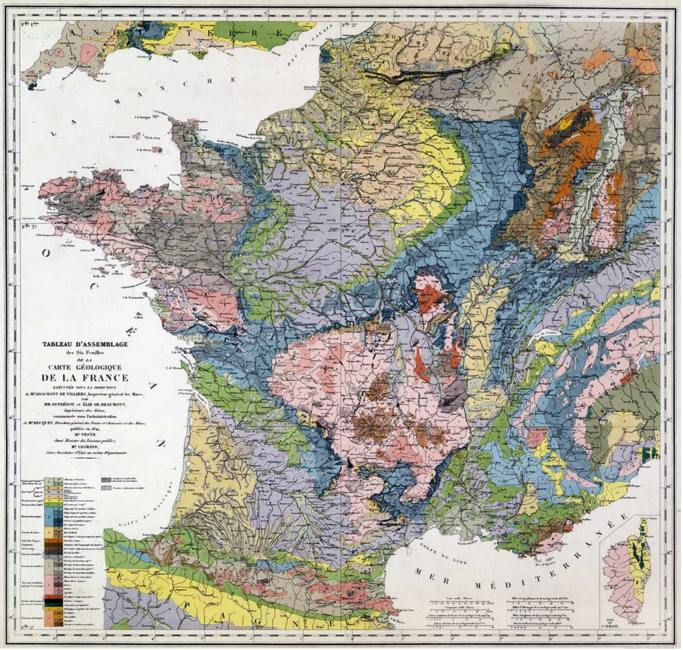
In Britain and the US there were a number of important surveys carried out by private individuals and groups who received their funding from subscription, investors, wealthy estate owners, or coal and petroleum companies. The most famous of these was Willam Smith (1769–1839), whose survey of England and Wales was extremely influential.

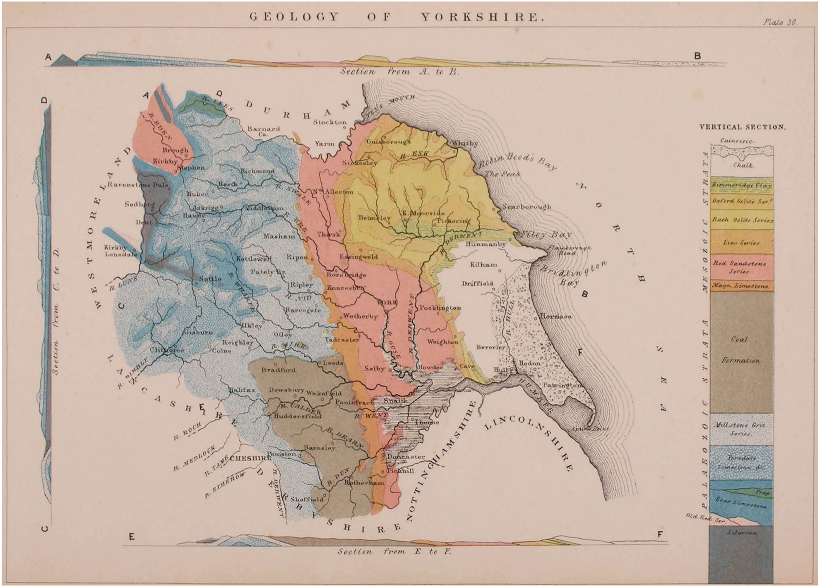
From 1825–1835, Dufrénoy and Élie de Beaumont led the Corps des Mines survey of the whole of France. Also in the 1830s, Great Britten and a number of individual American State governments commissioned geology surveys – generally with an emphasis on coal. The Geological Survey of Japan was founded in 1881.

“A new geological map of England and Wales with the inland navigations establishing the districts of coal,” William Smith, 1820



Geological survey map of France by Dufrénoy and Élie de Beaumont, 1841





Geology of Yorkshire, Phillips, 1855

Werner's strata

Abraham Gottlob Werner (1749–1817) was a mineralogist educated at Freiberg and Leipzig, later appointed Inspector and Teacher of Mining and Mineralogy at the Freiberg Mining Academy. His first work was an important text on identifying minerals based on a classification system that he developed, *Von den äusserlichen Kennzeichen der Fossilien* (1774, On the external characteristics of fossils) – here, *Fossilien* means *minerals*.

Werner instructed two generations of geologists and engineers in a field technique and mineral identification system that was based on identifying *characteristic strata* – that is, the layers in which certain minerals are usually found. Through this work he produced a chart for classifying minerals, similar to Linnaeus' chart for living organisms. Although he published little, he was a gifted teacher and had many influential students.

Werner's geological column

According to Werner's classification, he identified five classes of rocks, from which one could infer a history of the earth:

1. Primitive (*Urgebirge*): the original rocks: granite, gneiss, porphyry, etc. No fossils.
2. Transition (*Übergangsgebirge*): the deposits of the ancient oceans: carmoniferous limestone, devonian formations, etc.
3. Stratified (*Flötz*): stratified fossiliferous rocks, divided into 12 groups, such as sandstones, mixtures of clays and gypsum, mixtures of basalt, sand grus, etc.
4. Alluvial (*Aufgeschwemmte*): poorly consolidated sands, gravels, and clays: sand, clay, gravel, etc.
5. Volcanic: divided into (a) true volcanic rocks: lava, pumice, etc., and (b) pseudo-volcanic rocks: burned clay, hornstone, etc.

A foldout table from Werner's *On the External Characteristics of Minerals*. It divided up the minerals based on their properties (color, cohesion, and so on).

The text has a number of more specific tables that allow us to identify the characteristics of minerals.

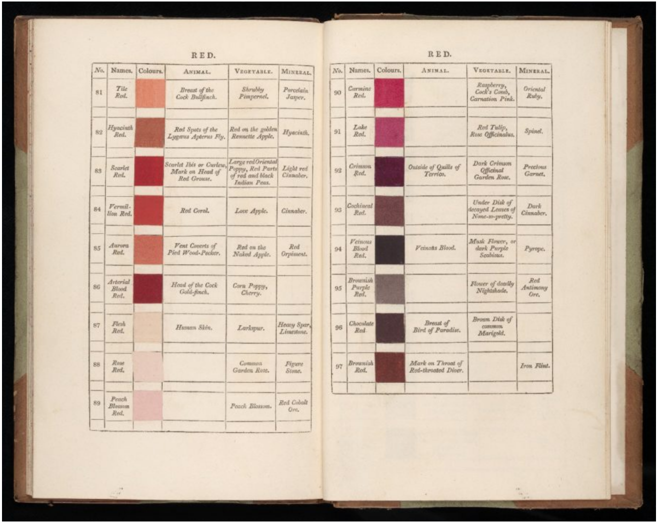
1ste Tafel. pag. 86

Die generischen Kennzeichen der Foßilien sind,

1) die Farbe,
2) der Zusammenhang,
nach welchen sie sich unterscheiden,
in

	feste,		flüßige,
	feste,	zerreibliche,	
das äußere Ansehen,	die äußere Gestalt, die äußere Oberfläche, der äußere Glanz,		
das innere Ansehen,	der innere Glanz,	der Glanz,	der Glanz,
	der Bruch,		
	die Gestalt der Bruchstücke,	das Ansehen der Theile,	
	die Durchsichtigkeit,		die Durchsichtigkeit,
	der Strich,		
	das Abfärben,	das Abfärben,	
	die Härte,		
	die Festigkeit,	die Zerreiblichkeit,	die Flüßigkeit,
	die Biegsamkeit,		
	das Anhängen an der Zunge,	das Anhängen an der Zunge,	
	der Klang,		

3) das Anfühlen,
4) die Kälte,
5) die Schwere,
6) der Geruch,
7) der Geschmack.



RED.

No.	Names.	Colours.	Animal.	Vegetable.	Mineral.
81	Tile Red.		Breast of the Cock Bullfinch.	Shrubby Pimpernel.	Porcelain Jasper.
82	Hyacinth Red.		Red Spots of the Lygæus Apterus Fly.	Red on the golden Rennette Apple.	Hyacinth.
83	Scarlet Red.		Scarlet Ibis or Curlew, Mark on Head of Red Grouse.	Large red Oriental Poppy, Red Parts of red and black Indian Peas.	Light red Cinnaber.
84	Vermillion Red.		Red Coral.	Love Apple.	Cinnaber.
85	Aurora Red.		Vent Coverts of Pied Wood-Pecker.	Red on the Naked Apple.	Red Orpiment.
86	Arterial Blood Red.		Head of the Cock Gold-finch.	Corn Poppy, Cherry.	
87	Flesh Red.		Human Skin.	Larkspur.	Heavy Spar, Limestone.
88	Rose Red.			Common Garden Rose.	Figure Stone.
89	Peach Blossom Red.			Peach Blossom.	Red Cobalt Ore.

RED.

No.	Names.	Colours.	Animal.	Vegetable.	Mineral.
90	Carmine Red.			Raspberry, Cock's Comb, Carnation Pink.	Oriental Ruby.
91	Lake Red.			Red Tulip, Rose Officinalus.	Spinel.
92	Crimson Red.		Outside of Quills of Terrico.	Dark Crimson Officinal Garden Rose.	Precious Garnet.
93	Cochineal Red.			Under Disk of decayed Leaves of None-so-pretty.	Dark Cinnaber.
94	Veinous Blood Red.		Veinous Blood.	Musk Flower, or dark Purple Scabious.	Pyrope.
95	Brownish Purple Red.			Flower of deadly Nightshade.	Red Antimony Ore.
96	Chocolate Red		Breast of Bird of Paradise.	Brown Disk of common Marigold.	
97	Brownish Red.		Mark on Throat of Red-throated Diver.		Iron Flint.

Werner also produced a method for describing colors

Hutton's plutonism

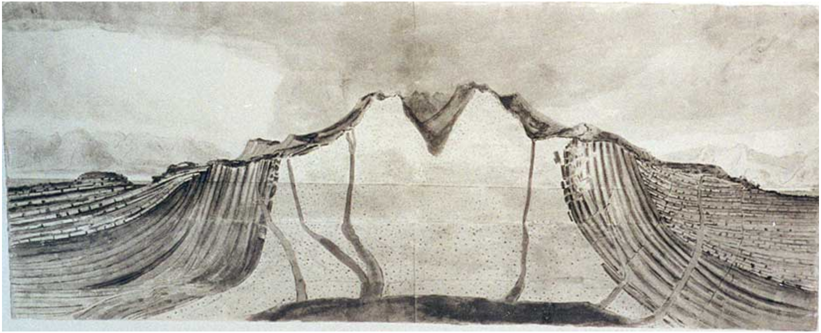
James Hutton (1726–1797), was a central figure in the Scottish Enlightenment. He made a living from his father's farms, and later settled in Edinburgh where he made the acquaintance of John Playfair, Joseph Black, David Hume and Adam Smith. He did theoretical work in medicine, agriculture and chemistry, but is mostly remembered for his work in geology. Although Hutton framed himself as an empiricist, his writings were fairly theoretical and much of his observation was carried out in order to support his theories.

Hutton described the earth as a sort of perpetual motion machine that did not age, and which went through a continuous series of cycles. His geological work was popularized by Playfair's *Illustrations of the Huttonian Theory of the Earth* (1802). Playfair, used the terminology of *neptunism* and *plutonism* to frame the debate between Hutton and Werner. This work was not very influential on the continent.

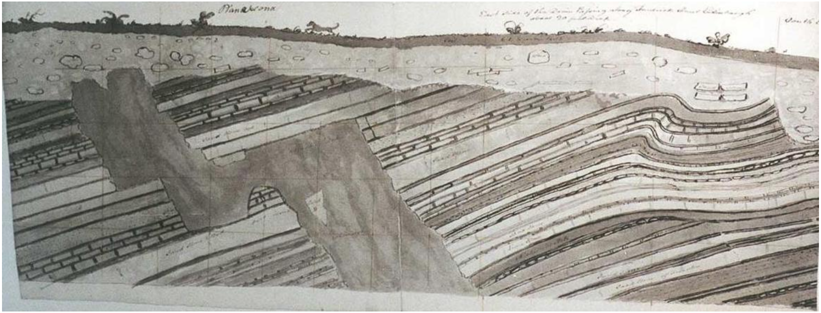
Hutton's approach

Hutton argued that an understanding of the processes involved in the formation of the current geological situation involves explaining the following phenomena:

1. Sedimentary rocks are found at different levels, and hence have to be transported.
2. Sedimentary rocks are consolidated from loose material such as sand, gravel, etc.
3. Sedimentary rocks are not all equally consolidated.
4. Sedimentary rocks are broken up with veins and fissures.
5. The veins and fissures of sedimentary rocks are filled with granite and other similar minerals (igneous rocks).
6. Sedimentary rocks may be folded and inclined at any angle.
7. There must be some mechanism other than sedimentation to produce all these effects.



James Clerk, unpublished watercolor draft of a plate for Hutton's *The Theory of the Earth*, 1795. East-West section, Norther Granite, Isle of Arran.



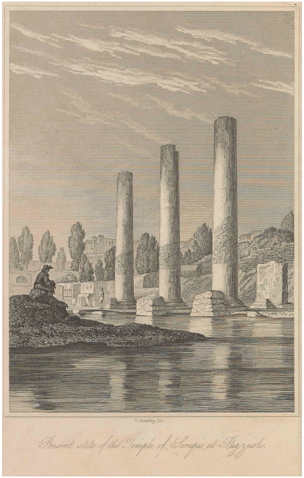
James Clerk, unpublished watercolor. Fredrick Street, Edinburgh.

A *circulation* of the Earth

Hutton proposed that these process were driven by a *central heat*, created by pressure, that lifted up continents and mountains, which were in turn eroded by rain and snow, producing sediment in the deep ocean, causing, in turn, pressure, heat, and the beginning of a new upheaval.

Hutton, *The Theory of the Earth*, 1795

"We are thus led to see a circulation in the matter of this globe, and a system of beautiful economy in the works of nature. This Earth, like the body of an animal, is wasted at the same time that it is repaired. It has a state of growth and augmentation; it has another state, which is that of diminution and decay. This world is, thus, destroyed in one part, but it is renewed in another; and the operations by which this world is thus constantly renewed, are as evident to the scientific eye, as are those in which it is necessarily destroyed."



Frontispiece of *Principles of Geology*, showing changes in sea level

Charles Lyell (1797–1875) was another Scottish geologist most famous for his *Principles of Geology*, 3 vols. (1830–1833), 12 eds. It was a synthetic work, arguing for an essentially Huttonian position, also supported by his own observations.

Lyell argued that the current structure of the earth, and all past changes, should be explained in terms of presently active causes – a principle of *actualism*. That is, he believed that the same causes have always been active, and they have always been active in the same way. *These are methodological positions.*

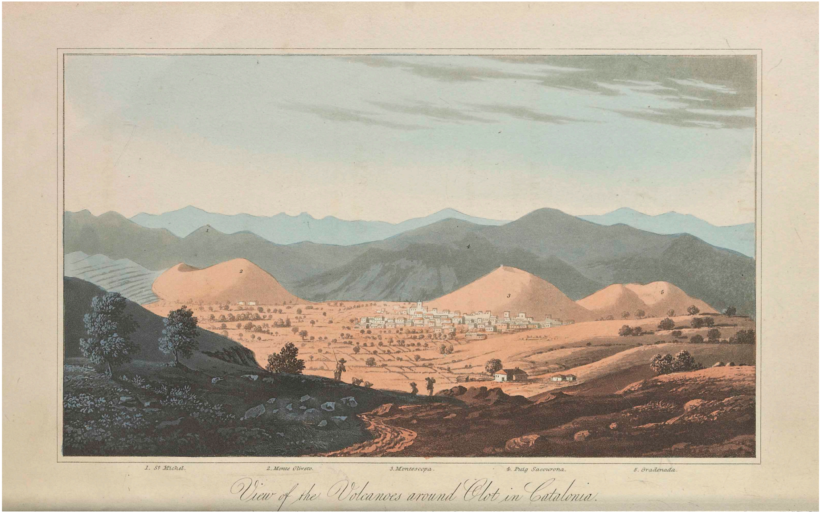


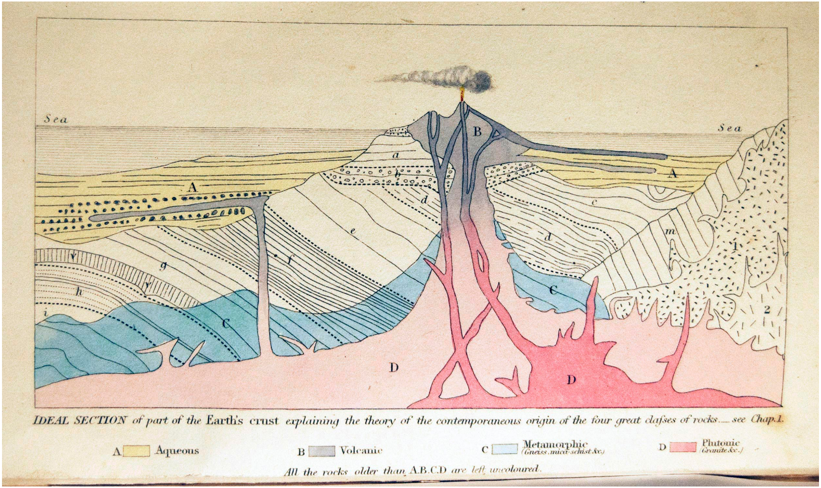
Image from *Principles of Geology*: Olot, Catalonia

Image from *Principles of Geology*: Etna, Sicily

Lyell's deep time

Lyell's ideas of uniformity gave rise to predictive claims that might be subject to empirical verification. For example, he held that geological formations, such as the Grand Canon in Arizona, are created by steady accumulation of small changes over vast periods of time. In this way, flooding and Earthquakes are purely local catastrophes. Moreover, he believed that, on the large scale, the earth has always looked and behaved more or less as it does now.

Lyell used the layers of strata to develop a history of the earth and to argue that the earth was much older than most people believed in the 19th century: 240 million years (%5.2 of current value!). He believed that there was no real evolution of animal species and that with the exception of humans, all animals would be found in all ancient strata. It was not until the 10th edition (1868) that he accepted that the appearance of mammals was recent.



Section of the earth's crust showing the simultaneous origin of the different types of rock, *Principles of Geology*

Relative timescale, based on minerals and fossils

Proposed Titles depending on the Series of Organic Affinities.			Ordinary Title.
Cainozoic Strata	Upper	=	Pleiocene Tertiaries.
	Middle	=	Meiocene Tertiaries.
	Lower	=	Eocene Tertiaries.
Mesozoic Strata	Upper	=	Cretaceous System.
	Middle	=	Oolitic System.
	Lower	=	New Red formation.
Palæozoic Strata	Upper ?	=	Magnesian Limestone formation. Carboniferous System.
	Middle ?	=	(Eifel and South Devon.)
	Lower	=	Transition Strata. Primary Strata.

(The terms are founded on the verb ζαω or ζωω—to live, combined with καινος—recent, μεσος—medial or middle, and παλαιος—ancient.)

John Philips, *Figures and Descriptions of the Palaeozoic Fossils of Cornwall, Devon and West Somerset* (1841). Palaeozoic: invertebrates and fish; Mesozoic: reptiles; Cainozoic: mammals

Élie de Beaumont's work on mountains

Jean-Baptiste Léonce Élie de Beaumont (1798–1874) was educated in mathematics and physics at the École Polytechnique. After work on the geological survey of France, he became professor of geology at the École des Mines, and later replaced Georges Cuvier (1769–1832) as chair of natural history at the Collége de France.

He argued that mountain ranges are produced by catastrophic events, saying that nothing seems to

Élie, "Recherches sur quelques unes des révolutions…," 1829

"… forecast a change of the Earth's crust which would assure us that the period of calm in which we live shall not be troubled by the appearance of a new mountain system, the effect of a new deformation of the land where we now live, whose present earthquakes forecast sufficiently that these foundations are not unshakeable."

Élie de Beaumont on the cooling earth

Élie argued that mountains were formed by periodic revolutions, such that the notion of catastrophe became moderated and extended. The mechanism for these repeated uplifts was supposed to be the fact that the earth is slowly cooling – what Élie called "secular cooling." As the center of the earth continuously cools, it shrinks, and this causes the crust to contract. This contraction causes periodic rippling and folding of the crust.

Élie also introduced a principle of directionality.

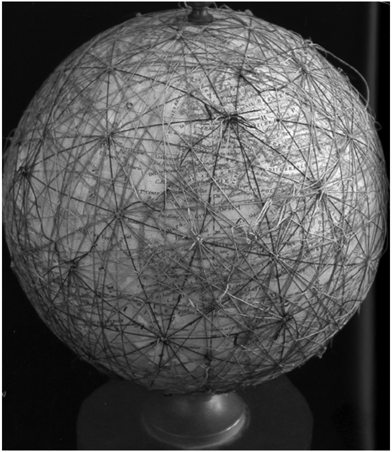
Élie, "Recherches…," *Manuel géologique*, 1832

"The stratigraphic position of an angular unconformity is at the same level in chains which are parallel to each other, but is different in chains which do not have the same direction … Deformations which have the same direction … were all produced by the same mechanism."

The pentagonal network

Élie de Beaumont and his students deduced a system of mountain chains and postulated that they formed a geometrical network on the globe.

They assumed that the great circles of formation were not scattered randomly but organized into a system of 15 circles crossing each other in 12 pentagons. These were purely mathematical considerations, and turned out to be wrong.



A model of idealized mountain ranges from the École des Mines de Paris

Élie de Beaumont, *Notice sur les systèmes de montagnes* (1852)

Overview

- Through the 18th and 19th centuries, naturalists came to understand that the earth was much older than had been believed in the medieval and early modern periods, and to realize that the earth and life sciences could be used to understand this change as a *historical process*.
- Although different researchers disagreed about the role of uniform or catastrophic changes, it came to be understood that although there may have been more catastrophic changes in the past, these had also been very gradual by the standards of human history.
- The plutonist position came to dominate, but there were still broad areas of neptunistic explanation.
- It came to be accepted that the changes that produced the current situation were more historical than developmental in nature.