Theories of the Earth

The Discovery of Deep Time

Sketches of Geologic Development

The descriptions and biographies below accompany the two page flow chart titled "Theories of the Earth". They flesh out the positions and personages and their role in the discovery of the Earth's history. They are listed in the order of class discussion.

Myth of the Eternal Return: *The notion that the world has no beginning, and no end*

- The notion that the universe is eternal and time is cyclical, with events repeating over and over again - like the beating of a heart, the waxing and waning of the Moon, the cycling of the seasons. The Babylonians developed a cosmic model based on periodicities of the planets in which each Great Year lasts 424,000 years; in the 'summer', when all the planets congregate in the constellation Cancer, there is a great fire, and the 'winter', marked by a gathering in Capricorn, is greeted by a great flood.. In a cyclical universe it was impossible even to frame the question of an age of the Earth - for it hadn't a beginning.
- "The Myth of the Eternal Return" was formulated by Mircea Eliade in 1974: This is the earliest and most important of Eliade's books on comparative religions. He traces through the many scripts and dogmas of the world's official and unofficial (i.e., primitive) religions the myth of the eternal return.
- From Mesopotamia mythology: *"But Ishtar is all this and more. She is the reborn. .. Know, O Prince, that death is the source of life, life is the cause of death. Dumuzi her lover must die in order to live. She is the rhythm, and all rhythms have an end, this is death, all have a beginning."* http://www.gatewaystobabylon.com/religion/eternal.htm

Judeo-Christian Concepts of Time: *The notion that the world has a beginning, and middle, and an end*

- In ancient history only the Judaic tradition eschewed the notion of a cycling eternity. The history of the world was a narrative; a simple story, with a beginning, a middle, and an end, spanning time from God's creation of the world on the first day all the way to the end of things.
- With the emergence of Christianity this story was elaborated further, with detailed revelations of what would come at the end of time, and with Christ's biography as a unique pivot.
- St. Augustine completed this great time-mapping project, arguing powerfully against the notions of cycling time. If life was doomed to follow patterns set in an earlier age, there would be no motivation to follow the teachings of Christ: what would be the point of trying to lead a better life, if every action you took was fixed before you were even born? And besides, cycles of time would violate one of Christianity's key precepts, that the Incarnation of Christ was a unique event. *"God forbid that we should believe in [the Eternal Return],'* Augustine wrote. *'For Christ died once for our sins, and rising again, does no more."*
- Augustine's pronouncements on Earth's history froze ideas of time in western human minds for thirteen hundred years. . . Earth's youth became powerfully lodged as essential to the faith, a doctrine it would be heretical to deny.

Stephen Baxter, Ages in Chaos, pages 19-20

James Ussher: 1581-1656, *The Annals of the World*

http://www.lhup.edu/~dsimanek/ussher.htm

- James Ussher, Archbishop of Armagh, Primate of All Ireland, and Vice-Chancellor of Trinity College in Dublin was highly regarded in his day as a churchman and as a scholar.
- Based on an intricate correlation of Middle Eastern and Mediterranean histories and Holy writ, Ussher deduced the date of the origin of Earth at 4004 B.C., a Saturday, about 6 in the evening (sources differ on Ussher's date). Ussher calculated the dates of other biblical events, concluding, for example, that Adam and Eve were driven from Paradise on Monday 10 November 4004 BC, and that the ark touched down on Mt Ararat on 5 May 2348 BC `on a Wednesday'.
- In 1701 Ussher's date was authorized by the church and incorporated into an authorized version of the Bible.

Thomas Burnet: 1680's-1690's, *The Sacred Theory of the Earth*

- Burnet began with Genesis and presented a model of the Earth's structure with ample stores of water within subterranean chambers to cause the Noachian flood. The waters of the present day oceans, Burnet believed, were insufficient to have caused the deluge, which Burnet regarded as world wide in its effects. Burnet estimated the volume of the subterranean waters required to flood the world at the equivalent of about 9 oceans.
- Burnet reasoned that as the materials of the primeval earth precipitated from the initial chaos, they were sorted according to their densities. Heavy rocks and metals formed the core with a liquid layer above; terrestrial materials and air were eventually precipitated to form a perfectly smooth, featureless surface, like that of an egg. Thus the original earth was

smooth and beautiful, without faults and wrinkles, such as it exhibits today. Burnet wrote: *In this smooth Earth were the first scenes of the world, and the first generation of Mankind; it had the Beauty of Youth and blooming Nature, fresh and fruitful, and not a Wrinkle, Scar or Fracture in all its body; no Rocks nor Mountains, no hollow Caves, nor gaping Channels, but even and uniform all over.* The climate also was like a perpetual spring, and there were no seasons in the antediluvial world.

In contrast, our present world is but a ruin, he said, and shows the effects of the collapse of the crust into subterranean cavities during the flood. The flood itself was the result of natural causes, Burnet argued, which culminated in the destruction of the world; when the flood waters had retreated into internal caverns, the earth had become "a gigantic and hideous ruin ... a broke and confused heap of bodies." http://www.sentex.net/~tcc/burnet.html

- The most popular geologic work of the 17th century, in four books. This work had a strong influence on James Hutton, the "father" of geology, although he eventually developed a very different theory of the Earth.

William Paley: *1743-1805, Natural Theology: or, Evidences of the Existence and Attributes of the Deity, Collected from the Appearances of Nature*

- Paley in the watchmaker argument developed the most important argument for how complexity arises through purpose and design.
- *. . . when we come to inspect the watch, we perceive. . . that its several parts are framed and put together for a purpose, e.g. that they are so formed and adjusted as to produce motion, and that motion so regulated as to point out the hour of the day; that if the different parts had been differently shaped from what they are, or placed after any other manner or in any other order than that in which they are placed, either no motion at all would have been carried on in the machine, or none which would have answered the use that is now served by it. . . . the inference we think is inevitable, that the watch must have had a maker -- that there must have existed, at some time and at some place or other, an artificer or artificers who formed it for the purpose which we find it actually to answer, who comprehended its construction and designed its use.*

  The marks of design are too strong to be got over. Design must have had a designer. That designer must have been a person. That person is GOD.
- Quote from Charles Darwin's Autobiography concerning Paley's influence on his thinking: *"In order to pass the B.A. examination, it was, also, necessary to get up Paley's Evidences of Christianity, and his Moral Philosophy. . . The logic of this book and as I may add of his Natural Theology gave me as much delight as did Euclid. The careful study of these works, without attempting to learn any part by rote, was the only part of the Academical Course which, as I then felt and as I still believe, was of the least use to me in the education of my mind. I did not at that time trouble myself about Paley's premises; and taking these on trust I was charmed and convinced of the long line of argumentation."*
- William Paley trained for the Anglican priesthood, graduating from Christ's College, Cambridge in 1763. He was appointed a fellow and tutor of his college in 1766, and rose through the ranks of the Anglican Church.

DEISM

http://www.religioustolerance.org/deism.htm

- *"We believe that God designed and created the world, and governs it through natural laws that can be discovered through reasoning, observation, and experience. We feel that God does not reveal himself to us through inspired or revealed texts or by supernatural means, but through creation itself."* Excerpt from the Peace Dale Christian Deist Fellowship's web site.
- The word "Deism" is derived from the Latin word for God: "Deus." Deism involves the belief in the existence of God, on purely rational grounds, without any reliance on revealed religion or religious authority. Most Deists believe that God created the universe, "wound it up" and then disassociated himself from his creation. Some refer to Deists as believing in a God who acts as an absentee landlord or a blind watchmaker. A few Deists believe that God still intervenes in human affairs from time to time.
- Early Deism was a logical outgrowth of the great advances in astronomy, physics, and chemistry that had been made by Bacon, Copernicus, Galileo, etc. It was a small leap from rational study of nature to the application of the same techniques in religion. Early Deists believed that the Bible contained important truths, but they rejected the concept that it was divinely inspired or inerrant. They were leaders in the study of the Bible as a historical (rather than an inspired, revealed) document. Lord Herbert of Cherbury (d. 1648) was one of the earliest proponents of Deism in England. In his book "De Veritate," (1624), he described the "Five Articles" of English Deists:
  1. Belief in the existence of a single supreme God
  2. Humanity's duty to revere God
  3. Linkage of worship with practical morality
  4. God will forgive us if we repent and abandon our sins
  5. Good works will be rewarded (and punishment for evil) both in life and after death

Nicholas Steno: *1638-1686 ; Preliminary discourse to a dissertation on a solid body naturally contained within a solid. (The book's title is often simply abbreviated to Prodromus.)*

http://www.ucmp.berkeley.edu/history/steno.html

- Steno laid out the three principles that allow us to unravel the Earth's geologic history.
  1. **Superposition** - rocks on the bottom of a stack are the first deposited and therefore the oldest; rocks on top are the last deposited and therefore the youngest.
  2. **Original Horizontality** - rocks are deposited horizontal; if they are no longer horizontal they have been deformed by a later event.
  3. **Lateral Continuity** - identical rocks that are now separated must at one time have been joined.
- Despite a relatively brief scientific career, Nicholas Steno's work on the formation of rock layers and the fossils they contain was crucial to the development of modern geology. The principles he stated continue to be used today by geologists and paleontologists.
- While examining the teeth of the shark, Steno was struck by their resemblance to certain stony objects, called glossopetrae or "tongue stones," that were found in certain rocks. Ancient authorities, such as the Roman author Pliny the Elder, had suggested that these stones fell from the sky or from the moon. Others were of the opinion, also going back to ancient times, that fossils naturally grew in the rocks. Steno's contemporary Athanasius Kircher, for example, attributed fossils to a "lapidifying virtue diffused through the whole body of the geocosm." Steno, however, argued that glossopetrae looked like shark teeth because they were shark teeth, that had come from the mouths of once-living sharks, and come to be buried in mud or sand that was now dry land.
- Steno's work on shark teeth led him to the more general question of how any solid object could come to be found inside another solid object, such as a rock or a layer of rock. The "solid bodies within solids" that attracted Steno's interest included, not only fossils as we would define them today, but minerals, crystals, incrustations, veins, and even entire rock layers or strata. Steno argued these must have grown from fluids percolating within the Earth, in the same manner that crystals could be made to grow in chemistry experiments. Finally, in the case of strata, layers on top of a set of strata conform to the shape of lower layers. . . and therefore, in a set of strata, the youngest layers must be those of the top, and the oldest must lie on the bottom. This conclusion also follows from Steno's reasoning that rock strata form when particles fall out of suspension in a fluid -- but it also applies to rocks that do not form in this way, such as many igneous rocks. This is now referred to as Steno's ***law of superposition***: layers of rock are arranged in a time sequence, with the oldest on the bottom and the youngest on the top, unless later processes disturb this arrangement. It is Steno's most famous contribution to geology.

Robert Hook: *1635-1703 ; Micrographia; Discourse of Earthquakes*

http://www.ucmp.berkeley.edu/history/hooke.html

- One of the earliest to propose the idea of extinction; that species had fixed life spans, after which they disappeared. He also argued that the Earth was much older than believed at the time. His age was 75,000 years, young by our standards, but old by the Ussher date of 6000 years.
- Hooke was perhaps the single greatest experimental scientist of the seventeenth century. His interests knew no bounds, ranging from physics and astronomy, to chemistry, biology, and geology, to architecture and naval technology.
- He was a keen observer of fossils and geology. Hooke had grasped the cardinal principle of paleontology -- that fossils are not "sports of Nature," but remains of once-living organisms that can be used to help us understand the history of life. (In the seventeenth century, a number of hypotheses had been proposed for the origin of fossils. One widely accepted theory, going back to Aristotle, stated that fossils were formed and grew within the Earth. A shaping force, or "extraordinary Plastick virtue," could thus create to stones that looked like living beings but were not. Hooke's contemporary, the naturalist and shell collector Martin Lister wrote in 1678 that "our English Quarry-shells were not cast in any Animal mold, whose species or race is yet to be found in being at this day.")
- Hooke examined fossils with a microscope -- the first person to do so -- and noted close similarities between the structures of petrified wood and fossil shells on the one hand, and living wood and living mollusc shells on the other. In Micrographia he compared a piece of petrified wood with a piece of rotten oak wood, and concluded that: *this petrify'd Wood having lain in some place where it was well soak'd with petrifying water (that is, such water as is well impregnated with stony and earthy particles) did by degrees separate abundance of stony particles from the permeating water, which stony particles, being by means of the fluid vehicle convey'd, not onely into the Microscopical pores. . . but also into the pores or Interstitia. . . of that part of the Wood, which through the Microscope, appears most solid. . .*
- Hooke's Discourse of Earthquakes, published two years after his death, shows that his geological reasoning had gone even further. Following in the footsteps of Leonardo da Vinci, Hooke explained the presence of fossil shells on mountains and in inland regions: *"Most of those Inland Places. . . are, or have been heretofore under the Water. . . the Waters have been forc'd away from the Parts formerly cover'd, and many of those surfaces are now raised above the level of the Water's Surface many scores of Fathoms. It seems not improbable, that the tops of the highest and most considerable Mountains in the World have been under Water, and that they themselves most probably seem to have been the Effects of some very great Earthquake."*

Georges-Louis Leclerc, Comte de Buffon: *1707-1788*

http://www.ucmp.berkeley.edu/history/buffon2.html

- Divided Earth history into six divisions (including a collision origin for the Earth). This began a trend for workers everywhere to divide and name local rock units.
- During the eighteenth century, two church doctrines provided sweeping biblical explanations for most questions about biological diversity: Separate Creation, the idea that all creatures have been created independently of one another by God and organized into a hierarchy ("chain of being") with Man occupying the most elevated rank beneath God; ***and*** the 6,000 year limit on the age of the planet.
- It is not the average person who questions two thousand years of dogma, but that is what Buffon did: 100 years before Darwin, Buffon, in his Historie Naturelle, a 44 volume encyclopedia describing everything known about the natural world, wrestled with the similarities of humans and apes and even talked about common ancestry of Man and apes. Although Buffon believed in organic change, he did not provide a coherent mechanism for such changes. He thought that the environment acted directly on organisms through what he called "organic particles". Buffon also published Les Epoques de la Nature (1788) where he openly suggested that the planet was much older than the 6,000 years proclaimed by the church, and discussed concepts very similar to Charles Lyell's "uniformitarianism" which were formulated 40 years later.

Giovanni Ardunio: (1714-1795)

- The first real attempts to apply systematic subdivisions to the rocks were made by Giovanni Arduino in Italy. Arduino classified the rocks of Northern Italy into Primitive, Secondary, and Tertiary. His classification was based on the appearance of the rocks and on the occurrence of fossils (see table below).

  http://www.cartage.org.lb/en/themes/Sciences/Earthscience/Geology/AboutGeology/Historyofgeology/Historyofgeology.htm
- Arduino was a mining specialist who developed possibly the first classification of geological time, based on study of the geology of northern Italy. The first record of the classification may be a letter dated from 1759 — dates on the web vary. His classification used only a few periods: **primitive** (or primary), **secondary** and **tertiary** — some pages on the web add a fourth type, variously quaternary, volcanic or alluvial. (see table below): http://en.wikipedia.org/wiki/Giovanni_Arduino

Abraham Gottlob Werner: *(1749-1817)*

- Enormously influential, Abraham Gottlob Werner was the strongest proponent of the "Neptunian" view of the earth, claiming that all rocks had been deposited in a primordial ocean. This view was accepted without question and prevailed until challenged by James Hutton near the close of the 18th century. http://www.strangescience.net/werner.htm
- In Werner's conception, all oldest rocks originated as crystalline sediments that were chemically precipitated from an initial universal ocean. These, his **Primitive** rocks, are granites, gneisses, schists composed of the least soluble, siliceous, earth materials. Typically they contain no fossils. The uneven surface of the initial chaotic precipitation of the Primitive crystalline rocks formed the main features of the present landscape. As such, the high mountains have always been. The volume of the universal ocean was reduced by the subtraction of Primitive crystallines and the highest peaks in the landscape became early exposed. Continued precipitation of crystalline materials, thereafter, plastered the mountain slopes with layers of slate and hard limestone. Intervening with these are steeply inclined layers of detrital sediments, mostly graywakes, derived from higher elevations. Some of the layers are fossiliferous. Permineralization at high elevations, testifies to an often high stand of the then ocean. In some regions, the attitude of the layers suggests the collapse of underground caverns. All these rocks are called **Transitional** because they are intermediate in their universal occurrence between the Primitive and later formations of local occurrence. Following the deposition of the Transitional, the residual liquor of a much lowered and land-subdivided ocean covered only foothill elevations. Then the ocean, in its turbulence, began to oscillate in its level so that the foothill elevations became built of alternating, essentially horizontal, layers of precipitates of the more soluble earth materials and, reworked detrital sedimentary rock. Called by the descriptive name **Stratified**, these rocks are typically shelly limestones, limestones with flint nodules, gypsum, salt, shales, sandstones, coals, and basalts. The ocean finally retreated to its present level and condition. Since then rivers have deposited gravels and muds at times of flood in lowland areas. Coastal peat and shales, limestones and weakly consolidated sandstones are also of this age. All these youngest sediments are called the **Alluvial**. During Alluvial time volcanism, where it is in evidence, is explained to be due to the underground burning of Stratified coals.

  http://www.geowords.com/histbooknetscape/a26.htm
- Werner was a careful mineralogist who drew up an excellent system of classification of minerals based on their properties. He did not travel extensively, but based most of his geological ideas on the small region around Freiburg with which he was familiar. Unlike many present-day scientists, Werner published few of his theories but the ideas presented in his popular lectures were soon spread throughout Europe by the enthusiasm of his students.

NEPTUNISM

- The theory that all the rocks of the Earth had precipitated from a primeval ocean. See description under Abraham Gottlob Werner.

19th CENTURY GEOLOGIC TIME SCALES

G. Ardunio (ca. 1759)	A.G. Werner (late 1790's)
	Volcanic Series - younger lava flows associated with volcanic vents
Tertiary Strata - poorly consolidated sands and gravels	**Transported Series** - poorly consolidated clays, sands, and gravels. Thought to have been deposited after final withdrawal of a worldwide ocean.
Secondary Strata - fossiliferous strata containing detritus from older rocks.	**Stratified Series** - obviously stratified fossiliferous rocks. Thought to represent the first deposits after receding of the worldwide oceans, formed by erosion of emergent mountains.
	Transition Series - strongly indurated stratified rocks such as graywacke, limestone, sills.
Primitive Rocks - crystalline rocks	**Primitive Series** - crystalline rocks, both metamorphic and igneous.

- Time Scale comparison available at http://norges.uio.no/timescale/C1_Fig2.7_Bleeker.pdf

FIRST GEOLOGIC MAPS

- The first geologic maps were a scientific breakthrough that is hard to appreciate from this perspective. But, geologic maps are the foundation of all geologic work. When entering a new area the first thing a geologist does is study the geologic map. And, if one is not available it must be made before anything else can be done.
- The Geologic Map of Great Britain (William Smith) and a geologic map of the Paris Basin (George Cuvier) were both drawn in the first decade or two of the 19th century.
- The first geologic maps were based on and established two principles that are foundations to a geological view of the world.
  1. Principle of Faunal Succession
  2. Principle of Fossil Correlation

William Smith: *1769-1839 ; Geologic Map of England and Wales*

http://www.ucmp.berkeley.edu/history/smith.html

- *Fossils have been long studied as great curiosities, collected with great pains, treasured with great care and at a great expense, and shown and admired with as much pleasure as a child's hobby-horse is shown and admired by himself and his playfellows, because it is pretty; and this has been done by thousands who have never paid the least regard to that wonderful order and regularity with which nature has disposed of these singular productions, and assigned to each class its peculiar stratum.* William Smith, notes written January 5, 1796
- The job of surveying canal routes required detailed knowledge of the rocks through which the canal was to be dug. This led Smith to examine the local rocks very carefully. While doing this, Smith observed that the fossils found in a section of sedimentary rock were always in a certain order from the bottom to the top of the section. This order of appearance could also be seen in other rock sections, even those on the other side of England. As Smith described it, *. . . each stratum contained organized fossils peculiar to itself, and might, in cases otherwise doubtful, be recognized and discriminated from others like it, but in a different part of the series, by examination of them.* This is a statement of the ***"principle of faunal succession."*** The layers of sedimentary rocks in any given location contain fossils in a definite sequence; the same sequence can be found in rocks elsewhere, and hence strata can be correlated between locations. The ***"principle of faunal correlation"*** is still used today.
- The map itself displayed in whole is an extraordinary sight. Its size alone - about 6 feet across by 9 feet high - is dramatic. The territory mapped in detail encompasses tens of thousands of square miles. It is well over 500 miles from Lands End to the Firth of Tay. Smith had begun his efforts to publish such a grand map about 1802.

http://www.unh.edu/esci/mapexplan.html

George Cuvier: *1769-1839 ; Geologic Map of Paris Basin*

http://www.ucmp.berkeley.edu/history/cuvier.html

- Cuvier along with Alexandre Brongniart (1770-1847), a French naturalist and geologist, mapped the Paris Basin. In reconstructing the changing sea levels of the Atlantic Ocean Brongnairt and Cuvier showed that fossils had been layed down during alternating fresh and salt water conditions thus establishing the fact that there existed a succession of fossils in different formations representing different environments. Cuvier notices that the more ancient a fossil the less it resembled present day organisms. In ordering fossils chronologically Cuvier, like Smith, was constructing a history of life on Earth using geologic strata. Thus began the science of biostratigraphy. Cuvier recognized mass extinctions, but believed they resulted from regional catastrophes.
- Without a doubt, Georges Cuvier possessed one of the finest minds in history. Almost single-handedly, he founded vertebrate paleontology as a scientific discipline and created the comparative method of organismal biology, an incredibly powerful tool. It was Cuvier who firmly established the fact of the extinction of past lifeforms. He contributed an immense amount of research in vertebrate and invertebrate zoology and paleontology, and also wrote and lectured on the history of science.
- Cuvier did not believe in organic evolution, for any change in an organism's anatomy would have rendered it unable to survive. He studied the mummified cats and ibises that Geoffroy had brought back from Napoleon's invasion of Egypt, and showed that they were no different from their living counterparts; Cuvier used this to support his claim that lifeforms did not evolve over time. Organisms were functional wholes; any change in one part would destroy the delicate balance. But the functional integration of organisms meant that each part of an organism, no matter how small, bore signs of the whole. Thus it was possible to reconstruct organisms from fragmentary remains, based on rational principles. Cuvier had a legendary ability to reconstruct organisms from fragmentary fossils, and many of his reconstructions turned out to be strikingly accurate. However, in practice, he based his reconstructions less on rational principles than on his deep knowledge of comparative anatomy of living organisms.
- What had happened to the great beasts of the past? Cuvier believed that the Earth was immensely old, and that for most of its history conditions had been more or less like those of the present. However, periodic "revolutions", or catastrophes (a word which Cuvier avoided because of its quasi-supernatural overtones) had befallen the Earth; each one wiped out a number of species. Cuvier regarded these "revolutions" as events with natural causes, and considered their causes and natures to be an important geological problem. Although he was a lifelong Protestant, Cuvier did not explicitly identify any of these "revolutions" with Biblical or historical events. However, some later geologists, notably Rev. William Buckland in England, suggested that the most recent revolution was the Biblical Flood. This remained a popular hypothesis until Louis Agassiz (who had studied with Cuvier) showed that the "flood deposits" were actually formed by glaciers.

http://www.csmate.colostate.edu/cltw/cohortpages/viney/fossilrecordhistoryoflife.html

Alcide Dessalines d' Orbigny: *1802-1857*

http://www.asa3.org/ASA/PSCF/1953/JASA3-53Erdman.html

- But it was left to Cuvier's successor, Alcide d'Orbigny, to go one step further by proposing that, after each catastrophe, a special act of creation of animal life took place, replenishing the earth with new creatures. *. . . twenty-seven times in succession, distinct creations have come to re-people the whole earth with its plants and animals after each of the geological disturbances which destroyed everything in living nature. Such is the fact, certain but incomprehensible, which we confine ourselves to stating, without endeavoring to solve the superhuman mystery which envelops it.*

CATASTROPHISM - *Past Cataclysmic Activity*

http://www.catastrophism.net/

- Catastrophism is the idea that many of Earth's crustal features (strata layers, erosion, polystrate fossils, etc) formed as a result of past cataclysmic activity. In other words, the Earth's surface has been scarred by catastrophic natural disasters.

PLUTONISM (a.k.a VULCANISM): *Earth as a heat engine, generating magma and mountain uplift*

http://www.geowords.com/h_/histbookpdf/a27.pdf

- Hutton's concept of the rock cycle required a source of internal Earth energy to drive it within and to be a mechanism of uplift. Hutton made field observations that persuaded him to classify some rocks (granite and basalt) as igneous. These, in his interpretation, had field associations which indicated intrusion and the introduction of heat and mineralizing fluids into sediments that, as a result, had become lithified, deformed (we would say, "to metamorphic rock" but plutonists did not distinguish that category of rocks and reasoned that only by being heated could unconsolidated sediments become stone), and raised. Hutton reasoned that Earth was in fact a giant heat engine. The great internal heat, which was obvious from volcanoes, powered these slow but vast changes. An insight, not so surprising Nigel Bunce and Jim Hunt suggest "considering that his close friends were [Joseph] Black who was a pioneer in research on heat and [James] Watt the steam engineer."

  Geologists who interpreted geological field evidence in favor of igneous activity as part of the Huttonian rock cycle became known as Plutonists or, what was the same, Vulcanists. Geologists who interpreted the same evidence as evidence of a Wernerian aqueous origin became known as Neptunists. The debate was real.
- Hutton was not alone in espousing these ideas, as seen in the quotes below.

- *All mountains, islands, and level lands have been raised up out of the bosom of the earth into the position they now occupy by the action of subterranean fires.* Lazzaro Moro (1687-1764), Venice (1740)
- *Go and see* —Nicolaus Desmarest who so refused to debate with Neptunists, he having provided in 1763 ample evidence (published in 1777) for the volcanic origin of ancient lava flows in the Auvergne.
- *Wherever the junction of the granite with the schists was visible, veins of the former. . . were to be seen running into the latter and pervading it in all directions, so as to put it beyond all doubt, that the granite in these veins, and consequently of the great body itself ... must have flowed in a soft or liquid state into its present position.* —James Hall, 1790

PLUTONIST-NEPTUNIST DEBATE

- During the late 1700's and first two decades of the 1800's the major debate about the Earth was between Werner's concept that all rocks precipitated from the oceans, and Hutton's concept that the Earth was a heat engine. The debate focused on the origin of basalt and granite (hence Plutonism), and much of Hutton's geologic explorations was the search for the defining piece of evidence that would prove their igneous origin. Hutton did find such evidence, but it was rejected by the Neptunists.

James Hutton: *1726-1797; Theory of the Earth*, 1785

- James Hutton must be regarded as the "father of modern geology". A medical graduate of Edinburgh University, Hutton inherited a comfortable income and took up farming. He spent a great deal of time examining interesting rock outcrops in Scotland and Northern England, and presented his ideas to the Royal Society of Edinburgh in 1785 in a paper entitled "Theory of The earth". The Royal Society of Edinburgh was at that time the most active scientific body in the world.

  Hutton recognized the importance of unconformities and pointed out that many igneous rocks clearly intruded surrounding rocks, and therefore were younger. Because Hutton and his followers held that igneous rocks came from molten material within the earth, they were called Plutonists. His friend, the mathematician John Playfair (1748-1819) publicized Hutton's theories and added further ideas.
- Stephen Baxter in his biography of James Hutton "Ages in Chaos" puts Hutton's beliefs in perspective, pointing out that in looking back we tend to see people through modern eyes, rather than as they really were. He begins Chapter 9, a summary of Hutton's ideas, thus, *"In the solitude of his farmhouse, Hutton brooded over the nature of God."*

  Hutton was a deist, not a theist, having given up those ideas under the influence of Maclaurin's lectures, but *"he seemed to be searching for a new certainty: 'Faith, faith of all things is what I want most,'* he wrote. *'I ha'nt a single grain to do me any good.'"*

  Hutton was struggling with these ideas at a time when the general belief was that the world was in decay from its idyllic past in the Garden of Eden; the Earth was a wreck and ruin, so they said, but Hutton could not see that. He believed the Earth had a purpose and *"Hutton decided at last a perfect world-machine could have no higher purpose than to sustain life."* But, if this is true then what sustains life. His reasoning goes like this: *"rocks decayed through erosion, the rubble was consolidated into new rocks, and then somehow uplifted to make new lands - erosion, deposition, consolidation, uplift. And cupped in the heart of this immense rocky machine, the priceless soil that sustained life was subtly created."*

  If this was true there had to be an uplifting force to counter the force of erosion, and this led Hutton and people like him to embrace the idea of Plutonism. These ideas were revolutionary at the time, and for the most part Hutton got it right.
- Hutton also seemed to return to ideas of "the great return" with his statement the Earth has "no vestige of a beginning no prospect of an end," saying that when looking at the rocks of the Earth he could not find any evidence of significant changes in the history. The oldest rocks seemed no different from rocks forming today.
- During Hutton's lifetime, and for a few decades after, the great geological debate was between Neptunism and Plutonism. Most of the attacks on Hutton's uniformitarianism ideas came from the Neptunists. Ironically, for all Hutton's striving to find evidence of God's hand in the world most of his critics used the charge of atheism to attack him and his ideas.
- It would be naive, however, to think that Hutton's ideas were well received. There was strong opposition during his lifetime, and it would take others to make his ideas popular. Particularly important is his biographer, John Playfair who wrote Illustrations of the Huttonian Theory of The Earth (1802). Playfair himself was a remarkable person: geologist, physicist, and mathematician. Talbot Rice (1954) says of him: *"The wide learning, the calm intellect and the clear thought, so apparent in all his writings, also marked his lectures. He was, according to one of his many illustrious pupils, 'a charming teacher, so simple, unaffected and sincere in manner, so chaste in style, so clear in demonstration'. By consolidating the learning of past generations and collating the discoveries and theories of his own time, he gave a comprehensive and unified presentation of the subjects he professed and thus laid the basis for future constructive researches in the fields of mathematics and natural philosophy."*

Richard Kirwan: *1733-1812; Examination of the Supposed Igneous Origin of Stony Substances*

- A Neptunist and vigorous opponent of James Hutton's theory of the Earth. In the last decade of the 18th century and first two decades of the 19th he published books and papers strongly criticizing Hutton's ideas.
- Kirwin was born into a Catholic family and at a young age developed a fascination with theology. At age twenty-one he entered a Jesuit novitiate, but was forced to give that up by the death of a brother, return to Scotland where he was forced to adopt the Protestant faith. Later he became a lawyer, but soon gave that up to become a chemist. From that he developed an interest in mineralogy which led him into geology. Academically powerful, he was motivated by a deep and rare religious conviction, and a righteousness fuelled by the experiences of his life.
  - Cited chemical evidence to prove that granite and other rocks could not have been created by heat.
  - Denied that all soils originated from erosion, arguing that not all soils get washed into the sea.
  - Said that the base rock of the world was granite laid down in the sequence of creation – just as Werner insisted.
  - Attacked Hutton on the mysterious nature of Earth's inner heat, which he called a gratuitous assumption.
  - Attacked Hutton's "no vestige of a beginning, no prospect of an end" philosophy. An infinite regression of cycling time led to paradoxes which Kirwan could not accept for philosophical and religious reasons. He accused Hutton of trying to revive pagan, anti-Christian ideas of the eternal return.

Roderick Murchinson: *1792-1861*

- The most politically powerful geologist of the 19th century. Developed the modern classification of the Paleozoic, which previously consisted only of the Greywacke and Coal Measures (Carboniferous). He first defined the Silurian system to distinguish his Welsh rocks from Sedgwick's older, Cambrian "territory"; he along with Sedgewick then defined the Devonian to resolve a stratigraphic dispute with Henry de la Beche, and finally defined the Permian as an intermediate between the Carboniferous and Triassic. His emphasis on biostratigraphy eventually brought him into a lifelong dispute with Sedgwick over the placement of the Cambrian-Silurian boundary (the two are now separated by the Ordovician), but also modernized geological thinking about time scales.
- Among the best known geologists of his time, Roderick Impey Murchison had no aversion to fame, wealth, priority or mixing with European nobility. He also had a well-earned reputation for browbeating his colleagues.

http://www.strangescience.net/murch.htm

Adam Sedgewick: *1785-1873*

http://www.ucmp.berkeley.edu/history/sedgwick.html

- Sedgwick was one of several great figures in what has been called the Heroic Age of geology -- the time when the great geological time periods were defined, and when much exploration and fundamental research was carried out. Sedgwick's work placed him at the epicenter of one of the most heated geological controversies of his day, stemming from his work with the gentleman geologist Roderick Impey Murchison. They explored the geology of Scotland in 1827, and in 1839 they jointly presented their researches on certain rocks in Devonshire, England, which had a distinctive fossil assemblage that led them to propose a new division of the geological time scale -- the Devonian.
- Sedgwick, who had been working in central Wales, proposed the existence of a separate system below the Silurian, which he named the Cambrian -- after Cambria, the Latin name for Wales. He and Murchinson presented a joint paper in 1835, entitled "On the Silurian and Cambrian Systems, exhibiting the order in which the older sedimentary strata succeed each other in England and Wales."
- In 1817 he took holy orders, and in 1818 he became Woodwardian Professor of Geology at Cambridge, holding a chair that had been endowed ninety years before by the natural historian John Woodward. He lacked formal training in geology, but he quickly became an active researcher in geology and paleontology. During his tenure, he immensely enlarged the geological collections of Cambridge University, and carried out important field research all over Britain. Sedgwick is said to have remarked, upon being appointed Woodwardian Professor, *"Hitherto I have never turned a stone; henceforth I will leave no stone unturned."*
- For one summer of his work in Wales which was to lead to this controversy, Sedgwick made a fateful choice of field assistant: a young Cambridge graduate named Charles Darwin. Darwin had passed his examinations for the Bachelor of Arts degree in January 1831, and began attending Sedgwick's geology lectures, which he found fascinating. That summer, the two men explored the rocks of north Wales; Darwin got a "crash course" in field geology from Sedgwick, an experience that would stand him in good stead over the next five years, on the round-the-world voyage of H.M.S. Beagle. During this voyage, Darwin sent rocks and fossils from South America back to Sedgwick, as well as descriptions of the geology of South America. These impressed Sedgwick, who wrote in a letter to Darwin's family:

  He is doing admirably in S. America & has already sent home a Collection above all praise. -- It was the best thing in the world for him that he went out on the Voyage of Discovery. . .

  In November 1835, before Darwin had returned to England, Sedgwick read some of Darwin's work on South American geology to the Geological Society of London. This greatly improved Darwin's reputation as a scientist; he was inducted into the Society shortly after his return. The two stayed friends until Sedgwick's death, but Sedgwick was upset and disappointed by Darwin's theory of evolution by natural selection. After reading The Origin of Species, Sedgwick candidly wrote to Darwin on November 24, 1859:

  If I did not think you a good tempered & truth loving man I should not tell you that. . . I have read your book with more pain than pleasure. Parts of it I admired greatly; parts I laughed at till my sides were almost sore; other parts I

read with absolute sorrow; because I think them utterly false & grievously mischievous-- You have deserted-- after a start in that tram-road of all solid physical truth-- the true method of induction. . .

- Sedgwick's own geological views were generally catastrophic -- he believed that the history of the Earth had been marked by a series of cataclysmic events which had destroyed much of the Earth's life. In this belief he followed Cuvier, and he was opposed to Charles Lyell's models of slow, gradual geological change and a more or less steady-state Earth.
- Sedgwick believed in the Divine creation of life over long periods of time, by "a power I cannot imitate or comprehend -- but in which I believe, by a legitimate conclusion of sound reason drawn from the laws of harmonies of nature." What Sedgwick objected to was the apparent amoral and materialist nature of Darwin's proposed mechanism, natural selection, which he thought degrading to humanity's spiritual aspirations. His letter of November 24 went on to state:

  This view of nature you have stated admirably; tho' admitted by all naturalists & denied by no one of common sense. We all admit development as a fact of history; but how came it about? Here, in language, & still more in logic, we are point blank at issue-- There is a moral or metaphysical part of nature as well as a physical. A man who denies this is deep in the mire of folly. Tis the crown & glory of organic science that it does thro' final cause, link material to moral. . . You have ignored this link; &, if I do not mistake your meaning, you have done your best in one or two pregnant cases to break it. Were it possible (which thank God it is not) to break it, humanity in my mind, would suffer a damage that might brutalize it--& sink the human race into a lower grade of degradation than any into which it has fallen since its written records tell us of its history.

William Whewell: *(1794-1866)*

http://plato.stanford.edu/entries/whewell/

- One of the most important and influential figures in nineteenth-century Britain. Whewell, a polymath, wrote extensively on numerous subjects, including mechanics, mineralogy, geology, astronomy, political economy, theology, educational reform, international law, and architecture, as well as the works that remain the most well-known today in philosophy of science, history of science, and moral philosophy. He was one of the founding members and an early president of the British Association for the Advancement of Science, a fellow of the Royal Society, president of the Geological Society, and longtime Master of Trinity College, Cambridge. In his own time his influence was acknowledged by the major scientists of the day, such as John Herschel, Charles Darwin, Charles Lyell and Michael Faraday, who frequently turned to Whewell for philosophical and scientific advice, and, interestingly, for terminological assistance. Whewell invented the terms “anode,” “cathode,” and “ion” for Faraday. Upon the request of the poet Coleridge in 1833 Whewell invented the English word “scientist;” before this time the only terms in use were “natural philosopher” and “man of science.”
- He was the most renowned of the writers of the Bridgewater Treatises in the 1830s, a Royal Society-organized collection of essays connecting religion/mysticism and science -- what was then known as "natural theology". Loosely, Whewell's basic argument was that knowledge of the world is acquired because there are "fundamental" and uniform laws of science which we are able to discover. Whewell took this as evidence of the existence of a divinity to provide such uniformity. These underlying scientific laws of the world are precisely the "Ideas" that God used in his creation of it. Taking it a step further, Whewell went on to argue that science, by "discovering" these laws, was itself a providential task as it brought men closer to understanding the majesty of God's design. http://cepa.newschool.edu/het/profiles/whewell.htm
- Whewell also famously opposed the idea of evolution. First he published a new book, “Indications of the Creator”, 1845, composed of extracts from his earlier works to counteract the popular anonymous evolutionary work “Vestiges of the Natural History of Creation.” Later Whewell oppossed Darwin's theories of evolution.

http://www.victorianweb.org/science/whewell.html

Charles Lyell: *1797-1875; Principles of* Geology, 1830; Uniformitarianism

http://www.mnsu.edu/emuseum/information/biography/klmno/lyell_charles.html

- Lyell originally started his career as a lawyer, but later turned to geology. Geology soon became his forte and as member of the Geological Society, he took part in the lively debates in the 1820s about how to reconcile the biblical account of the Flood with geological findings. Lyell, as well as Roderick Murchison and George Poulett Scrope became an outspoken opponent of the diluvial (Neptunist) position. http://www.victorianweb.org/science/lyell.html
- His zoological skills aided in his extensive studies and observations throughout the world. He became an author of *The Geological Evidence of the Antiquity of Man* in 1863 and *Principles of Geology* (12 editions). Lyell argued in this book that, at the time, presently observable geological processes were adequate to explain geological history. He thought the action of the rain, sea, volcanoes and earthquakes explained the geological history of more ancient times.

  Lyell rebelled against the prevailing theories of geology of the time. He thought the theories were biased, based on the interpretation of Genesis. He thought it would be more practical to exclude sudden geological catastrophes to vouch for fossil remains of extinct species and believed it was necessary to create a vast time scale for Earth's history. This concept was called Uniformitarianism. The second edition of Principles of Geology introduced new ideas regarding metamorphic rocks. It described rock changes due to high temperature in sedimentary rocks adjacent to igneous rocks. His third volume dealt with paleontology and stratigraphy. Lyell stressed that the antiquity of human species was far beyond the accepted theories of that time.
- The principle of Uniformitarianism was a direct confrontation with Catastrophist models, but became in time the prevailing view of how the Earth works. This assumed first of all the constancy of natural laws (except as regarded the origin of

new species which was left rather vague). The kinds of causes which affected the earth in the past must be assumed to have been exactly those we see in operation today (such as erosion, sediment deposition, volcanic action, earthquakes

- What was really peculiar to Lyell are two ideas rarely associated with his Principles of Geology: the older ideas that earth and water trade substances and shape each other, maintaining some kind of long-range balance (the steady-state Earth), and that time and life proceed in cycles. It was conceivable to Lyell that man and our familiar animals could all become extinct, only to be replaced by dinosaurs again in a subsequent creation, followed, in some distant age, by a "new creation" of man. Aside from historians of science, Lyell's belief in cyclic time has been all but forgotten.

http://stephenjaygould.org/people/charles_lyell.html

CATASTROPHIST AND UNIFORMITARIANIST DEBATE:

- During the 19th century the great debate about the Earth was between these two great schools of thinking. And, it was primarily in Great Britain (especially Scotland) that some of the most seminal thinking was done. The idea of catastrophism is the older, and you notice that the term shows up commonly in the descriptions above. It posits a more violent past, declining to a more peaceful present Noah's flood was thought to be the last great catastrophe.

  The idea of uniformitarianism began with James Hutton, was extended by Charles Lyell, and in large measure has been the driving philosophy of geology ever since. It represented a dramatic break from past thinking, and away from theistic (Church endorsed) concepts of the Earth.
- Geology today has incorporated neo-catastrophist concepts into its language (asteroid impacts, category five hurricanes, and giant tsunamis are pretty dramatic catastrophes), and we will develop a formal language to talk about this.
- The confusion comes with arguments of modern creationism—a distinctly religious perspective of the Earth harkening back to older theistic catastrophist thinking. Because creationism uses catastrophic events—e.g. Noah's flood—in its model of the Earth, geology for a while entrenched itself in uniformitarian thinking as a reaction (for a geologist to speak of a catastrophic geologic event was taken by creationists as support for their theory, even though it was not meant that way.)
- The table below contrasts the main positions of the 18th century schools of catastrophist and uniformitarianism.

Catastrophism	**Uniformitarianism**
1. Theistic - proponents sought evidence of God's hand at work in the rocks of the Earth - including evidence of Biblical events such as Noah's flood.	1. Deistic (*The proof of the wisdom of God was that he created an entirely self-sufficient natural world.)- The infant geology was to be reared on hard one facts rather than seduced with speculation.* Unless theories could be tied to rocks as experienced they were just speculations
2. Earth began as a perfect place (Garden of Eden) and has declined to it present state of wrack and ruin.	2. Hutton's concept of the uniformitarian, cyclical nature of Earth processes, driven by a source of internal Earth energy.
3. Earth is young. Generally accepted Ussher's 4004 BC age of the Earth, although this position changed with time.	3. Earth is old. Recognized that if processes were like those today then it would require much longer periods of time for observed events to occur.
4. Events in the past were more dramatic — catastrophic — than today since the Earth is winding down.	4. Quality and intensity of geologic agents have never varied - present processes are adequate to understand the past.
5. New species were supernaturally created.	5. Initially uniformitarian thinking was ill-defined on the origin of species - until Charles Darwin published The "Origin of Species."
6. Earth has a history - it is evolutionary.	6. Anti-evolutionary: The Earth has *"no vestige of a beginning, no prospect of an end."* This changed when Darwin's ideas were published.

Charles Darwin: *1809-1882; On the Origin of Species by Means of Natural Selection, 1859*

- Today best known for his evolutionary theory, Darwin in his life time was well respected for his geological work. He had worked with Adam Sedgewick as a young man, and took Charles Lyell's Principles of Geology with him on his voyage on the research ship Beagle. On his return Darwin had seen and experienced more geology than virtually any other geologist in Great Britain, cementing his stature as a geologist.
- Darwin was a reserved individual who avoided controversy. Yet, it was his work on evolution that fractured the community of geologists working in his time. Darwin was most aligned with the uniformitarian thought of Charles Lyell, but Lyell could not accept Darwin's evolution. Likewise, Adam Sedgewich, who had been Darwin's early mentor in geology also recoiled from his ideas. From is publication, the Origin split the scientific world into those who advocated "argument

from design" for the origin and evolution of life - leading to modern day Creationism, and the line of thought that leads to modern geologic thought.

William Thomson (Lord Kelvin): *1824-1907*

- Thomson was a brilliant and creative mathematician and physicists who made many contributions, including major ones in the area of thermodynamics (the Kelvin temperature scale was devised by him.) Thomson published more than 600 papers. He was elected to the Royal Society in 1851, received its Royal Medal in 1856, received its Copley Medal in 1883 and served as its president from 1890 to 1895. In addition to his activities with the Royal Society, as one would expect of such an eminent Scottish professor, he served the Royal Society of Edinburgh over many years. He served three terms as president of this Society, first from 1873 to 1878, for the second time from 1886 to 1890, and for the third time from 1895 until his death in 1907. Thomson served as president of yet a third society when he was elected as president of the British Association for the Advancement of Science in 1871.
- One of the strongest opponents to Darwin and the Uniformitarian theory of the earth were the physicists, led by Lord Kelvin, who maintained that the earth could not be more than 100 million years old. They made the assumption that the earth began as a molten mass and was in process of cooling. The discovery of radioactivity in minerals about 1896 showed that the earth was cooling down at a much slower rate than Kelvin had estimated and thus his figure for the age of the earth was too low. Since then techniques based on the breakdown of radioactive isotopes of uranium, strontium, potassium, carbon and other elements have made it possible to measure the age of the earth and the extent of each geological period.
- The author of the biography of Thomson, puts forward the view that during the first half of Thomson's career he seemed incapable of being wrong while during the second half of his career he seemed incapable of being right. This seems too extreme a view, but Thomson's refusal to accept atoms, his opposition to Darwin's theories, his incorrect speculations as to the age of the Earth and the Sun, and his opposition to Rutherford's ideas of radioactivity, certainly put him on the losing side of many arguments later in his career. http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Thomson.html