

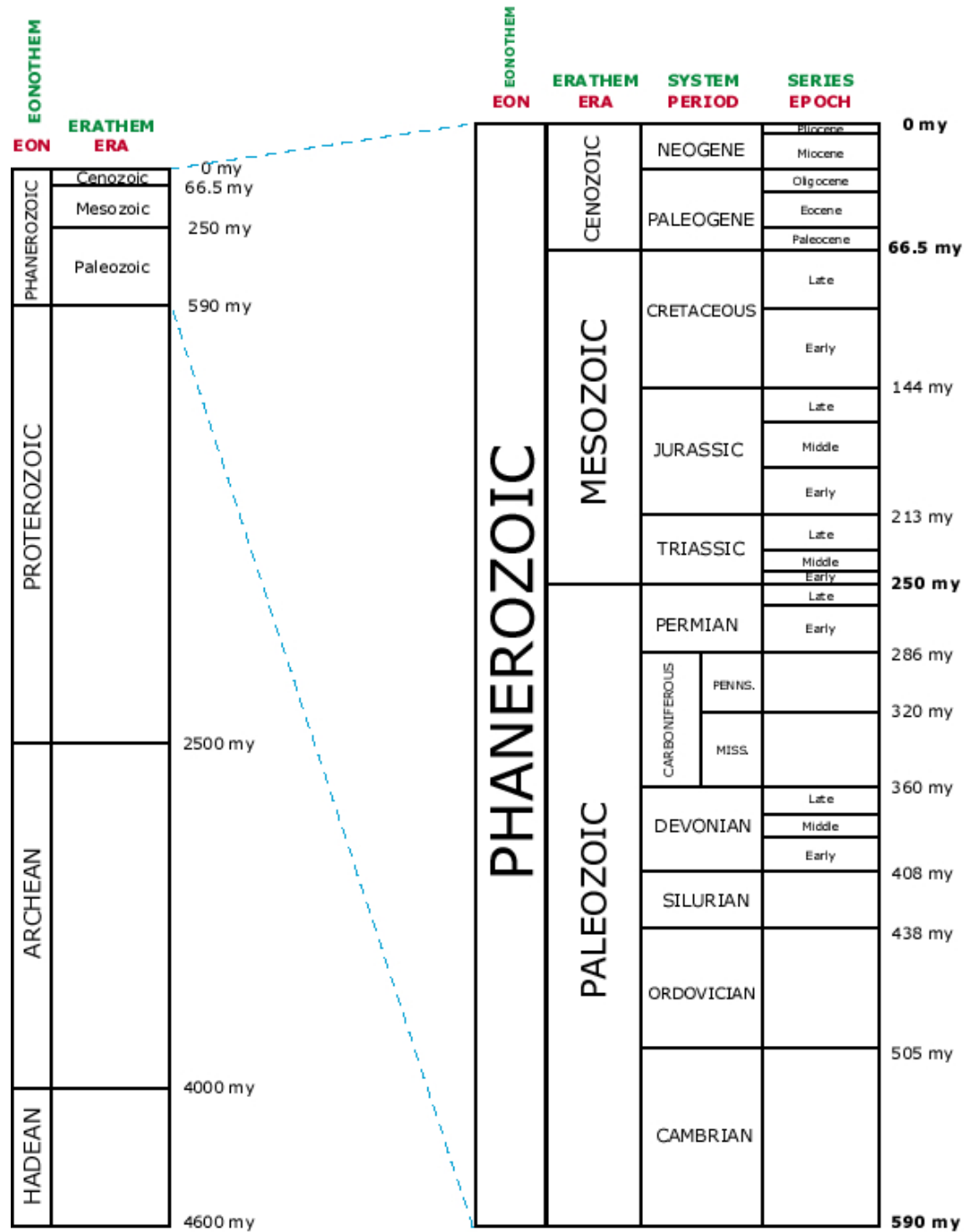


# GEOLOGIC TIME

Alessandro Grippo, Ph.D

# Introduction & Review

- Immensity of Geologic Time & Implications
- Geological Time
  - Relative Dating
  - Numerical Dating
- Geologic Time Scale
  - A relative Time Scale based on rock sequences and fossil successions, with radiometric dates expressed as years before the present



# Stratigraphy

- Study of **rock successions**
  - sequences of rocks with (relative ) time significance
  - sedimentary rocks and a few igneous rocks
- **Correlation** (of)
  - to correlate means to be able to establish equivalency in time
- Geological **events and processes** in time and space
  - anything recorded in rocks is an “event”
  - events can follow each other in time (a relative sequence)
  - events can occur simultaneously at different locations (hence, they can be correlated)

# Stratigraphy:

## Rock Successions, Correlation, Geological Events



Mississippian (Lower Carboniferous) sequence from Arrow Canyon, Nevada

CSULA Stratigraphy field trip, 2015 © Alessandro Grippo

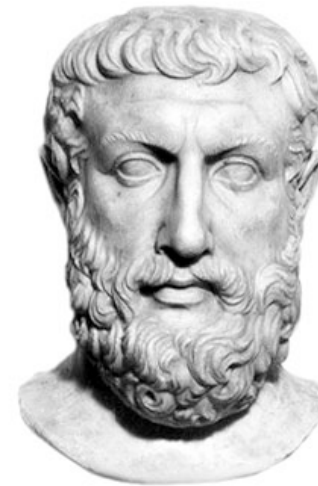
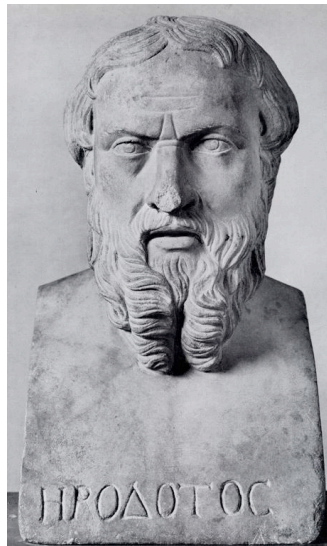
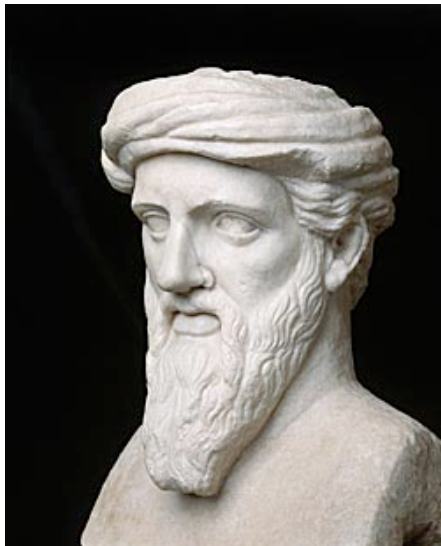
# Early Concepts

## of Stratigraphy, Geologic Time, and Earth's Age

- Perception of natural world was different in different parts of the world
  - Far East: Earth eternal and immutable
  - India: Earth changes in infinite cycles of creation
  - Greece: more realistically, Earth changed because of natural laws (no Gods necessary)
    - Fossils recognized (not always, not by everybody) as remnants of ancient forms of life

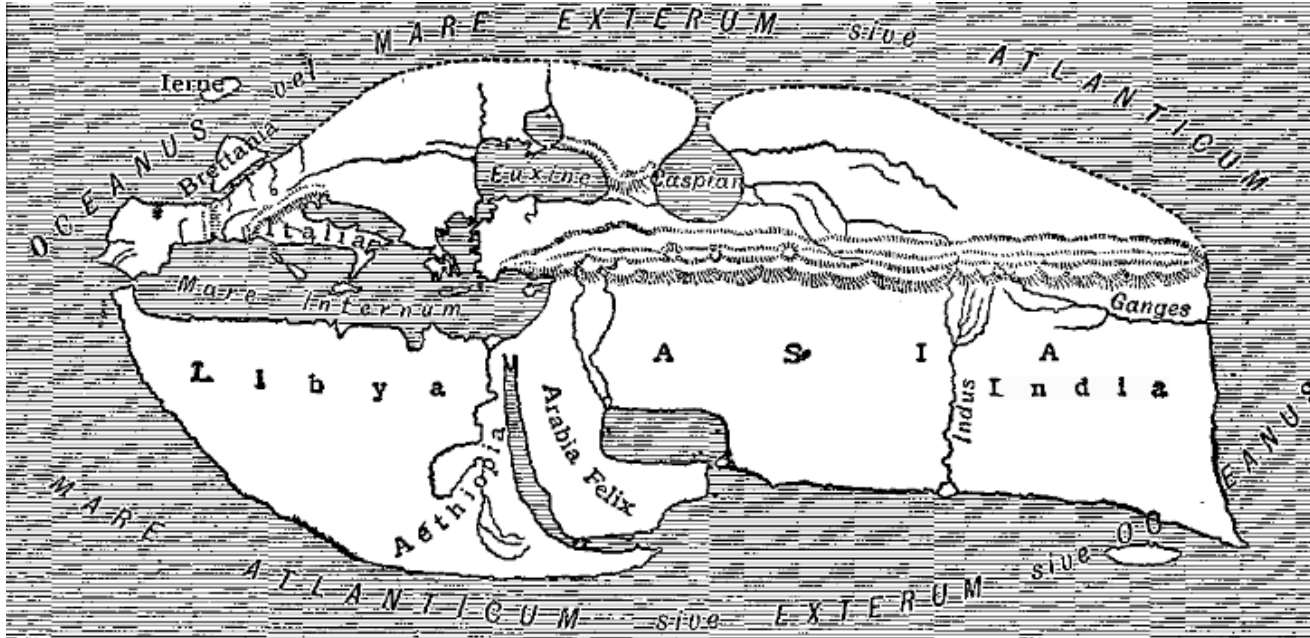
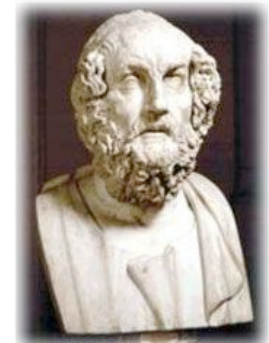
# Greeks

- Pythagoras, Herodotus (6<sup>th</sup> / 5<sup>th</sup> century BC)
  - shells on mountaintops were marine in origin
  - then ocean must at some time have covered mountains
  - still, fossils of Nummulites in Pyramids limestone were from lentils?
- Xenophanes (5<sup>th</sup> century BC)
  - shells on mountaintops prove that change is possible, and land and ocean can “blend” together



# Greeks and Romans

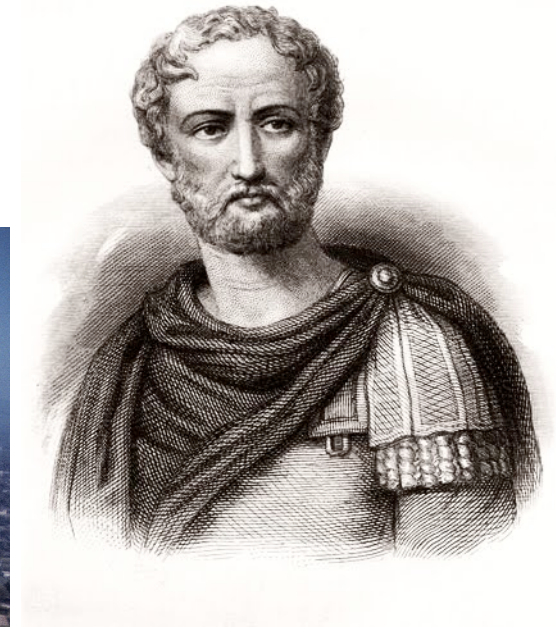
- Aristotle (4<sup>th</sup> century BC)
  - fossils produced by “formative force” imitating extant organisms
- Strabo (64 BC – 24 AD)
  - fossils on land: sea level rises and falls, subsidence, uplifting
  - “derive explanations from obvious and daily occurrence”
  - made excellent geographic maps for the time





# Romans (1)

- Pliny the Elder (23 AD – 79 AD)
  - Historia Naturalis (first ever encyclopedia on nature)
  - changes on Earth because of natural causes
  - died while witnessing volcanic eruption at Pompeii



The ruins of Pompeii with  
Mount Vesuvius in the  
background, Naples, Italy

(© from news.nationalgeographic.com)

# Romans (2)

- Tertullian (155 AD – 240 AD)
  - Advent of Christianity
  - Tried to fit natural laws into religion
- Edict of Constantin (AD 315)
  - Christian religion becomes official
  - Freedoms restricted
- Hypatia (370 AD – 415 AD)
  - Science and philosophy were blasphemy
  - Hypatia accused of magic, killed, dismembered, burned by Christians
- Fall of Roman Empire (AD 476)



# Dark Ages

- Western world in ruins
- Many science and philosophy books erased to print prayers and religious tales
- Arab invasion of Middle East, northern Africa, Spain, Sicily
- Arabs discovered western science but kept similar attitudes towards science, except for a few philosophers, such as Avicenna
- Avicenna (*Ibn-Sina*, 980-1037)
  - translated Greek and Roman works
  - fossils as organic materials
  - possibly failed attempts to life



# Early Renaissance

- Albertus Magnus (Swabia, Germany, 1200 - 1280)
  - fossils as remains of living organisms
  
- Leonardo Da Vinci (Tuscany, Italy, 1452-1519)
  - erosion, transportation deposition
  - action of rivers
  - superposition, correlation, sedimentary sequences
  - so famous for his works of art and engineering that his geologic notes were overlooked

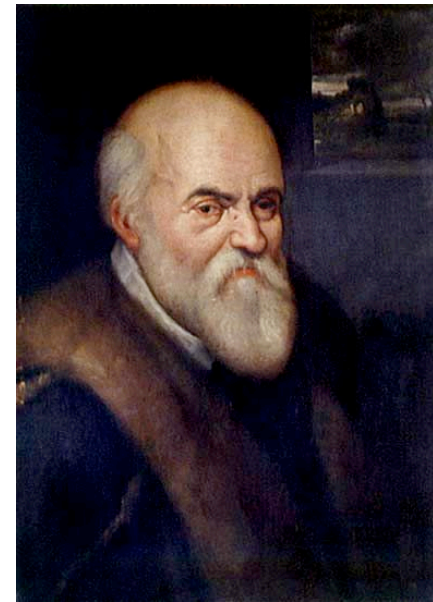


# Renaissance

- Georgius Agricola (*George Bauer*, Saxony, Germany, 1556)
  - *De Re Metallica*
  - Ore deposits and mining industry
  - Understood Superposition



- Ulisse Aldrovandi (Bologna, Italy, 1522-1605)
  - defined by Linnaeus as “the father of Natural History”
  - first to use the word “geology” in its proper scientific meaning



# Religious opposition to Science

- James Ussher (Ireland, 1581-1656)
  - established “age of Earth” based on Bible genealogy
  - said Earth was “created” by God on 10/23/4004 BC
  - This date was officially accepted by the church
  - It was considered heresy to dispute it
  - All creatures were individually created by God



# Steno and Stratigraphy

- By the early 1600s, stratigraphy started to be at the core of every serious geologic study
- Nicolaus Stenonis, or **Steno** (born in Denmark, lived in Florence, Italy, 1638-1686)
  - was also a Bishop, like Ussher
- Was the first to clarify the three basic principles of stratigraphy:
  - Superposition
  - Lateral Continuity
  - Original Horizontality



NICOLAI STENONIS  
DE SOLIDO  
INTRA SOLIDVM NATVRALITER CONTENTO  
DISSERTATIONIS PRODRVMVS.

A D

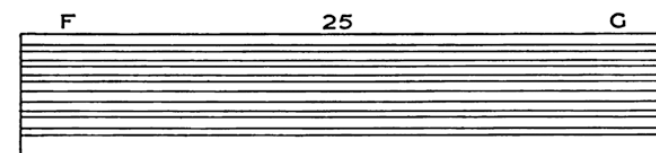
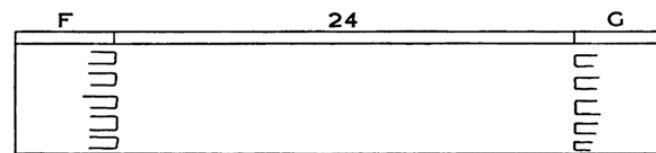
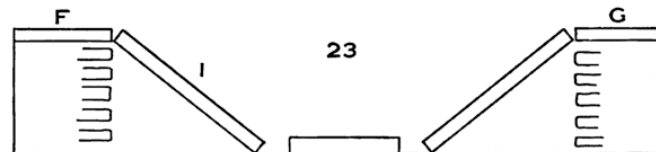
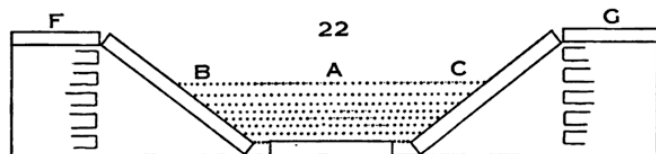
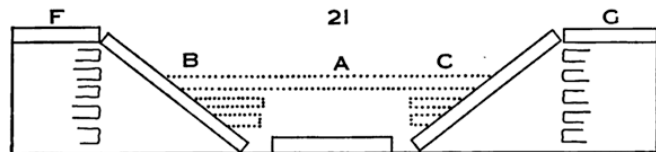
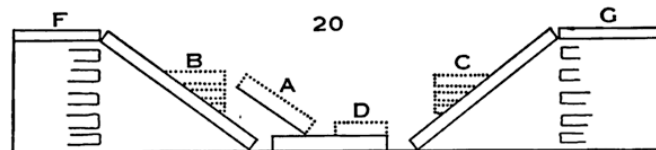
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FERDINANDVM II.  
MAGNVM ETRVRIÆ DVCEM.



FLORENTIÆ

Ex Typographia sub signo STELLÆ MDCLXIX.  
SVPERIORVM PERMISSV.





# Georges-Louis Leclerc, Comte de Buffon

- Buffon (France, 1707-1788)
  - First ever to compare humans and apes
  - Hypothesized common ancestry
  - Convinced of organic change
  - Said Earth could not be only 6000 years old
  
  - Fascinated by diversity of life
  - Pursued causes and explanations beyond dogma
  - Paved the way for subsequent revolutionary thinkers



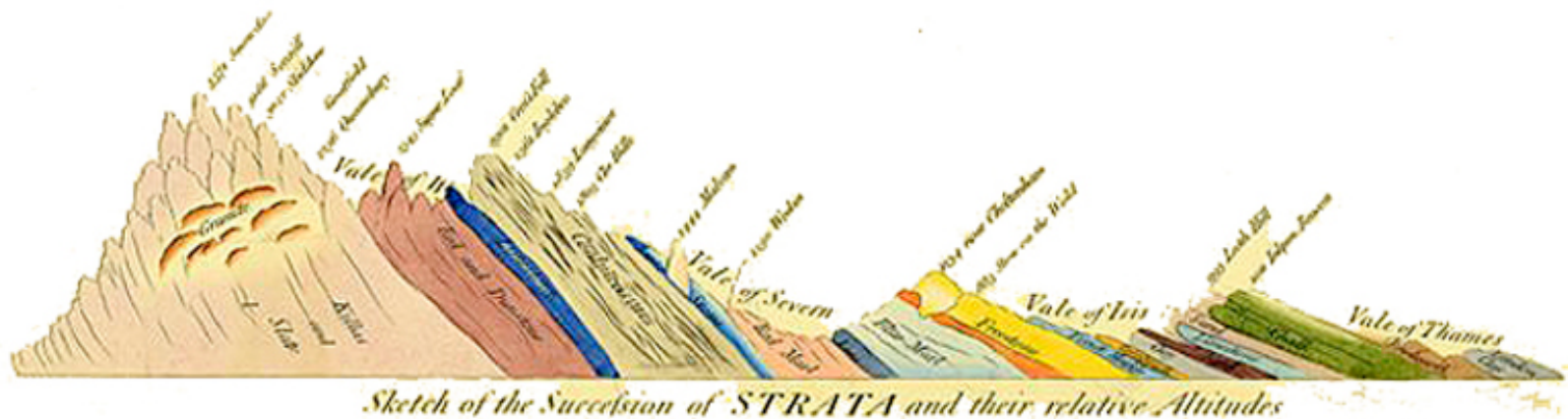
# Uniformitarianism

- James Hutton (Scotland, 1726-1796)
  - Uniformitarianism
    - *“The present is the key to the past”*
  - “Deep Time”
  - Unconformities
  
  - Cycles of erosion, transportation, deposition, burial, uplifting
  
  - *“No vestige of beginning no prospect of an end”*
  
  - His ideas contradicted religious beliefs



# Principle of Floral and Faunal Succession (Principle of Fossil Succession)

- William Smith (England, 1769-1839)
  - Industrial revolution (starting in 1760s) prompted search for sources of energy
  - Canals were cut to bring Coal to coastal harbor cities
  - Smith was an engineer who cut canals
  - He learned his rocks, the sequence, their fossil contents



William Smith's "Sketch of the Succession of STRATA and their Relative Altitudes"

# William Smith

- Fossils found in a sequence always follow each other in a specific order
- The order was the same even when rocks were found as isolated layers at different locations
- It was then possible to *correlate* these layers with each other based on fossil content (and not the kind of rock)
- This is the **Principle of Faunal and Floral Succession**:
  - fossil faunas and floras follow each other in a sedimentary sequence according to a known and predictable order

- Smith's discoveries allowed him to publish the first large-scale Geologic Map ever conceived

William Smith's "Strata of England and Wales" geologic map, preserved at the headquarters of the Geological Society of London, England



# Catastrophism, Gradualism, Uniformitarianism

- George Cuvier (France, 1769-1832)
  - pioneer of Catastrophism, as opposed to Uniformitarianism
  - he was the first to recognize *extinctions*, but said they happened because of natural catastrophes
  
- Charles Lyell (England, 1797-1875)
  - Principles of Geology (1830), publicized Hutton's' work
  - “Gradualism”, his own, extreme version of Uniformitarianism



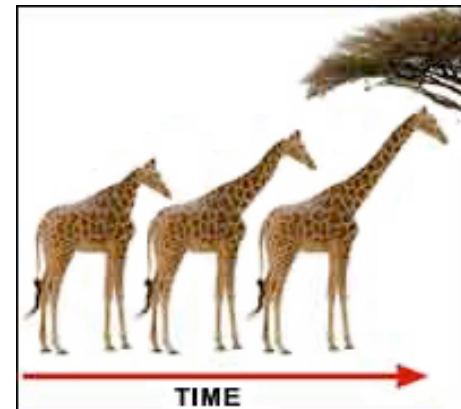
# Life is not spontaneous

- Lazzaro Spallanzani (Reggio Emilia, Italy, 1729-1799)
- worked with Laura Bassi (Bologna, Italy, 1711-1788)
  - first female University professor in Europe
- Spallanzani:
  - experimented with life
  - demonstrated that life cannot arise by spontaneous generation but only through reproduction
    - that is, life cannot be “created” by spirits or Gods



# Evolution (1)

- Jean-Baptiste Lamarck (France, 1744-1829)
  - life arose from spontaneous generation, at different times through Earth history
  - life forms were not fixed: evolution of life through natural processes
    - change through use and disuse
    - inherent change because nature goes from simple to complex
  - British naturalists, still lagging behind, refused his “blind primal force” ideas: life was a reflection of God’s benevolent design



Simple forms

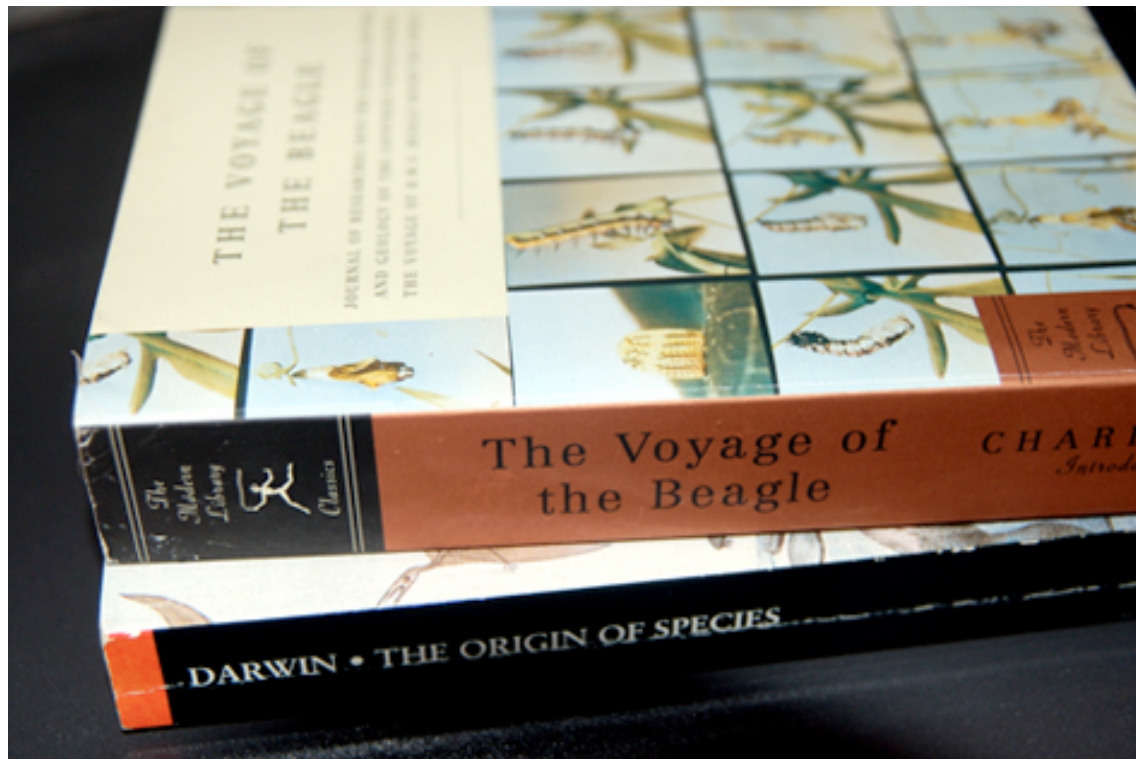


Complex forms



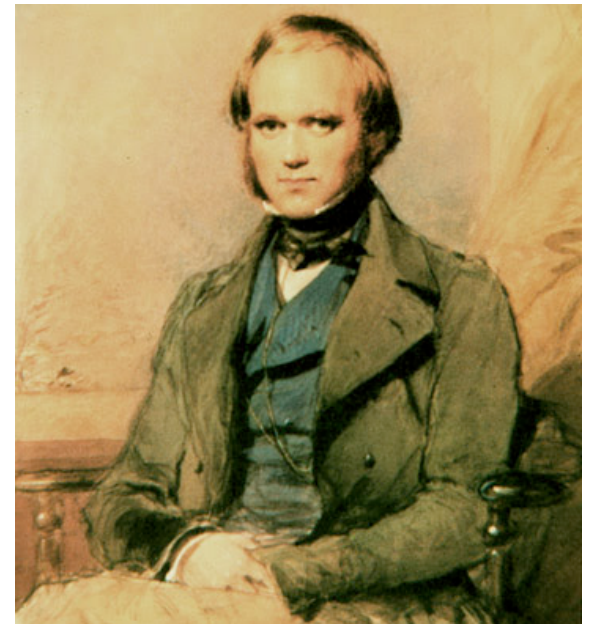
# Evolution (2)

- Charles Darwin (England, 1809-1882)
  - trip aboard HMRS The Beagle in the 1830s, with Lyell's Principles of Geology
  - observed Principle of Uniformitarianism in his trip
  - developed Theory of Evolution by Gradual Variation and Natural Selection
  - published *On the Origin of Species by Means of Natural Selection*



# Evolution (3)

- Darwin's theory also explained Smith's Principle of Fossil Succession
- When both are applied to Steno's Superposition, we realize that we can use fossils for dating and correlation
- Darwin's problem with the Precambrian
  - Evolution worked in the Phanerozoic; Precambrian record was absent
  - Nobody knew we had to look for soft-bodied fossils of bacteria and primitive organisms
  - Even if we had known, we did not have the technology to look for them



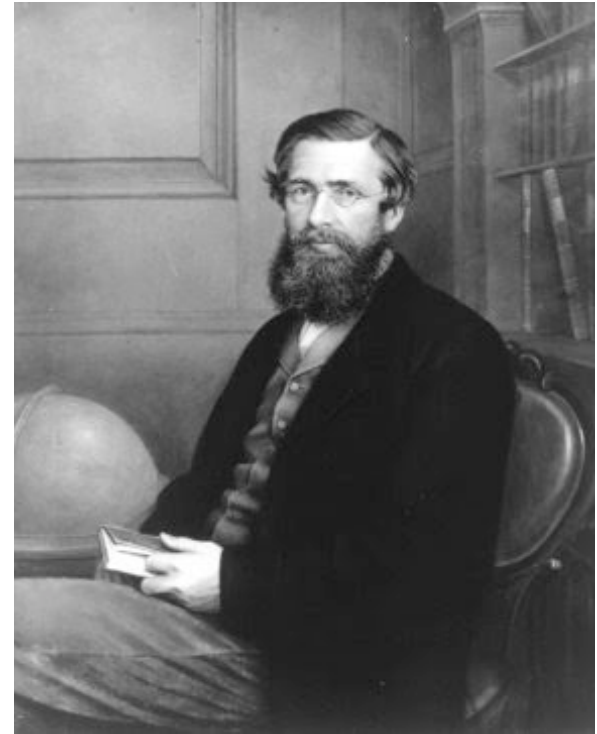
# Evolution (4)

- Lamarck and Darwin looked at the same evidence but their ideas were different:
  - Darwin did not accept the arrow of increasing complexity driving life history
  - Darwin said that change occurred only because of adaptation of life to changing environments from generation to generation
  - in the end, even Darwin did not know about genetic inheritance

Lamarck	Darwin
◆ Use and disuse	◆ Variation
◆ Transmission of acquired characteristics	◆ Inheritance
◆ Increasing complexity	◆ Differential survival
◆ No extinction	◆ Extinction

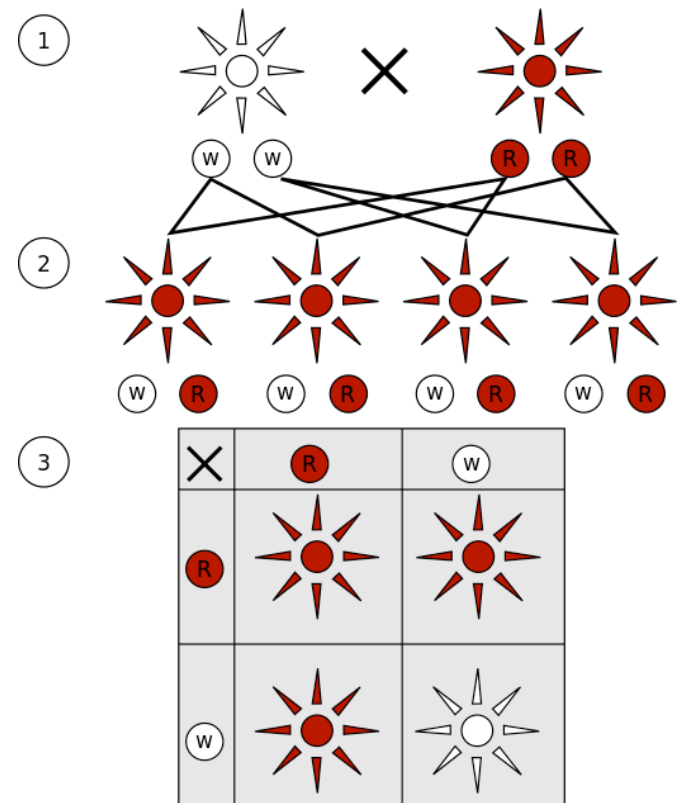
# Evolution (5)

- Alfred Russel Wallace  
(England, 1823-1913)
  - Friend and correspondent of Darwin
  - Came up with theory of Evolution by Natural Selection independently from Darwin
    - Darwin thought evolution arose from competition between individuals of the same species to feed and reproduce
    - Wallace thought evolution arose from environmental pressure on species



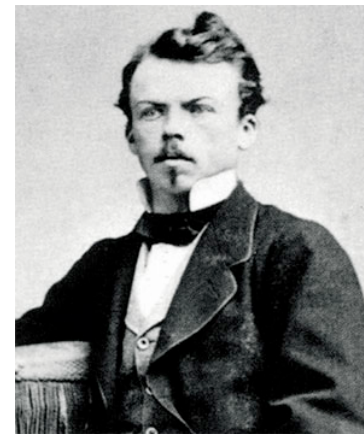
# Evolution (6)

- Gregor Mendel (Moravia, Czech Republic, 1822-1884)
  - *Experiments on Plant Hybridization* (1865)
  - Laws of inheritance
  - His ideas rediscovered in 1900



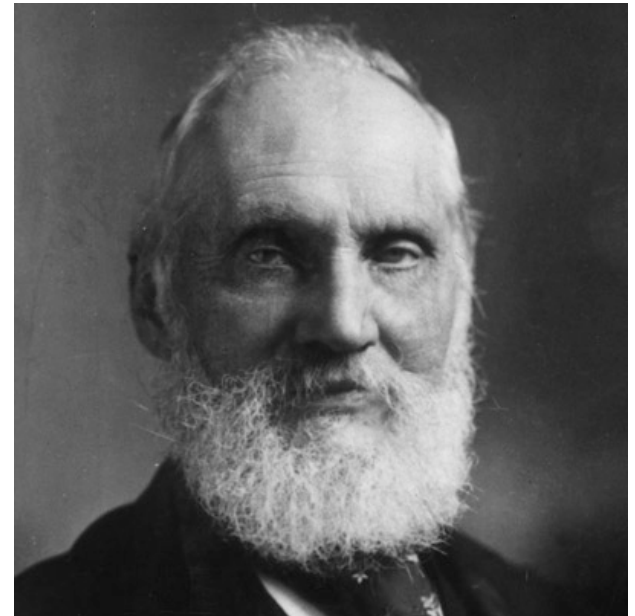
# Evolution + Fossils = Range Zones (Biostratigraphy)

- Alcide d'Orbigny (France, 1802-1857)
  - developed Smith's principles into the concept of Fossil Assemblages (associations of two or more fossils)
- Albert Opper (Germany, 1831-1865)
  - Opper tried to use d'Orbigny ideas in Germany
  - Fossils were not matching (nobody knew about lateral facies change)
  - established Overlapping Range Zones
    - The range of a taxon is the total vertical interval through which that taxon occurs in the rock record
  - developing Biostratigraphic Zones led to a refined Geologic Time Scale, with the subdivisions we know today



# A crisis in Geology

- Lord Kelvin (Ulster, 1824-1907)
  - as a physicist, he estimated the Age of Earth based on the thermal gradient as measured in mines
  - he came up with an estimate of a maximum age of 400 million years of age for Earth
  - he claimed to have destroyed Uniformitarianism
  - as a theorist, and not a field geologist, he had good math but did not realize that Earth's core maintained a constant temperature through time
  - he messed up with geologists' ideas
  - the discovery of radioactivity destroyed Kelvin's arguments



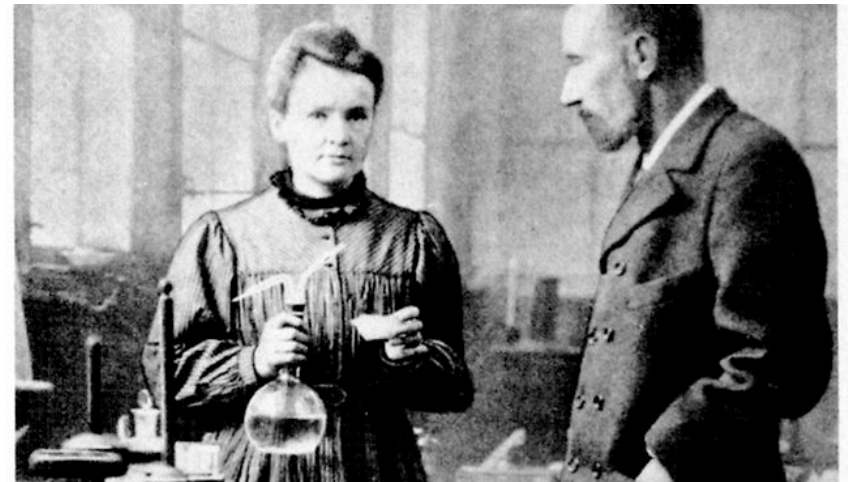
# Radioactivity

- Henri Becquerel (France, 1852-1908)
  - discovered a “mysterious radiation” (1896)
- Marie Curie (Poland, 1867-1934)
  - understood radioactivity in U & Th
  - first female lecturer at the Sorbonne, Paris
- Pierre Curie (France, 1859-1906)
  - together with his wife, they discovered the radioactive elements such as Po & Ra



Becquerel, Marie Curie and Pierre Curie all won a Nobel prize for the discovery of Radioactivity.

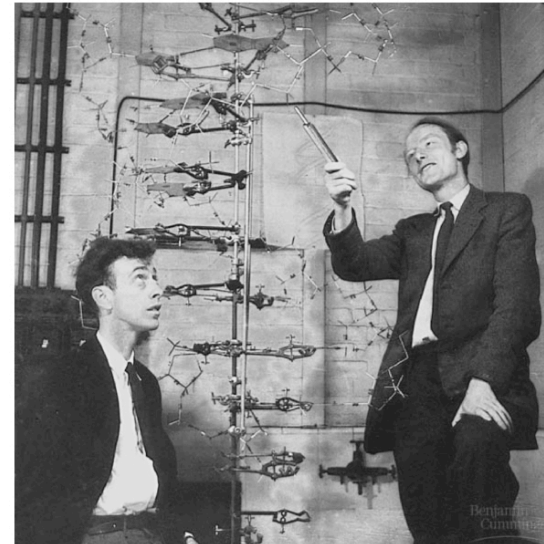
Marie Curie then won a second Nobel prize for her discovery of the element Radium





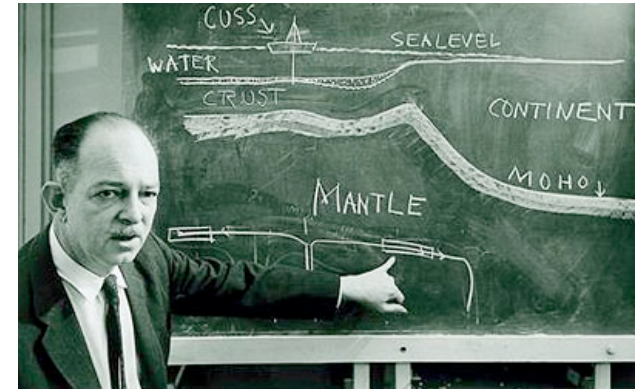
# Other important discoveries: Evolution

- Friedrich Miescher (Switzerland, 1844-1895)
  - discovered DNA
- James Watson (England, b. 1928) and Francis Crick (England, 1916-2004)
  - put DNA evidence together to model the structure of Double Helix (1953)
  - from here, Evolution mechanisms explained



- **Continental Drift (1912)**

- Alfred Wegener (Germany, 1880-1930)



- **Sea-floor spreading (1960)**

- Harry Hess (U.S.A., 1906-1969)

- **Plate Tectonics**

- several geoscientists (1960s)
- Fred Vine (England, b. 1939) and Drummond Matthews (England, 1931-1997)
  - paleomagnetism on ocean floor



- **Precambrian Life mystery resolved**

- William Schopf (U.S.A., b. 1941) and others

