GE 11a, 2014, Lecture 1
Time, stratigraphy and relative dating
Understanding of the Earth ca. 1700  
(the end of the ‘scientific revolution’)

• Earth proven to be an oblate spheroid (Newton’s predictions, confirmed by French geographers). Thus, earth is a fluid at large scale
• Earth density ~ 5 g/cc; moment of inertia less than for a homogeneous sphere
• Existence and approximate locations of nearly all major land masses known
• Liebniz distinguishes igneous from sedimentary rocks and postulates their origins. Notes some special process needed to place sediments at high altitude in mountain belts
• 1st-order dichotomy of land vs. sea floor noted as important clue to earth structure and history
• Interior supposed to be hot

These facts are the foundation of our understanding of the earth’s structure and dynamic behavior, but 18th century scientists failed to grasp the big picture, leaving geology far behind physics, chemistry and parts of biology. Why? Time is the key to earth science, and it was deeply misunderstood.
Natural Philosophy (‘catastrophism’ to its detractors)
Thomas Burnet; 1680’s

- History has a knowable beginning and end
- Natural history is made up of a sequence of unique events
- These events follow natural laws, although most interesting events were unusually grand in scale
- Scientists can unravel all of Earth’s history based on a correct reading of an extant record.
- That record is the Old Testament.

Key observations for Natural Philosophy

- Distinction between continents and oceans
- Water can ‘create’ and ‘destroy’ land (deposition and erosion)
- There are lithified sediments on high mountains
- The bible tells us of a great flood
Natural Philosophers were also called ‘Neptunists’

• Water moving across the surface of the earth is the agent of all significant geological change

• Water will eventually wear down the highs and fill in the lows; thus history is an arrow pointing toward a flat, static earth

A wave-carved British coastline
Catastrophes are central to ‘Catastrophism’

An Indonesian volcano following a large eruption
The Catastrophists view of the North Atlantic
Actualism, or Gradualism (‘uniformitarianism’, originally to its foes; now to all)
James Hutton, 1780; Charles Lyell, 1830

• ‘No vestige of a beginning, no prospect of an end’
• History is comprised of an effectively endless number of similar cycles
• The processes that drive those cycles are subtle but can be seen all around you with careful observation
• The ‘ghost in the machine’ that keeps things from running down is unseen heat and movement at depth (made to respond to thermodynamicists and their pesky third law)
• A trained eye can understand the workings of these cycles by observing the ‘geological’ record.
Gradual processes are central to ‘gradualism’

Mass wasting on an Italian hillside
The equivalence of modern and ancient sediments is central to ‘uniformitarianism’

Cross-bedded sands in the Namibian desert

Cross-bedded sandstone, Arizona
Actualists also referred to as ‘plutonists’ due to their focus on sub-surface igneous materials as drivers of earth processes.
Uniformitarianism is usually described as the ‘winner’ of this debate, but it contained some ideas we now find bizarre:

• Uniformity of natural law (e.g., gravity; this one’s o.k.)

• Uniformity of process (nothing has ever happened that can’t be seen happening in the world today)

• Uniformity of rate (‘gradualism’)

• Uniformity of state; non-progression (I.e., the world has always looked more or less like it does today)
Breaking this deadlock requires development of a natural, rather than literary or theological, record of earth history.

Many rock types exhibit a ‘stratigraphy’ (systematic sequence of sort of horizontal layers) that lets us ask questions about relative time, and thus history.

*Chalk layers, Cyprus*
We know less about stratigraphy on other planets, but the MSL lander in Gale Crater, Mars, is trying to address that.
Steno’s law: When a layer of sediment or lava is deposited, it has an ‘up’ and a ‘down’ side. Any younger sediment or lava deposited on a pre-existing, older one must be laid down with the younger one’s ‘down’ surface contacting the older one’s ‘up’ surface.

Seems so obvious as to be not worth saying out loud. But what about the Plutonists’ injected igneous layers? Even this trivial sounding idea might take a surprising level of skill and judgment to apply in practice.
Logical principles of stratigraphy - the tools for measuring relative time

(2) **Original horizontality**: Sedimentary strata are originally deposited in horizontal sheets; i.e., deposition is sensitive to gravity.
Whoever thought up original horizontality was a genius

Mud flats on the Trinity river, Texas
Whoever thought up original horizontality was a genius

Dry lake bed, Death Valley
Whoever thought up original horizontality was a genius
Original horizontality is stupid

Sand dunes in Namibia
Original horizontality is stupid

Badwater alluvial fan, Death Valley
Original horizontality is stupid

Stromatolites in Shark Bay, Australia
Logical principles of stratigraphy - the tools for measuring relative time

(3) **Truncation rule** (‘cross-cutting relations’): Geometric truncation of one planar or linear geologic feature (e.g., a sedimentary bed) by another generally indicates that the truncated feature is older.

![Diagram showing truncation rule](image)

i.e., faulting post-dates deposition of unit 2 on unit 1
Compaction faulting in Holocene sands, Pakistan
Apply the three principles of stratigraphy to propose a history based on an outcrop sketched on the board...
Siccar Point, Scotland
The cathedral of Uniformitarianism
FIGURE 1.20  The unconformity—known as "Hutton's Unconformity"—at Siccar Point, east of Edinburgh, Scotland. The geologic history represented by this outcrop is shown schematically. (i) Deposition of older rock layers; (ii) deformation of older rock layers; (iii) uplift and erosion of older rock layers, forming an ancient land surface; (iv) subsidence of old land surface and deposition of younger rock layers over it; and (v) uplift, tilting, and erosion. Hutton recognized that this outcrop required an enormous stretch of time to undergo all of these processes if the processes occurred at rates comparable with those observed today.
William Smith — the principle of faunal succession (1793) and Geologic Maps

Outcrop of the ‘Great oolite’ (in yellow); Smith 1799
Major divisions of geological time

The other 90% of earth history (no [obvious] life forms)

Paleozoic (old life forms)

Mesozoic ('middle' life forms)

Cenozoic (new life forms)
Unformitarianism trips on its own shoe laces: ‘measurements’ of absolute age

Charles Darwin and the age of the Chalk Downs (central England)

\[
\text{Age} = \frac{\text{Volume of valley}}{\text{Rate of sediment discharge}}
\]

Measure from topography
Collect sediment in buckets hung in stream

\(~ 45 \text{ billion years} ~\)

i.e., the Chalk Downs in central England took 3-4x the currently-understood age of the Universe to be carved by erosion
The ambiguity of landforms: uniformitarianists and catastrophists each have their ‘own’ valleys.
This debate can still be found in a newspaper or web site near you.

"that most complex of godless movements spawned by the pervasive and powerful system of evolutionary uniformitarianism"

A canyon in six days!