Paleontology and Geologic Time

Fossil (L. “dug up”)

- Originally referred to any unusual object dug from within the Earth.
- Gems, crystals, “figured stones”, fossils, etc.
- Fossils were not understood to be the remains of ancient organisms.

Why was it hard to connect fossils with ancient life?

- Many fossils are from extinct, unfamiliar organisms.
- Fossils are found in rock - how could a living thing get inside a rock?
- Rocks and crystals have geometric and astronomical shapes, why can’t rock take on the appearance of plants and animals?
- No understanding of a long “geologic” history for the Earth - it was understood to have been created as is.
Nicholas Steno (1638-1686)
• studies “tongue stones”
• becomes convinced they are shark teeth entombed in rock.

By the end of the 1600’s several works appeared arguing for the organic origin of fossils.

The Prodromus!

Problem: how does the shark tooth get inside of the rock?

*De solido intra solidum naturaliter contento dissertationis prodromus*
“Preliminary discourse to a dissertation on a solid body naturally contained within a solid.”

Hey, I should write a book!

The Prodromus!

Scillo’s treatise
*Vain Speculation Undeceived by Sense* (1670)

“serpent stone”
from Martin Lister’s
*The History of Shells* (1692)
By the early 1700’s, the presence of fossils in rock in high mountains was invoked as proof of the Old Testament flood.

Why Noah’s Flood was important in the development of Paleontology

- Provided an impetus to study fossils as the remains of living organisms.
- Provided an early explanation for the deposition of sedimentary strata.
- Began to place fossils and strata within a deep time historical narrative.

In the late 1700’s and early 1800’s the study of fossils leads directly to the development of a geologic history of the Earth.
Temporal sequence of geological strata based on the Neptunist theory of Abraham Werner

<table>
<thead>
<tr>
<th>Primary</th>
<th>crystalline rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transitional</td>
<td>hard, layered rock</td>
</tr>
<tr>
<td>Secondary</td>
<td>coal-bearing rock and chalk</td>
</tr>
<tr>
<td>Diluvial</td>
<td>gypsum deposits and clays</td>
</tr>
<tr>
<td>post-Diluvial</td>
<td>surface gravels and sands</td>
</tr>
</tbody>
</table>

circa 1790

**Georges Cuvier (1769-1832)**

- French comparative zoologist
- Expert on vertebrate skeletons
- Studied vertebrate remains being excavated from secondary and tertiary strata in the Paris Basin.
- Proved extinction.
- First geologic correlations using fossils.
- Published "Discourse on the revolutions of the surface of the globe".

Cuvier proved that some species were now extinct by comparing fossil and modern elephant bones.
Cuvier showed that the bones of animals being found in the secondary strata were from giant reptiles.

Mosasaur jaw being excavated from the chalk at Maestricht, Late 1700’s.

Mosasaur skull
Cuvier proved the existence of several unique ages in the history of the Earth prior to the appearance of mankind.

"Fossils alone reveal successive epochs in the formation of the globe."

The Puzzle of Geologic Time

- Based on fossils, Cuvier developed a broad sketch of geologic time within the framework of Primary, Transitional, Secondary, Tertiary strata.
- The puzzle: How to subdivide geologic time in more detail and how to determine which strata in different places are time-equivalent?
- How do we put rock layers into the correct time order?
Geologic Systems - regional packages of rock strata with distinctive fossils first described by geologists in the late 1700’s and early 1800’s.

<table>
<thead>
<tr>
<th>Cretaceous System</th>
<th>19th Century</th>
<th>18th Century</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diluvial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tertiary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transitional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Diluvial: 19th Century: "Parisian chalk" 1820, "Gravels" 1821
- Secondary: 19th Century: "English chalk" 1818, "Penn strata" 1819
- Transitional: 19th Century: "Devonshire strata" 1820, "Muschelkalk - Trias" 1817
- Primary: 19th Century: "Crystalline (metamorphic) strata" 1820

- New Red Sandstone: 19th Century: "Wenlock Limestone" 1820
- Old Red Sandstone: 19th Century: "Welsh Greywackes" 1820
- Devonshire strata: 19th Century: "Magnesian Limestone" 1819
- Maghinean Limestone: 19th Century: "Coal Measures" 1819
- Oolites: 19th Century: "Lias" 1818
- Sicilian strata: 19th Century: "Muschelkalk - Trias" 1817
- Parisian chalk: 19th Century: "London Clay" 1818, "Parisian gypsum beds" 1820
- Crystalline (metamorphic) strata: 19th Century: "Mountain Limestone" 1818


Geologic Systems: 19th Century: "Cretaceous System" 1820

D'Omalius d'Halloy, 1822
Problem - how do you determine the order in which rock layers formed?

At a single place, layers can be ordered using Steno’s law of Superposition.

East Devonshire

Within a local region, rock layers can be correlated on the basis of their lithology (physical characteristics) to define a geologic system.

Correlation - the matching-up of rock layers between different places.

- Identify the same rock layer exposed in different places (tracing out a rock layer) - lithostratigraphic correlation.

- Identify rock layers in different regions that formed during the same interval of Earth History (matching up layers that formed at the same time) - chronostratigraphic correlation.
How can we identify age-equivalent strata if the layers cannot be correlated based on their physical features?

Great Britain

Continental Europe

William Smith (1769-1839)
surveyor, civil engineer

Smith’s work as a surveyor and canal digger allowed him to create the first accurate geologic map of a large region.

His careful observations of fossils allowed Smith to identify strata that were equivalent in age.
Smith discovered that fossil species occur in a unique, non-repeating sequence through time.

If Smith did not recognize the rock layer he was working in he could rely on the fossils to show him where he was in the overall sequence.

Fossils are the key to correlating strata based on age.

Geologic Systems and Geologic Time

- Once a particular regional system of strata was formally named and its fossils described, other regional systems with the same fossils were correlated to it and given the same name.

- Many European geologists worked through the 1800’s, naming, describing, and correlating regional systems.

- The original system names came to stand for particular intervals of geologic time.
Geologic Systems and Geologic Time

- For example, the Jurassic System was originally named for the rocks and fossils of the Jura Mountains between France and Switzerland.

- Now the Jurassic Period refers to the time interval during which the fossil species of the Jurassic System lived.

- Any rock layers with these fossils can be identified as Jurassic in age.

W. Phillips
1821

“transition slates”

Adam Sedgwick (1785-1873)  Roderick Impey Murchison (1792-1871)
Figure 2. Section along the western flank of the Ural mountains showing the conformable nature of the contact between the Carboniferous rocks (to the east) and the overlying rocks assigned by Murchison to the Permian. From Murchison, de Verneuil, and von Keyserling 1845.

Diagram showing the general stratigraphy between the Paleozoic and Mesozoic (or Secondary). From Murchison, de Verneuil, and von Keyserling 1845.

<table>
<thead>
<tr>
<th>circa 1790</th>
<th>circa 1870</th>
</tr>
</thead>
<tbody>
<tr>
<td>post-Diluvial Diluvial</td>
<td>Continental Europe</td>
</tr>
<tr>
<td>British Isles</td>
<td>Modern Time Scale</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Quaternary</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Tertiary</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Cretaceous</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Jurassic</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Triassic</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Permian</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Carboniferous</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Devonian</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Silurian</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Ordovician</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Cambrian</td>
</tr>
<tr>
<td>Diluvial</td>
<td>Precambrian</td>
</tr>
</tbody>
</table>
Charles Lyell
(1797 - 1875)

- Used fossils to subdivide the Tertiary Period into epochs.
- Defined discrete time intervals based on the percentage of fossil species still found alive in the present.

Geologists originally collected and described fossils because they were the key to understanding geologic time.

The geologic timescale is subdivided into eras, periods and epochs on the basis of fossils.
Subdivisions of Time

<table>
<thead>
<tr>
<th>Time Unit</th>
<th>Range (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eon</td>
<td>$1 \times 10^9$</td>
</tr>
<tr>
<td>Era</td>
<td>$1 \times 10^8$</td>
</tr>
<tr>
<td>Period</td>
<td>$1 \times 10^7$</td>
</tr>
<tr>
<td>Epoch</td>
<td>$1 \times 10^6$</td>
</tr>
<tr>
<td>Stage</td>
<td>$1 \times 10^5$</td>
</tr>
<tr>
<td>Substage</td>
<td>$1 \times 10^4$</td>
</tr>
<tr>
<td>Zone</td>
<td>$1 \times 10^4$</td>
</tr>
<tr>
<td></td>
<td>- $6$</td>
</tr>
</tbody>
</table>

Modern Geologic Time Scale

- **Eons / Eonothems**
  - Hadean
  - Archean
  - Proterozoic
  - Phanerozoic

- **Periods**
  - Paleozoic
    - Cambrian
    - Ordovician
    - Silurian
    - Devonian
    - Carboniferous
    - Permian
  - Mesozoic
    - Triassic
    - Jurassic
    - Cretaceous
  - Cenozoic
    - Paleocene
    - Eocene
    - Oligocene
    - Miocene
    - Pliocene
    - Pleistocene
    - Holocene

- **Eons**
  - Paleogene
    - Paleocene
  - Neogene
    - Oligocene
    - Miocene
    - Pliocene
    - Pleistocene
  - Cenozoic
    - Quaternary

- **Age of the Earth**
  - 4600 Ma (4.6 billion years)
  - 408 Ma
  - 355 Ma
  - 250 Ma
  - 208 Ma
  - 146 Ma
  - 57 Ma
  - 1.6 Ma

- **Four Eons of Geologic Time**
  - **Hadean**
  - **Archean**
  - **Proterozoic**
  - **Phanerozoic**

- **“First Life”**
  - Earliest shelly fossils

- **“Visible Life”**
  - Earliest known life forms
Changes in relative diversity of eight major classes of marine invertebrates during the Phanerozoic. From Phillips 1860.
How do we assign sedimentary layers to their correct place in time?

- fossils
- each time interval in Earth history is defined by a unique set of species that existed at that time.
- Species evolve, live for a short time, and go extinct.
- The same species never evolves twice (extinction is forever).
- Evolution provides a “biological calendar” that geologists use to keep track of time.
- Extinction creates the boundaries between geologic time intervals.