How we view the layered nature of the Earth

Development of Stratigraphic Principles over time
Stratigraphy is change, both vertical and horizontal

- Distribution of layered rock
  - Vertical = changes through time
  - Horizontal = Facies changes and tectonism
Two classical methodologies

- descriptive (documents change—it is the catalog!!)
- interpretive (correlation and why?!!)
Questions regarding Stratigraphy

• Is it dead?
• Is it a tool?
• Why study stratigraphy?
• Why understand a tool?
• Isn’t stratigraphy already fully developed?
  – Is classification a science?
  – Aren’t we reinventing the wheel
DYNAMIC STRATIGRAPHY

- Stratigraphers recognize and interpret change.
- Requires background in petrology, classification, and paleontology.
DYNAMIC STRATIGRAPHY

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Types of stratigraphy

- Litho-
- Bio-
- Seismic
- Sequence
- Chemo-
- Eco-
- Magneto-
- Electro-
- Etcetera….

- Basin Analysis
- Depositional modeling
- Stratigraphic modeling
Stratography is the basis for

- Geological Mapping
- Tectonics
- Stratigraphy *sensu lato*
- Paleontology
Fossils

• rocks, minerals, or other materials “dug-out” of the Earth
• “sports of nature”, fortuitously resembles antiquities or remains of the “once living”
• believed to have “grown in the Earth” such as coal, ores. Mines were often closed to “replace” ores, similar to letting fields rest
Surficial geology and topography

- thought to be the result of the Noachian Deluge, from the Middle ages to the 1700’s
- Historical records extended back to about 2000 BC.
- Judeo-Christian bible chronologies extend back to about 4000 BC, and Earth created within a “week”
The computation of the ages of the world.

<table>
<thead>
<tr>
<th>Period</th>
<th>Event</th>
<th>Date</th>
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<tbody>
<tr>
<td>1</td>
<td>The creation of the world</td>
<td>1656</td>
</tr>
<tr>
<td>2</td>
<td>To Abraham</td>
<td>292</td>
</tr>
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<td>3</td>
<td>To the departure of Israel out of Egypt</td>
<td>503</td>
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<td>4</td>
<td>To the temple building</td>
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<td>5</td>
<td>To the captivity of Babylon</td>
<td>503</td>
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<td>6</td>
<td>To Christ</td>
<td>483</td>
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<td>7</td>
<td>To this present</td>
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<td>The Hebr.ws</td>
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<td>The summe of the ages of the world after the computation of</td>
<td>589</td>
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</tbody>
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**FINIS.**

**FIGURE 3.2.** Calculations of the "age of the world" were made long before Bishop Ussher. (Cooper's Chronicle, 1560)
Kircher, 1665, erroneous water cycle

**FIGURE 5.1.** “Just as blood circulates in the human body, water rises from the sea through underground veins into subterranean fountains from which it issues in springs, losing its saltiness in the process.” (Kircher, 1665)
FIGURE 7.4. Eruption of Etna and the great lava flow of 1669. (Borelli, 1670; photograph courtesy of R. D. Gurney, Ltd., London)
1581-1656—Bishop James Ussher

• Anglican Archbishop of Armagh and Primate of Ireland

• Calculated age of the earth by adding patriarchal lineages in the Bible, 4004 BC, Oct 23rd
In the beginning God created Heaven and Earth, Gen. 1, v. 1. which beginning of time, according to our chronologie, fell upon the entrance of the night preceding the twenty third day of Octob. in the year of the Julian [Roman] Calendar, 710 [=4004 BC].

Upon the first day therefore of the word, or Octob. 23. being our Sunday, God, together with the highest Heaven, created the Angels. Then Having finished, as it were, the rooife of the building, he fell in hand with the foundation of this wonderfull fabrick of the world, he fashioned this lowermost Globe, consisting of the Deepe, and of the Earth; all the Quire of Angels singing together, and magnifying his name therefore....And when the Earth was void and without forme, and darknesse covered the face of the Deepe, on the very middle of the fist day, the light was created; which God severing from the darknesse, called the one day, and the other night.
1581-1656—Bishop James Ussher

- Problems with Ussher's Interpretation—
  - Biblical history of Israel not complete from Ezra/Nehemiah to Christ
  - Has to be tenuously cross-linked to other cultural records from Persia, Chaldea, and the Romans.
  - Jewish Chronology based on lunar months
  - Leap year problems had led to abandonment of older Julian calendar for new Gregorian calendar in 1582.
  - Ussher as archbishop wanted nothing to do with a “pope-based” calendar, although he was forced to use it and it was later accepted by protestant scholars and even put inside editions of the King James translation of the Bible (e.g. 1701).
16th Century—Leonardo DaVinci

- remarked in journals that the fossil shells found high on mountain tops were not the result of the deluge”…things heavier than water do not float high…unless shells float on waves….” Therefore the shells were not the result of a universal deluge
- shingle, or layers are “…petrified muds from oceans, uplifted from the sea”
1638-1686—Nicolaus Steno, Nicoli Stenonis, Nils Steensen, Niels Stenson

- based partly on Aristotelian philosophy of “rock fish”
- Steno formulated three principles
  1. “in a sequence of layered rocks any layer is older than the layer next beyond”
  2. horizontality
  3. “...originally laterally continuous unless terminated against another solid substance”
- Steno’s prologue translated in English not long after publication, but may not have significant impact on development of stratigraphy.
- Steno coined the word “facies”
- Later became the Apostolic Vicar for Northern Germany
1638-1686—Nicolaus Steno, Nicoli Stenonis, Nils Steensen, Niels Stenson

- Born in Copenhagen, Trained in medicine, renowned anatomist
- Description of *Glossopetrae* based on dissection of sea monster brought to him by Duke of Tuscany
1638-1686—Nicolaus Steno, Nicoli Stenonis, Nils Steensen, Niels Stenson

1669 Published “De solido intra solidium naturaliter contento dissertationis prodromus”
(Prologue to a Dissertation on how a solid body is enclosed by the processes of nature within another solid body)

Suggested that:

– strata within the Earth are deposits of a fluid

– stratification forms from deposition by differential settling of denser and heavier parts
1638-1686—Nicolaus Steno, Nicoli Stenonis, Nils Steensen, Niels Stenson

Recognized two temporal groups:

- strata in which part a homogenous relatively fine produced at the time of creation from a fluid which at that time covered all things.

- strata that contain fragments of other strata, or organic remains “…must not be reckoned among the strata which settled down from the first fluid at the time of creation”

Suggested that where and how strata form can be deduced from analysis of particulates of rock body.
The last six figures, while they show in what way we infer the six distinct aspects of Tuscany from its present appearance, at the same time serve for the reader comprehension of what we have said about the earth's strata. The dotted lines represent the sandy strata of the earth, so called from the predominant element, although various strata of clay and rock are mixed with them; the rest of the lines represent strata of rock, likewise named from the predominant element, although other strata of a softer substance are sometimes found among them. In the Dissertation itself I have explained the letters of the figures in the order in which the figures follow one another: here I shall briefly review the order of change.

Figure 25 shows the vertical section of Tuscany at the time when the rocky strata were still whole and parallel to the horizon.

Figure 24 shows the huge cavities eaten out by the force of fires or waters while the upper strata remained unbroken.

Figure 23 shows the mountains and valleys caused by the breaking of the upper strata.

Figure 22 shows new strata, made by the sea, in the valleys.

Figure 21 shows a portion of the lower strata in the new beds destroyed, while the upper strata remain unbroken.

Figure 20 shows the hills and valleys produced there by the breaking of the upper sandy strata.
FIGURE 4.10. “[This] we found near Lhan Deilo in Caermarthenshire ... whereof we found great plenty, must doubtless be referred to the Sceleton of some flat Fish.” (Lhwyd, 1698)
1687-1764—Antonio Lazzaro Moro

• about 1740 recognized two classes of rocks and mountains
  – Massive, nonstratified rocks, therefore the “older mountains”
  – Younger mountains and rocks are stratified, from volcanic eruptions of “liquid rocks”, which could encase fossils

• Moro = 1st vulcanist.  (1st neptunist = Woodward)
1713-1795—Giovanni Arduino

- about 1760, established four-fold classification of rocks and mountains:
  - **Primary**—contain metal ores and lack fossils
  - **Secondary**—well lithified, bedded rocks with marine organisms
  - **Tertiary**—lo mountains and hills, mostly unconsolidated sediments, primary associated with volcanic rocks
  - **Alluvium**—materials washed away from three primary types and loosely deposited stuff.

- director of mines in Tuscany, professor of mineralogy at Padua (Padova)
1719-1767—Johann Gottlob Lehman

- About 1756, developed a three-fold division of rocks, based on studies the Thueringerwald and Harz Mountains.

1. **Urgebirge**—primitive rocks, crystalline (formed from chemical precipitation), lack fossils, metallic ores, formed at time of creation, cores of great mountain chains.

2. **Floetzgebirge**—layered mountains and stratified rocks, formed from sediments eroded from primary mountains, deposited in between primary mountains. May have formed from Noachian flood. Found on flanks of Urgebirge.

3. **Angeschwemmtegebirge**—alluvial, unconsolidated, formed within restricted geographic areas. Recent volcanic rocks are associated with the Angeschwemmtegebirge.
1722-1773—Georg Christian Fuechsel

- About 1761, divided middle division of Lehman (Floetzgebirge) into nine units, each representative of a discrete unit of time. Used term Alluvium.
1777—Peter Simon Pallas

- Son of a professor of surgery, invited to St. Petersberg Akademie in Russia by Catherine II of Russia to become a natural history professor

- Investigations in the Ural Mountains led him to develop a three-fold classification of rocks

- Found a new class of meteorite, which was named after him: *Pallasite.*
1707-1788—Georges-Louis LeClerc, Comte de Buffon

- Popularizer of science, influential naturalist, equivalent to Carl Sagan of time
- 1749 publication, translated into English 1797
- Broke with young Earth theory, suggested in print that Earth is about 75,000 years old (private conversations revealed that he thought it to be much older)
- Earth formed from a molten fragment torn from the Sun by a comet, and cooling of that fragment influential in earth’s formation.
- Seven great epochs in publication—formation of planet, consolidation, waters covered continents, waters withdrew, elephants and southern animals to the north, continents separate, man appears.
1749-1817—Abraham Gottlob Werner

- Greatest figure in Geology at end of 18th century.
- Charismatic and influential teacher, Freiberg School of Mines (1755-1817)
- Native of Saxony
- Built on theories of Lehman—epitomized neptunists
- Published *Kurze Classification und Beschreibung der verschiedenen Gebirgsarten* in 1857
Abraham Gottlob Werner (1749-1817)

- Age 19 (1769)—Began studies at the new *Bergakademie Freiberg*

- Age 24 (1774)—publishes book “*Von den äusserlichen Kennzeichen der Foßilien*” (Leipzig)

- Age 25 (1775)—Appointed *Inspektor und Lehrer für Bergbaukunst und Mineralogie (seine lieblings Wissenschaft)*
Abraham Gottlob Werner
Some famous students

- Christian Samuel Weiss
- Leopold von Buch
- Alexander von Humboldt
- Jean d’Aubisson de Voisins
- August Breithaupt
- Robert Jameson
- Friedrich Mohs
- Gotthilf Heinrich von Schubert
- Henrik Steffens
- Friedrich von Hardenberg
Abraham Gottlob Werner
Some famous students

Students involved with mineral studies
- Christian Samuel Weiss
- Friedrich Mohs

Students involved with stratigraphy
- Robert Jameson
- Alexander von Humboldt
- Jean d’Aubisson de Voisins
- Leopold von Buch

Students in letters
- Gotthilf Heinrich von Schubert
- Henrik Steffens
- Friedrich von Hardenberg

- August Breithaupt
1750-1817—Abraham Gottlob Werner
1750-1817—Abraham Gottlob Werner

- Ascribed formation of almost all rock to primeval Ocean and consequent precipitation
- Assumed mountains are original topographic features, 1st granite from “universal ocean”.
- Tilted strata on formed on flanks of Urgebirge in situ
- May slide down before consolidation, producing breakage and contortion
The plate on the opposite page is a cross-section along a SE-NW line from the SE side of the Erzgebirge to the NW end of the Harz. This drawing is on page 441 of the lecture notes taken by Adolph L. Schippan during Werner's lectures on geology which he gave in the academic year of 1814/15. It is similar to a sketch extant in Werner's own notes and presumably is a copy of a sketch that Werner presented in class.

From left to right, SE to NW, the letters indicate the following rocks:

- u granite
- a gneiss (unconformable relative to the older granite u)
- b mica schist
- c clay slate, including primitive trap
- d second porphyry, including syenite (interrupted, unconformable and overlapping—overlap is not shown)
- e transition rocks
- f Old Red Sandstone
- g first fleetz limestone, including Kupferschiefer
- h first fleetz gypsum
- i rock salt
- k second or variegated sandstone
- l second fleetz gypsum
- m Muschelkalk, that is, second fleetz limestone
- n alluvial
- m Muschelkalk
- l second fleetz gypsum
- k second variegated sandstone
- i rock salt
- h first fleetz gypsum
- g first fleetz limestone
- f Old Red Sandstone
- e transition rocks (unconformable relative to the older granite w)
- w granite, newer than u
1750-1817—Abraham Gottlob Werner

- **Five fold division of stratified rock:**
  1. *Urgebirge*—crystallized form Primeval Ocean
  2. *Uebergangsgebirge*—“transitional” greywacke, mica slate, limestone and diabase with a few fossils
  3. *Floetzschichten*—sedimentary, fossil-bearing rocks with some basalt
  4. *Aufgeschwemmtegebirge*—poorly consolidated sediments (clay, sand, gravel) derived from erosion and left behind as water retreated.
  5. Volcanic rocks deposited last, restricted locations, cause by burning coal seams.
1750-1817—Abraham Gottlob Werner

• Three implications of Werner’s theories
  – World-wide recognition of strata (produced by erosion of \textit{concentric layers}), a simple stratigraphic column, global!
  – Local variations due to original undulatory surface of \textit{Urgebeirge} and irregular retreat of floodwaters.
  – Formation concept of lithological homogeneity.
1727-1797—James Hutton

- Trained as a physician, became farmer and industrialist, producing the 1st chemical factory in Britain, often known as the Gentleman Farmer.

- 1785—read paper in Edinborough, Scotland, published in full in 1788, expanded to two volumes in 1795—*Theory of the Earth*
1727-1797—James Hutton

- **1795—Theory of the Earth**
  - Discoverer of deep time
  - Discoverer of unconformities, used concept of unformitarianism (word was NOT used until William Whewell (1832)
  - Viewed Earth as a Grand Machine for producing habitable worlds
  - Developed concept of rock-cycling
  - Suggested that Granite is magmatic
  - Methodology—if present processes apply, some cannot be observed
  - Earth is infinitely old and cyclic, Fossils may have existed more than once
  - Empirical results
1748-1819—John Playfair

- Mathematician, wrote *Illustration of the Huttonian Theory of the Earth*, 1802.
- Influenced the acceptance of Hutton’s work as the main working theory of geology (including Charles Lyell)
1707-1788—Georges-Louis LeClerc, Comte de Buffon

- Popularizer of science, influential naturalist, equivalent to Carl Sagan of time
- 1749 publication, translated into English 1797
- Broke with young Earth theory, suggested in print that Earth is about 75,000 years old (private conversations revealed that he thought it to be much older)
- Earth formed from a molten fragment torn from the Sun by a comet, and cooling of that fragment influential in earth’s formation.
- Seven great epochs in publication—formation of planet, consolidation, waters covered continents, waters withdrew, elephants and southern animals to the north, continents separate, man appears.
1769-1832—Baron Georges Léopold Chrétien Frédéric Dagobert Cuvier

- Professor of Natural History and Anatomy
- 1800—Published *Mémoires sur les espèces d'éléphants vivants et fossiles.*
- 1799—Published *Tableau élémentaire de l'Histoire naturelle des animaux*,
- 1799—Published *Regne animal distribué d'après son organisation*
- 1825—Published *Discours sur les revolutions de la surface du globe*,

**FIGURE 9.1.** Brongniart's stratigraphy of the Paris Basin. (Cuvier, 1818)
1769-1839—William “Strata” Smith

- Born in Oxfordshire, England,
- SELF-trained surveyor and civil engineer, developed canals, mines, quarries
- 1793 and 1799 produced the first geologic maps.
- Mapped coal seams near Bath. Lateral continuity and regular succession of formations over large area
- [http://www.unh.edu/esci/wmsmith.html#geological](http://www.unh.edu/esci/wmsmith.html#geological)
1769-1839—William “Strata” Smith

The Map That Changed the World

Sold for 50 pounds each (equal to half of Smiths Pension, or roughly $1200-2500 at current rates)

Sold few, heavily plagiarized by several of the Geological Society of London and sold as rivals

Detailed sheets of counties
16 sheets (included legend)
1769-1839—William “Strata” Smith

• Discovered that the strata of England are in a predictable order, and that their fossil contents are in the same order.

• 1815, Published the *Strata Identified by Organized Fossils*

• Published the Geological Table of Organized Fossils in 1816, while the map was in press

• Received the 1st Wollaston Medal in 1831, and was dubbed “The Father of English Geology” by Adam Sedgewick

• [http://www.unh.edu/esci/wmsmith.html](http://www.unh.edu/esci/wmsmith.html)
1769-1839—William “Strata” Smith
1769-1839—William “Strata” Smith
1785-1873—Adam Sedgwick

- No formal training in geology (theologian, holy orders 1817, appointed to Woodwardian professor of Geology at Cambridge (1818)

  “Hitherto I have never turned a stone; henceforth I will leave no stone unturned.”

- Worked with Murchison through 1839, published work on rocks in western Wales and Welsh Borderland “On the Silurian and Cambrian Systems, exhibiting the order in which the older sedimentary strata succeed each other in England and Wales
1774-1853—Leopold von Buch

- Student of Abraham Werner, and friend of von Humboldt.
- Traveled widely
- Refined the Jurassic System
1785-1873—Adam Sedgwick

- Sedgwick's Cambrian was based on the sequence of rocks in western Wales, Murchison’s Silurian in Welsh borderland was based on pre-fossil fish content. Murchison came to believe that the Cambrian was really Silurian without fossils. Sedgwick of course disagreed. Both wanted the accolades of documenting the “origin of life” on Earth. Sedgwick’s upper Cambrian really overlapped with Murchison’s lower Silurian.
17xx-18xx—Charles Lyell

- Add text here
1769-1859---Friedrich Heinrich Alexander, Baron von Humboldt

- groomed himself as a scientific explorer (student of Werner, accompanied by botany, languages, astronomy, culture, finance)
- embarked on expedition 1799-1804 through the Western Hemisphere
- Napoleon and von Humboldt were the best known men in Europe
- Represented the scientific side of his country as Goethe represented is literary side
- Humboldt Counties (NV and CA), rivers, animals, plants etc.
- Named the Jurassic System for Rocks in the Jura Mountains
1792-1871—Sir Roderick Impey Murchison

• After a young career in the British army (eight years), Murchison, turned his focus to science and joined and became one of the stalwart contributors to the Geological Society of London.

• Murchison loved to travel with his wife, and was later knighted for his contributions, which included the establishment of the Silurian System, Devonian System, and the Permian System.

  – *Geology of Cheltenham* (1834)
  – *The Silurian System* (1839)
  – *On the Geological Structure of the Northern and Central Regions of Russia in Europe* (1841)
  – *Geology of Russia in Europe and the Ural Mountains* (1845)
1792-1871—Sir Roderick Impey Murchison

- After leaving the military in 1818, he became interested in the young science of geology and joined the Geological Society of London.

- Explored the greywacke rocks underlying the Old Red Sandstone at Welsh/England border, from which he established the Silurian System. Disagreed with Sedgwick about Lower Silurian.

- Worked with Lyell and Sedgwick.

- Published paper with Sedgwick in 1839 on rocks of the Old Red Sandstone in southern England, which they named Devonian.

- Named the Permian for Rocks in the Ural Mountains (1845).
1792-1871—Sir Roderick Impey Murchison

Murchison's Jurassic Correlation? British National Archives
1842-1920—Charles Lapworth

- Lapworth was trained as teacher, patiently mapped a series of supposedly thick Silurian Rocks near the Scottish border (1869), which he proved were actually thickened through repeated faulting by using index fossils.
- Proposed the establishment of the Ordovician System for the controversial overlap between Sedgwick's Cambrian and Murchison's Silurian in 1879.
1775-1829—William Daniel Conybeare and William Phillips (1775-1828)

- Conybeare wrote Part 1 of *Outlines of the Geology of England and Wales* (1822), a second edition of what was to be a larger enterprise as the brainchild of William Phillips.
- Part 1 documented the Carboniferous, and was the only part of the planned series that was published.
- Conybeare’s interest in geology came through lectures by Dr. John Kidd. Friend of William Buckland.
- Phillips helped establish the Geological Society of London (1807), and wrote several textbooks on geology.
1775-1829—Friedrich August von Alberti

- 1834—named the Trias for the tripartite group of rocks in southern Germany: Bunter Ss, Muschelkalk, and Keuper
- Monographie des Bunten Sandsteins, Muschelkalks und Keupers, und die Verbindung dieser Gebilde zu einer Formation (Stuttgart-Tübingen: Cotta), 1834
- Renowned for salt exploration
“The various deposits of the same facies areas and similarly the sum of the rocks of different facies areas are formed beside each other in space, though in cross-section we see them lying on top of each other. As with biotopes, it is a basic statement of far-reaching significance that only those facies and facies areas can be superimposed primarily which can be observed beside each other at the present time.”
1860-1937—Johannes Walther


- Geologist and Paleontologist, worked on sedimentary rocks and fossils, including a habilitation on crinoids.
- Field research in Italy, Greece, Egypt, Scotland, Ceylon, and the Urals.
- University Professor returned to his alma mater to teach
- Renowned for his educational skills, emphasizing use of local examples.

Significant Publications include:
- Einleitung in die Geologie als historische Wissenschaft (1893–1894)
- Geschichte der Erde und des Lebens (1908)
- Allgemeine Paläontologie (1919–1927)