A short history of North America

Indiana in its plate tectonic setting

P. David Polly
Department of Geological Sciences
Indiana University
Bloomington, Indiana 47405 USA
pdpolly@indiana.edu
Objectives

1. Introduction to Geological Time Scale
2. Structure of the Earth, formation of rocks and continents
3. Early history of the Earth
4. Continental history of the Phanerozoic
5. Oxygen, carbon dioxide, and sea level through the Phanerozoic
Basic geological time scale

Quiz next Friday (25 January)

Mnemonic for Paleozoic Periods:

- Cold: Cambrian
- Oysters: Ordovician
- Seldom: Silurian
- Develop: Devonian
- Many: Mississippian
- Precious: Pennsylvanian
- Pearls: Permian

<table>
<thead>
<tr>
<th>Era</th>
<th>Period</th>
<th>Epoch</th>
<th>Age (millions of years ago)</th>
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<td>Archean</td>
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<td>2.5 billion</td>
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<td>Phanerozoic</td>
<td>Cenozoic</td>
<td>Quaternary</td>
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<td>Cambrian</td>
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- Archean (2.5 billion years ago)
- Phanerozoic (4.6 billion years ago)
Structure of the Earth

**Lithosphere**, or crust
The outer layer of the earth that ‘floats’ on its surface

**Oceanic crust**
Heavy, basaltic crust that forms the ocean floors and originates at spreading ridges

**Continental crust**
Lighter, more varied crust that has formed from tectonism and erosion

**Asthenosphere**
A ‘plastic’ layer that is easily deformed by the massive movements in the mantle
Major types of crustal rock
Indiana’s surface rocks are exclusively felsic

**Continental crust: felsic**
High concentration of silica and aluminum as quartz and feldspar. Average density is 2.7 g/cm³

**Oceanic crust: mafic**
High concentration of iron (Fe) and magnesium in basalt rocks. Average density is 3.0 g/cm³
Crustal rock floats
and felsic continental crust floats higher than mafic oceanic crust

Light crust floats higher, heavy crust sinks lower
this is an important observation about basins filling with sediments:
they sink as they fill, thus allowing more sediments to enter the basin

Isostasy = equilibrium point of continental “floating”
Convection, creation of crust, and plate movements

Heavier ocean crust (mafic) is created by upwelling at mid-ocean rides and low and heavy, slipping under lighter crust when plates come together.

Continental crust (felsic) is created when ocean crust is subducted and melts. Lighter elements bubble up and float high (orogeny).
Early history of the Earth

GA = gigannum, or billions of years ago  
MA = megannum, or millions of years ago

Hadean, 4.6 - 3.8 Ga

- Oldest rocks = 4.2 Ga (zircon grains in ancient sandstones)
- Origin of life = circa 4.0 Ga

Archaean, 3.8-2.5 Ga

- Oldest intact crust from Acasta Gneiss and Nuvvuagittuq Greenstone Belt Canada and Greenland = 4.4 - 3.8 Ga
- Earliest fossils of photosynthetic bacteria = 3.5 Ga
- Oxygen in atmosphere at low levels = 2.5 Ga

Proterozoic, 2.5 Ga - 545 Ma

- Sediments continue to cover and enlarge continents
- Eucaryote life = 2.1 Ga
- Multicellular life (metazoans) = 1.8 Ga
- First “ice age”, or glacial period, “Snowball Earth” = 650 Ma
- Vendian life (complex, soft-bodied animals) = 650 - 542 Ma
Anatomy of a continent

**Craton** = oldest, most stable part of continent, mostly rock formed by cooling of early molten crust (also called “shield”)

**Mountain belts** = formed by later “orogenies” due to plate movements

**Sediments** = formed by weathering, erosion, transport, and deposition

**Igneous rocks**: crystalize from molten material (sea floor spreading centers, orogenic centers)

**Sedimentary rocks**: originate by weathering and erosion from other rocks (Indiana’s surface rocks are sedimentary)

**Metamorphic rocks**: transformed and recrystallized igneous and sedimentary rocks
Surface bedrock of North America
Skeleton outline of NA’s history

1. **Archean:** Craton forms as “microcontinents” cooled from molten crust
2. **Archean:** Microcontinents collide to form larger craton (Laurentia)
3. **Proterozoic:** Laurentia grows as mountains of early craton erode and are transported to margins
4. **Early Paleozoic:** Laurentia begins to collide with other continents, especially along what is today eastern margin (Taconic Orogeny, Ordovician; Acadian Orogeny, Silurian-Devonian)
5. **Late Paleozoic:** Continents come together into Pangea (Alleghenian Orogeny, Pennsylvanian)
6. **Mesozoic:** Pangea splits apart into modern continents
7. **Cenozoic:** Mountains and basins of western North America and Central America formed as NA moves westward and northward
Proterozoic (>524 Ma)

Craton eroding flat and growing wider by depositing sediments around margins
Early Paleozoic (542-359 Ma)

- Continent grows
- Sea level high, extensive shallow seas
- Taconic and Acadian orogenies form older parts of the eastern mountains
Late Paleozoic (359-251 Ma)

- Terrestrial part of grows
- Alleghenian Orogeny as NA, Europe, and Africa start to collide
- Formation of supercontinent Pangea, in which all continents were connected
Mesozoic (251-65 Ma)

- Pangea starts to break apart
- Eastern mountains erode, no more orogenies on that margin
- Western mountains start to form as NA is pushed to the west and north
- Sea levels high in Cretaceous, flooding lower parts of the continent
Cenozoic (65 - 0 Ma)

- Continent takes on modern form
- Western and Central American mountains continue to form
- Gulf coast extend from sediment deposition and reef building
- Glacial cycles in late Cenozoic
Atmospheric oxygen levels over Phanerozoic

**Figure 1**  Plot of percent atmospheric O$_2$ versus time calculated by the rock abundance model. The upper and lower light lines represent the margin of error as deduced by sensitivity analysis (after Berner & Canfield 1989).
Atmospheric carbon dioxide levels over Phanerozoic

**Fig. 5.** Standard plot versus time of $R_{CO_2}$, the ratio of mass of $CO_2$ in the atmosphere at time $t$ to that in the present atmosphere, based on the carbon mass balance model of the present study. The curve represents the best estimate of the various parameters that go into the model. Dashed lines show the envelope of approximate error based on sensitivity analysis. The vertical arrow denotes that early Paleozoic $CO_2$ levels may have been even higher than those shown; see text for discussion. Values used (see Table 2): $C = 0.75$; $f_E(t) = 0.15$ for 570 to 350 Ma; $f_E(t) = 0.75$ for 300 to 130 Ma; $f_A(t)$ and $f_D(t)$ from Fig. 2; $f_D(t)$ from Fig. 3.
Sea level changes in the Phanerozoic

**Eustasy** = change in sea level due to its rise and fall

Major controls on eustasy:

1. **Plate movements**
   (rise in sea floor associated with increased mantle upwelling beneath ridges)

2. **Volume of continental ice caps**
   (trap water, preventing it from returning to the oceans)

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*Figure 5*  Eustatic curves for the Phanerozoic. *A. This paper. B. After Vail et al (1977)*.

Modern topography of North America
First order sequences of strata in North America

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**Sea Level**

- Low
- High
- Low
- High
- Low
- High
- Low
- High
- Low

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Figure 6. Time-stratigraphic relationships of the sequences in the North American craton. Black areas represent nondepositional hiatuses; white and stippled areas represent deposition. (Stippling introduced only to differentiate successive depositional episodes.)

- **= No deposition**
- ** = Major sedimentary units**