To this point, we have focused on systems operating within the atmosphere or hydrosphere. Now we turn our attention to the lithosphere and:

- **Exogenic systems?**
  - reshape and wear down landscapes

- **Endogenic systems?**
  - create new crust and rejuvenate landforms

**Creationist interpretations:**

- Neptunism
- Catastrophism
History of Earth History

- Scientific Interpretations
  - Plutonism
    - Earth's interior is molten, all rocks of volcanic origin, James Hutton (1795), Theory of the Earth
  - Uniformitarianism (gradualism)
    - the present is the key to the past
    - same processes operating to shape the Earth today have been operating throughout geologic time, James Hutton (1795), Theory of the Earth
    - Charles Lyell (1830), Principles of Geology

Geologic Time

- Most endogenic and exogenic systems operate very slowly
- Intervals of time are determined by:
  - relative ages:
    - principle of faunal succession
    - principle of superposition
  - absolute ages:
    - radioactive dating techniques

Geologic Time Scale

Divides Earth's history into:

- Eons
  - Eras
    - Periods
      - Epochs

Analogous to:

- Years
  - Months
    - Weeks
      - Days
Earth’s Internal Energy

Two sources of energy drive endogenic systems:

1. _______________________

2. _______________________

Note: friction is also important on a very local/regional scale.

Earth in Cross-Section

Heavier elements migrated inward

Lighter elements were displaced outward

Concentric zones of differential composition and thermal characteristics.
Core

Divided into two regions, separated by variable transition zone

Inner core -

Outer core –

Magnetic Reversals and Polar Wandering

Mantle

Separated from outer core by another transition zone

Consists of lighter materials so less dense than core

Subdivided into:
- lower mantle
- upper mantle

Temp ↑ with depth
Rigidity ↑ with depth, due to pressure
Exception - asthenosphere
Upper Mantle

- Upper mantle
- Asthenosphere
- Upper most mantle

Upper most mantle + Crust = Lithosphere

Asthenosphere

Radioactive decay:
- increased heat energy
- convective currents
- plastic deformation

Heat energy variable - results in?

Depth of convection?

Lithosphere

Extends from surface to depth of approx. 70 km

Includes:
- Oceanic crust
- Continental crust

Boundary between crust and uppermost mantle?
Continental vs. Oceanic Crust

Continental crust:
- 
- 

Oceanic crust:
- 
- 

Isostasy

Crust is buoyant

Rising and falling crust?

The Geologic Cycle

Hydrologic cycle
- exogenic
- erosion, transport, & deposition of crustal material

Rock cycle
- creation of new rock
- intrusive = endogenic
- extrusive = exogenic

Tectonic cycle
- creation, deformation, and recycling of crust

Driven by: Solar energy, Internal heat energy, Gravity
### The Geologic Cycle

Continual cycle of:
- formation
- deformation
- erosion
- Recycling

Through:
- physical
- chemical
- biological

processes

Driven by: Solar energy, Internal heat energy, Gravity

---

### Rocks and Minerals

- Crust is composed of rock made of minerals
- Mineral – element or combination of elements, forms an inorganic compound
- Rock – assemblage of minerals bound together
- All rocks classified as either:
  1. 
  2. 
  3.

- A genetic classification
Minerals and Rocks

### Table 11.1 Common Elements in Earth’s Crust

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage of Earth’s Crust by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen (O)</td>
<td>46.6%</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>27.7%</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>8.1%</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>5.0%</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>3.5%</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>2.8%</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>2.6%</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>2.1%</td>
</tr>
<tr>
<td>All others</td>
<td>1.3%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Note: A quartz crystal (SiO₂), common of Earth’s surface abundant elements, silicon (Si), and oxygen (O₂). Image photo. (Copyright Pearson Canada Inc.)

---

**Igneous Rocks**

- Solidify/crystallize from molten rock

- Formed by either:
  - **intrusive** - from ________
    - endogenic, coarse grained
  - **extrusive** - from ________
    - exogenic, fine grained

---

**Igneous Processes**

- Intrusive and Extrusive Igneous Formations

---

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Types of Igneous Rocks

<table>
<thead>
<tr>
<th>General characteristics</th>
<th>Mafic Minerals</th>
<th>Sedimentary Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess uranium</td>
<td>Lower</td>
<td>Lower</td>
</tr>
<tr>
<td>Deposits in moving body</td>
<td>Higher</td>
<td>Higher</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mineral family</th>
<th>Quartz</th>
<th>Feldspar</th>
<th>Mica</th>
<th>Amphibole</th>
<th>Pyroxene</th>
<th>Olivine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification</td>
<td>Cenosphere</td>
<td>Anhedral</td>
<td>Anhedral</td>
<td>Anhedral</td>
<td>Anhedral</td>
<td>Anhedral</td>
</tr>
<tr>
<td>Chemical origin</td>
<td>Silica</td>
<td>Silica</td>
<td>Silica</td>
<td>Silica</td>
<td>Silica</td>
<td>Silica</td>
</tr>
</tbody>
</table>

Clastic vs. Chemical Sed. Rx.

- Clastic rocks are formed from clastic materials.
- Chemical precipitates form from chemical processes.
- Deposition in layers by exogenic processes.

Principle of original horizontality

Clastic sedimentary rock - sandstone
Lithification

Conversion of sediments to rock by?

1. 

2. 

3. 

Study of sequence, spacing, distribution, and age of sed. rx. is called ______________

Clastic vs. Chemical Sed. Rx.

<table>
<thead>
<tr>
<th>Unconsolidated Sediment</th>
<th>Grain Size</th>
<th>Rock Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulders, cobbles</td>
<td>&gt;80 mm</td>
<td>Conglomerate (breccia, if pieces are angular)</td>
</tr>
<tr>
<td>Pebbles, gravel</td>
<td>&gt;2 mm</td>
<td>Conglomerate</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>0.5–2.0 mm</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Medium-to-fine sand</td>
<td>0.062–0.5 mm</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Silt</td>
<td>0.0010–0.0063 mm</td>
<td>Siltstone (mudstone)</td>
</tr>
<tr>
<td>Clay</td>
<td>&lt;0.0039 mm</td>
<td>Shale</td>
</tr>
</tbody>
</table>

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**Metamorphic Rocks**

- Transformation of existing rocks by:
  - heat and/or pressure
  - change in chemical and/or physical properties

- Occur as a result of:
  - tectonic forces
  - regional metamorphism
  - contact metamorphism

---

**Types of Metamorphic Rocks**

<table>
<thead>
<tr>
<th>Metamorphic Rocks</th>
<th>Metamorphic Equivalent</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>Slate</td>
<td>Foliated</td>
</tr>
<tr>
<td>Sandstone</td>
<td>Gneiss</td>
<td>Foliated</td>
</tr>
<tr>
<td>Limestone, dolomite</td>
<td>Marble</td>
<td>Nonfoliated</td>
</tr>
</tbody>
</table>

---

**The Rock Cycle**
Plate Tectonics & Continental Drift

- As accurate maps showing entire continents became available, it was noted that some continents appeared to “fit together”
- Alfred Wegener (1912) was the first to present a hypothesis to explain this
  - continental drift

---

Continental Drift?

- He used evidence from:
  - fossil record
  - climatic record
  - geologic record

- But . . . he couldn’t explain how entire continents actually move?

---

Sea Floor Spreading

- Then in the 1960's Harry Hess and Robert Dietz propose theory of sea floor spreading
  - Based on existence of interconnected ridges, called mid-ocean ridges
    - result of crust being pulled apart
    - caused by convective currents in the asthenosphere
    - extrusion of lava creates new sea floor
Magnetic Reversals

Plate Tectonics & Continental Drift

Eventually led to theory of **plate tectonics**

- Explains processes such as:
  - lithospheric plate movements
  - sea-floor spreading
  - subduction zones
  - orogenic activity
  - crustal deformation
  - earthquakes
  - volcanism
### Three Types of Plate Boundaries

<table>
<thead>
<tr>
<th>Divergent Boundaries</th>
<th>Convergent Boundaries</th>
<th>Transform Boundaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-ocean ridges and rift valleys</td>
<td>Subduction zones where plates collide</td>
<td>In association with divergent boundaries</td>
</tr>
<tr>
<td>New crust is formed</td>
<td>Old crust destroyed</td>
<td>Crust neither created nor destroyed</td>
</tr>
<tr>
<td>Tensile forces - pulling apart</td>
<td>Compressional forces - pushing together</td>
<td>Shearing forces - sliding past one another in opposite directions</td>
</tr>
</tbody>
</table>
The Formation and Breakup of Pangaea

Along the mid-Atlantic Ridge, the surface started to rift wide at 150 mya and the North American Plate began moving to the north and opening up the Gulf of Maine. As India moved northward the Arabian block was subducted into the Red Sea. Earthquakes and volcanic activity increased rapidly in the Gulf of Aden. As Asia continued to rotate counterclockwise, the Indian plates travelled the thousand thousand kilometers.
Building Continental Crust & Terranes

1. From a nucleus of crystalline rock: craton
2. Volcanic activity associated with subduction zones
3. Accretion of exotic terranes onto continental margins

Orogenesis

An orogeny is a mountain building episode

Types of orogenic events are caused by collisions between:
- Oceanic vs. Continental plates
- Oceanic vs. Oceanic plates
- Continental vs. Continental plate collision

Oceanic Plate vs. Continental Plate Collision
Folding and Broad Warping

Faulting

Forces → fracture
Differential movement = fault
Surface along which movement occurs = fault plane
Type of faults depends on movement of footwall and hanging wall

Earthquakes

Occur along fault or plate boundary

Elastic-rebound theory
• Sticking points called asperities
• Stress accumulates until frictional forces are exceeded
• Magnitude is function of number and size of asperities

Focus vs. Epicentre
Explosive/Violent Settings

- high viscosity (thick) magma
- rich in silica and aluminium
  - producing felsic or granitic rock
  - characterized by:
    - steep sloped composite volcanoes - layers of ash, rock lava
    - ejection of pyroclastic material
**Effusive/Non-violent Settings**

- low viscosity (watery) magma
- high in iron and magnesium
- producing basaltic or mafic rock
  - characterized by:
    - gently sloped **shield volcanoes** from a single vent
    - **flood basalts** from elongated fissures

**Shield and Composite Volcanoes Compared**

**Hot Spots**

- Located in upper mantle and asthenosphere
- Concentration of radioactive materials = volcanic and geothermal activity
- As plate moves, location of volcanic features migrates, hot spot remains in same location
Yellowstone

Forces and Features at Plate Boundaries