Geologic Structure of Earth - The interior of the Earth is layered. Concentric layers: crust, mantle, liquid outer core and solid inner core.

Evidence (indirect) for this structure comes from studies of Earth's dimensions, density, rotation, gravity, magnetic field, behavior of seismic waves and meteorites.

Density is a key concept for understanding the structure of Earth - differences in density lead to stratification (layers).

Density measures the mass per unit volume of a substance.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Density is expressed as grams per cubic centimeter.

- Water has a density of 1 g/cm³
- Granite Rock is about 2.7 times more dense

Waves associated with earthquakes:

- P waves - Primary, compressional, arrive first, pass through solid, liquid and gas, oscillate in the direction of propagation
- S waves - Secondary, 'side-to-side' or shear waves, arrive second, cannot pass through liquid, pass through solid, oscillate in the direction transverse to propagation
Earth's layers – chemical composition and physical properties

- **Core**: ~3500 km thick, average density 13 g/cm³, 30% of Earth's mass and 16% of its volume
  - Inner core: radius of 1200 km, primarily Fe & Ni
  - Outer core: 2260 km thick, Temp of 3200°C, liquid (partially melted), viscous, less dense
- **Mantle**: 70% Earth's mass & 80% of its volume, 2866 km thick, @ Temp of 100-3200°C, Mg-Fe silicates, solid but can flow, average density 4.5 g/cm³
- **Core**: Composed primarily of iron
  - Density = 13 g/cm³

Earth's crust: cold, brittle

- Thin layer, 0.4% of Earth's mass and 1% of its volume
- **Continental Crust**:
  - Primarily granitic type rock (Na, K, Al, SiO₂)
  - 40 km thick on average
  - Relatively light, 2.7 g/cm³
- **Oceanic Crust**:
  - Primarily basaltic (Fe, Mg, Ca, low SiO₂)
  - 7 km thick
  - Relatively dense, 2.9 g/cm³
- Cool, solid crust and upper (rigid) mantle “float” and move over hotter, deformable lower mantle

Lithosphere & Asthenosphere: More detailed description of Earth's layered structure according to mechanical behavior of rocks, which ranges from very rigid to deformable

1. Lithosphere: rigid surface shell that includes upper mantle and crust (here is where plate tectonics work), cool layer
2. Asthenosphere: layer below lithosphere, part of the mantle, weak and deformable (ductile, deforms as plates move), partial melting of material happens here, hotter layer

Summary Table 1 - Physical Properties

<table>
<thead>
<tr>
<th>Layer</th>
<th>Chemical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental Crust</td>
<td>Composed primarily of granite</td>
</tr>
<tr>
<td></td>
<td>Density = 2.7 g/cm³</td>
</tr>
<tr>
<td>Oceanic Crust</td>
<td>Composed primarily of basalt</td>
</tr>
<tr>
<td></td>
<td>Density = 2.9 g/cm³</td>
</tr>
<tr>
<td>Mantle</td>
<td>Composed of silicon, oxygen, iron, and magnesium</td>
</tr>
<tr>
<td></td>
<td>Density = 4.5 g/cm³</td>
</tr>
<tr>
<td>Core</td>
<td>Composed primarily of iron</td>
</tr>
<tr>
<td></td>
<td>Density = 13 g/cm³</td>
</tr>
</tbody>
</table>

Summary Table 2 - Composition

<table>
<thead>
<tr>
<th>Layer</th>
<th>Physical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithosphere</td>
<td>Cool, rigid, outer layer</td>
</tr>
<tr>
<td>Asthenosphere</td>
<td>Hot, partially melted layer which flows slowly</td>
</tr>
<tr>
<td>Mantle</td>
<td>Denser and more slowly flowing than the asthenosphere</td>
</tr>
<tr>
<td>Outer Core</td>
<td>Dense, viscous liquid layer, extremely hot</td>
</tr>
<tr>
<td>Inner Core</td>
<td>Solid, very dense and extremely hot</td>
</tr>
</tbody>
</table>

Isostasy

A term used to refer to the state of gravitational equilibrium between the lithosphere and the asthenosphere, which makes the plates (seem like) “float” at an elevation that depends on their thickness and density - areas of Earth's crust get to this equilibrium after rising and subsiding until their masses are in balance.

Less dense continental blocks "float" on the denser mantle
Buoyancy: a 10 kg object can float if it lands on a liquid (water) body large enough that the object can displace a volume of liquid that weighs 10 kg and there is still more liquid left.

Buoyancy: depends on the mass and density of the object and of the liquid in which object floats.

Icebergs: 10% of volume above water, 90% of volume below surface.

Isostatic equilibrium: continental mountains float high above sea level because the lithosphere sinks slowly into the deformable asthenosphere until it has displaced a volume of asthenosphere equal to the mass of the mountain’s mass.

Very slow process – if it goes too fast for some reason then the rock will crack (fracture) and a fault occurs, and cause earthquakes.

Age of Earth was not easily determined, nor accepted as ‘that old’!

The Fit between the Edges of Continents Suggested That They Might Have Drifted

Evidence for Seafloor Spreading

- Earthquake epicenters
- Heat flow
- Ocean Sediments
- Radiometric dating of rocks of ocean and continental crust
- Magnetism

Synthesis of Continental Drift and Seafloor Spreading → Theory of Plate Tectonics

Main points of theory (Wilson, 1965):

- Earth’s outer layer is divided into lithospheric plate
- Earth’s plates float on the asthenosphere
- Plate movement is powered by convection currents in the asthenosphere seafloor spreading, and the downward pull of a descending plate’s leading edge.

Hess and Dietz in 1960 proposed a model to explain features of ocean floor and of continental motion powered by heat → mantle convection.

Chapter 3 – on to Plate Tectonics

Movement of the Continents – Continental Drift

- Continents had once been together advanced by Alfred Wegener during the 1920’s
- Ultimately rejected - Until new technology provided evidence to support his ideas.
  - Seismographs revealed a pattern of volcanoes and earthquakes.
  - Radiometric dating of rocks revealed a surprisingly young oceanic crust.
  - Echo sounders revealed the shape of the Mid-Atlantic Ridge.

Synthesis of Continental Drift and Seafloor Spreading → Theory of Plate Tectonics

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Lithosphere

A plate is the cooled surface layer of a convection current in upper mantle.

Tectonic plate is the cool surface, the result of a convection current rising from the (hot) upper mantle (spreading center) - as it cools it becomes denser so gravity 'pulls' it down (subduction zone).

Heat transfer: conduction (contact)

Convection (motion of an agent, currents)

Heated water rises, cools at the surface and falls around the container's edge.

Figure 2.13

Age of sea floor vs. distance from ridge crest

Model of Mantle Convection

Spreading centers - where new sea floor and oceanic lithosphere form

Subduction zones - where old oceanic lithosphere descends

Chapter 3 - Plate Tectonics

- Plate Tectonics - a unified model with ideas from continental drift and sea floor spreading
- Lithosphere broken into plates
- Plates move
- Boundaries between plates are sites of geologic activity
Earthquake Epicenters

Shallow epicenters - crustal movement (less than 100 km)
Mid-deep epicenters subduction (greater than 100 km)

As plates float on the deformable asthenosphere, they interact among each other. The result of these interactions is the existence of 3 types of boundaries:

- Divergent: plates move away from each other, examples:
  - Divergent oceanic crust: the Mid-Atlantic Ridge
  - Divergent continental crust: the Rift Valley of East Africa

- Convergent: plates move toward each other.
  Three possible combinations: continent-ocean, ocean-ocean, continent-continent

- Transform: neither (a) nor (b), plates slide past one another - transform faults.
  Example: San Andreas fault

Plates → Rigid Slabs of Rock

Seven major plates - Pacific, African, Eurasian, North American, Antarctic, South American, Australian
Minor plates - Nazca, Indian, Arabian, Philippine, Caribbean, Cocos, Scotia, Juan de Fuca

Fracture Zones-Transform faults

Plate boundaries in action: (1) plates move apart, (2) plates move toward each other, (3) plates move past each other

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Oceans are created along divergent boundaries

Recall that seafloor spreading was an idea proposed in 1960 to explain the features of the ocean floor. It explained the development of the seafloor at the Mid-Atlantic Ridge. Convection currents in the mantle were proposed as the force that caused the ocean to grow and the continents to move.

The breakdown of Pangea showing spreading centers and mid-ocean ridges

2 kinds of plate divergences

Mid Atlantic Ridge
South Indian Ridge

East African Rift System

Island Arcs Form, Continents Collide, and Crust Recycles at Convergent Plate Boundaries

Convergent Plate Boundaries - Regions where plates are pushing together can be further classified as:

- Oceanic crust toward continental crust - the west coast of South America
- Oceanic crust toward oceanic crust - occurring in the northern Pacific.
- Continental crust toward continental crust - one example is the Himalayas.

3 kinds of plate convergences

Modern divergence
East African Rift System

Convergent Plate Boundaries

- Continent – Ocean
- Ocean – Ocean
- Continent – Continent
Continent – Ocean
West Coast of South America

- Continent – Ocean
- Mount St. Helens

Island Arcs Form, Continents Collide, and Crust Recycles at Convergent Plate Boundaries

The formation of an island arc along a trench as two oceanic plates converge. The volcanic islands form as masses of magma reach the seafloor. The Japanese islands were formed in this way.

Many discoveries contribute to the theory of plate tectonics but the most compelling evidence comes from The Earth’s Magnetic Field

- Rocks record the direction of magnetic field (Magnetite)
- Magnetic field direction changes through geologic time
  - Polar reversals recorded in rocks
  - 560 °C = rock solidifies (Curie Point)
  - Captures magnetic signature
- Particles of Magnetite align with the direction of Earth’s magnetic field at the time of rock formation
The patterns of paleomagnetism support plate tectonic theory. The molten rocks at the spreading center take on the polarity of the planet while they are cooling. When Earth’s polarity reverses, the polarity of newly formed rock changes.

(a) When scientists conducted a magnetic survey of a spreading center, the Mid-Atlantic Ridge, they found bands of weaker and stronger magnetic fields frozen in the rocks.

(b) The molten rocks forming at the spreading center take on the polarity of the planet when they are cooling and then move slowly in both directions from the center. When Earth’s magnetic field reverses, the polarity of new-formed rocks changes, creating symmetrical bands of opposite polarity.