Plate Tectonics and the Structure of the Earth

Outline
- Structure of the Earth
- Lithosphere vs. Asthenosphere
- Earth’s Topography
- Isostasy
- Plate Tectonics
- Plates on a Map: Quakes & Volcanoes
  - Oceanic Plates
  - Continental Plates
- Plate Boundaries

Reading
- Hand out on my website
- Online Module Linked to my website. Use Internet Explorer (It requires Flash)
- For next lab watch: GEOCOAST - Using Geological Compass: Measuring Strike, Dip & Dip Direction on Ecampus

Earth’s Internal Structure 1
- 6380 km in radius (~3800 miles)
- Core (3470 km)
  - Metallic (Fe, Ni)
    - Inner core - solid (1/3)
    - Outer core - liquid (2/3)
- Mantle (~2900 km)
  - Dense solid rock
  - Rich in Mg and Fe
- Crust (0-80 km thick)
  - Less dense
  - Rich in Si and Al
How do we know what the Earth’s internal structure is?

- Propagation of seismic waves

Seismic Velocity Profile of Earth

What are the Plates?

- Lithosphere
  - Crust + Uppermost Mantle
  - Rigid (tectonic plates)
- Asthenosphere
  - Weak part of the upper Mantle

Asthenosphere

- Mechanical boundary layer
- Zone of weakness
- Seismic low-velocity zone
- Zone of partial melting (2-4% melt)
- Its depth is controlled by Temperature (1300 deg C)
- Allows the plates to slide over it
Ocean Basins vs. Continents

Continental vs. Oceanic crust
- Light (2650 kg/m$^3$)
- ~ Granite
- High elevation
- Not so strong
- Can be very old
- Lasts for ever
- Complex
- Moves passively
- Dense (2850 kg/m$^3$)
- ~ Basalt
- Low elevation
- Strong
- Young
- Gets recycled
- Simple
- Drives plate motions

Isostasy
- The lithosphere “floats” in the asthenosphere
- Like blocks of wood of different density or thickness in a bathtub

Two columns of equal total mass

Isostasy
- Each column of rock will have the same mass down to the level of compensation
- High topography is compensated by thick low-density crust beneath
Is the mantle really weak?
- Depends on rate of deformation
- Continent under the load of a glacier

Norway Topography - Isostatic Rebound

The distribution of earthquakes defines the plate boundaries

Sea-floor spreading is the engine of plate tectonics

Rules of Seafloor Spreading
- Mantle convects at about 1-10 cm/yr
- Rising convection at mid-ocean ridges
- Sinking at the trenches
- Oceanic basins are impermanent, continents are permanent
- The earth is a dynamic body, its surface always changing.

The ocean floor is a tape recorder
Take-Home Messages

- Earth is layered according to density
- The asthenosphere is a zone of weakness at the base of the plates
- Isostasy: The crust “floats” in the mantle
- Oceanic crust is basaltic, continental crust is granitic
- Plates movement is driven by convection
- The newly formed ocean floor records the magnetic field, and reveals the pattern of plate motion

Outline

- Plate Motions
- Plate Driving Forces
- Plate rotations and Euler Poles
- Plate Boundaries
  - Divergent
  - Convergent
  - Transform
- Structural Environments

Computer simulation of a magnetic field reversal

Polarity at the surface

Favre & Sheyko, 2017
ETH Zurich

Last Lecture-Review of Plate Tectonics

- Structure of the Earth
- Lithosphere vs. Asthenosphere
- Earth’s Topography
- Isostasy
- Plate Tectonics
- Plates on a Map- Quakes & Volcanoes
  - Oceanic Plates
  - Continental Plates

The sequence of reversals is distinctive

Columbia River basalts
Magnetostratigraphy

Magnetic Polarity Reversals
The engine of Plate Tectonics: Subduction

- Old ocean lithosphere sinks into the mantle at the trenches
- Earthquakes show us where the slabs are
- Volcanoes form at subduction zones

Seismic anisotropy model of the subducted lithosphere under Peru

Eakin et al., 2015
Deep Seismic Tomography: Tonga-Kermadec Subduction

(Anar, 2007)

What causes the Plates to move?

Driving Force
- Slab Pull (90%)
- Ridge Push (10%)

Resisting Force
- Basal Drag
- Mantle resistance
- Continental resistance
- Transform resistance

Plate Motions

Velocity in cm/year

All Plate Motions are Rotations around a "Pole of rotation"

Motion with respect to what?

• Frames of reference:
  - Another plate
  - Mantle
  - Hotspots

Fracture zones and mid ocean ridges follow the geometry of plate rotations
Plate Boundaries

- Divergent (plates move apart)
- Convergent (plates move together)
- Transform (plates move past each other)

Each plate boundary type has its characteristic structures

<table>
<thead>
<tr>
<th>Plate Boundaries</th>
<th>Structural Environments</th>
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<td>Compressional</td>
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<tr>
<td>Transform</td>
<td>Strike-slip</td>
</tr>
<tr>
<td>None</td>
<td>Passive</td>
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Divergent Boundaries = Extensional Structural Environment
- State of Stress - extensional
- Processes - Thinning and stretching of the crust
- Types of Structures - rifts, normal faults
- Examples - mid-ocean rifts, Basin and Range, East Africa Rift

Normal Faults
Normal Faults

Fault-Block Mountains

Basin and Range Faulting

Convergent Boundaries = Compressional Structural Environment

- State of Stress: compression
- Processes: Thickening and shortening of the crust
- Types of Structures: Fold and thrust belts, big mountains
- Examples: Andes, Himalayas, parts of the Rocky Mts.
Folds due to horizontal shortening

The Appalachians

Canadian Rockies
Continental Collision

Collisional Boundary

The Himalayas

Mount Everest

Transform Boundaries=
Strike-slip Structural Environment

- State of Stress- horizontal shear
- Processes- shearing
- Types of Structures- transform faults, major strike-slip faults, (also normal and thrust)
- Examples- San Andreas fault, Alpine fault (NZ), Anatolian fault (Turkey)
- Transform Boundary
- The most famous fault

San Francisco Bay
San Andreas Fault

Oceanic Transform Fault
Transforms Link other types of plate boundaries. They may grow, shrink or be stable.

What type of plate boundary is there along the US East Coast?

Passive Margin

Continental Growth

- Material added onto the continents at convergent boundaries
- Example:
  - Everything west of Nevada has been added to North America in last 700 Ma
Continental Growth

Take-home Messages

- The downward pull of subducting slabs drives plate motions
- All plate motions are rotations
- 3 kinds of plate boundaries create 3 different structural environments
- Gravity causes deformation at passive margins
- Continents grow by accretion at their edges