Introduction to Oceanography
Lecture 5: Plate Tectonics 1

Southern California Margin
• Southern CA has an unusual margin

Deep Ocean Basins
What about in the very center of the ocean basins?

Mid-Ocean Ridges
• Earth’s longest continuous mountain chain
  ~ 60,000 km long, ~1/3 of ocean floor area
  Relief: ~ 2-3 km above abyssal plains
The Mid-Ocean Ridge System


The Mid-Ocean Ridge System

Mid-Ocean Ridge Features

- Ridge Axis Rift Valley
  - Depth ~ 1 km,
  - Width ~ 10-20 km
  - Widespread volcanism
  - Shallow earthquakes
  - Perpendicular fractures

Mid-Ocean Ridges & Isostasy

- Keeping isostasy in mind, why do mid-ocean ridges stand up so high above the ocean bottom?

Questions?

- Why do we have oceanic and continental crusts?
- Why are there deep-sea trenches, mid-ocean ridges and long seamount chains?

Introduction to Plate Tectonics

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History of Plate Tectonic Theory

• Plate tectonics is a fundamental, unifying theory in all of the Earth Sciences.
• Explains locations of most earthquake zones, volcanoes, the age of the sea floor, and the shape of the Earth’s surface.
• Plate tectonic theory has only been accepted for ~40 years
  – more recent than evolution (Biology - late 1800’s), quantum mechanics (Phys/Chem - early 1900’s).
• Why? – the best evidence is under water!

The Scientific Method

• The process whereby scientists build accurate models of natural phenomena
  – Accurate: consistent and non-arbitrary
  – Empirical: based on observation and measurement

The Scientific Method

1) Observe phenomenon
2) Generate a testable hypothesis to explain phenomenon
   – Untestable hypotheses cannot become scientific theories
   – Earliest hypothesis of Plate Tectonics proposed by Alfred Wegener (1912): Continental Drift
3) Test hypothesis

Wegener’s Continental Jigsaw Puzzle

Observation 1: The coastlines of the continents around the Atlantic Ocean appear to fit together (particularly South America and Africa). Australia, India, Antartica and Madagascar also seem to fit together.

Observation 2: When the continents are fit together, many geologic features line up across the boundaries. Examples include mountain belts, types of fossils, belts of ~200 million year old and older rocks.

The Scientific Method

3) Experiments test if hypothesis is valid
   – Can the hypothesis predict the results for related phenomena?
   – Wegener’s hypothesis is incomplete:
     If continents drift and oceans close, what happens to the rocks in the ocean crust?
     • In 1910’s little was known about the ocean floor and Earth’s interior. Few instruments to make measurements.
     • BUT - from 1930’s through 1950’s much was learned about Earth structure, the age of rocks, and the seafloor.

     – WWII and Cold war ocean surveys, global satellite gravity surveys & global seismometer stations provide the necessary clues

Probing the Earth with Seismology

• Cold, brittle crust
• Energy radiates out as seismic waves
• Like a flash bulb inside the Earth
Probing the Earth with Seismology

Earthquake waves are detected with a seismometer.

Observation 3: Earthquakes are concentrated in a few “strips” or lines near the Earth’s surface. This suggests “cracks” or boundaries between rigid areas.

Earthquakes near Trenches

Observation 4: At trenches (e.g., NE. of Japan) earthquakes get deeper with distance. Earthquakes happen in rocks that are cold & break rather than flow. Deep earthquakes suggest a slab of cold material that was recently at the Earth’s surface.

Records of Earth’s magnetic field

• Convection in outer core generates the Earth’s magnetic field
  – Dominantly dipolar magnetic field
    – like a bar magnet aligned near the rotation axis
  – Magnetic poles reverse locations ~1/250,000 years
  – Last reversal ~780,000 years ago

Dating rocks with magnetism

• At volcanoes, molten rock erupts and cools. As it cools crystals form (it solidifies).
• Some crystals with iron in them are magnetic. They tend to line up with the Earth’s magnetic field when they cool down.
• If the Earth’s magnetic field reverses, the crystal magnets stay put -- they are frozen in place.
• A magnetometer towed behind a boat will pick up a weak field if the crystal magnets point the opposite direction from the Earth’s field. (They partly cancel each other out).
• A magnetometer will pick up a strong field if the crystals point the same direction and the Earth’s magnetic field.

The oceanic “tape recorder”

Magnetic survey of a mid-ocean ridge in the Atlantic Ocean near Iceland.

Areas of strong and weak magnetism on either side of the mid-ocean ridge are mirror-images.

The crest of the ridge has strong magnetism (i.e., crystals and Earth aligned.)
Farther away weaker magnetism (Crystals formed when the Earth’s field was reversed).
Many oscillations from strong to weak.
Interpretation: New crust forms symmetrically at mid-ocean ridges.

Crust formed just before 3rd to last reversal
Crust formed just before last magnetic reversal
Crust formed just before last magnetic reversal
Crust formed just before 2nd to last reversal
Crust formed just before 3rd to last reversal

This interpretation is confirmed by the age of sediments and volcanic rocks on the seafloor (youngest at the top of the ridge).

Seafloor-spreading movies!
Movies run from 9.9 million years ago to present

Magnetic stripes not just found in Atlantic!
Faults, sediments complicate interpretation of magnetic patterns on the seafloor, but they are the best high-resolution record of ancient plate motions, and the history of the ocean basins.