Using Data to Build an Understanding of Earth

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What is Earth Science?

- The use of physics, mathematics, chemistry and biology to build a quantitative understanding of Earth and its environs.
- Fundamentally why do we do this? It gives us a predictive ability to address the future behavior of the system.

Types of Earth Science

- Geophysics: Application of Physics to Earth
- Geology: Study of the solid Earth
- Meteorology: Study of Earth's atmosphere
- Oceanography: Study of Earth's oceans
- Planetary Science: Comparative study of other planets
- Geobiology: Latest sub-field addressing biological effects on Earth.

What do Earth Scientists do?

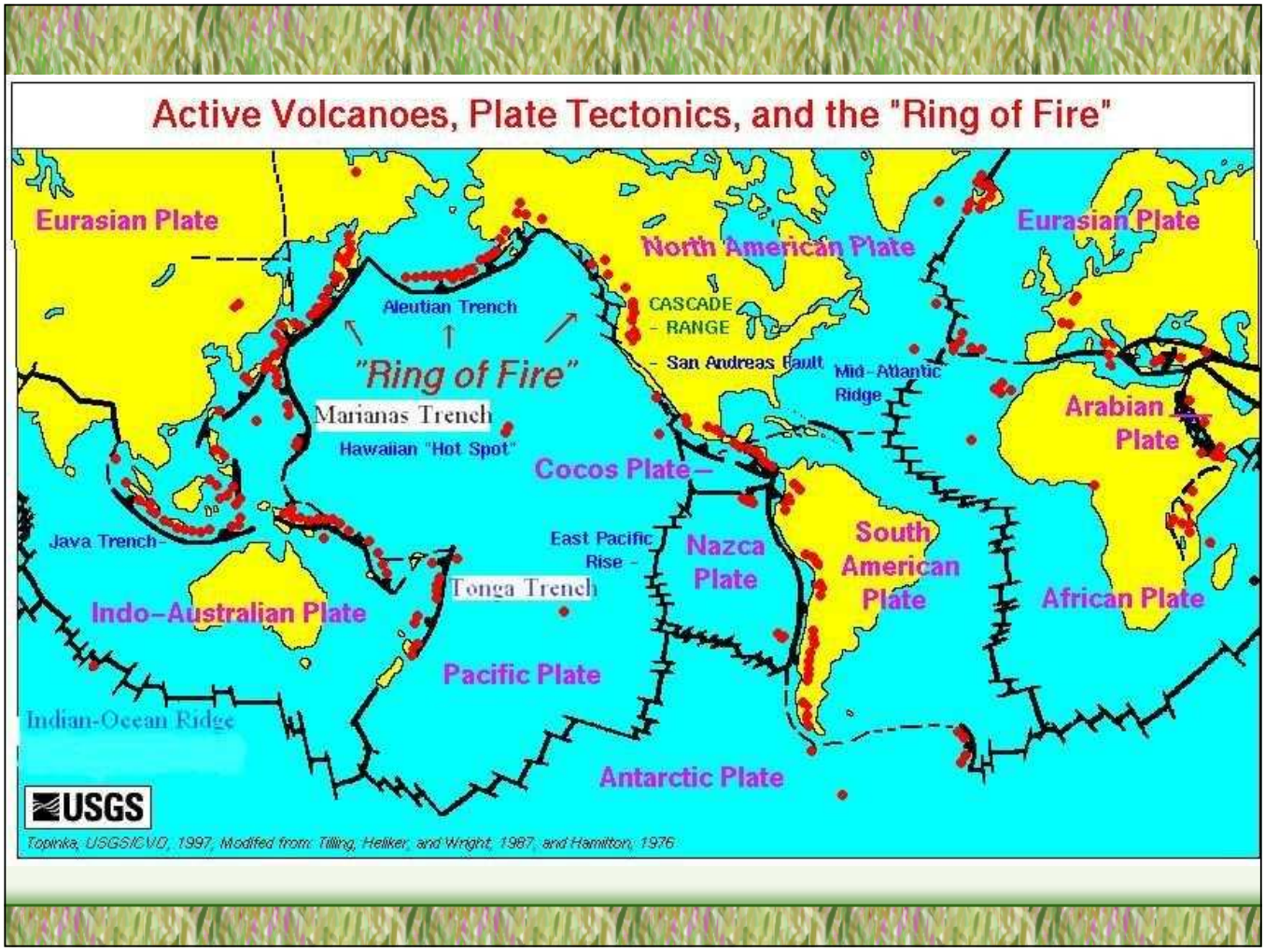
- Apply the scientific principle: Formulate hypotheses and then test those hypotheses.
- In Earth Science, data usually plays a critical role in testing and formulating hypotheses.
- In general, each area of Earth Science have major paradigms that form the basis of the field.

Solid Earth Science

- Major paradigm: *Theory of plate tectonics*
- Theory states: Earth's surface is made up of rigid plates that move relative to each other.
- This theory is the equivalent of General relativity and quantum theory to Physics
- Quote: *"There is nothing like data to ruin a perfectly good theory"*

Plate Tectonics

- As with all theories it is not perfect; but it explains much of the behavior of the solid Earth.
- Earth scientists ask: How do we test this theory and if it is correct what can it tell us about the behavior of Earth?
- NOTE: Theory was only developed in mid-1960s.



Example: Development of Plate Tectonics

- Observation: Basic feature of the Earth
  - Mountains, flat areas, oceans – Topography
  - Mixture of old and new rocks – Fossils/Geology
  - Dynamic processes – Earthquakes, volcanoes
- Question: Is there a single explanation for all these phenomena?
- Note the variety of data used.

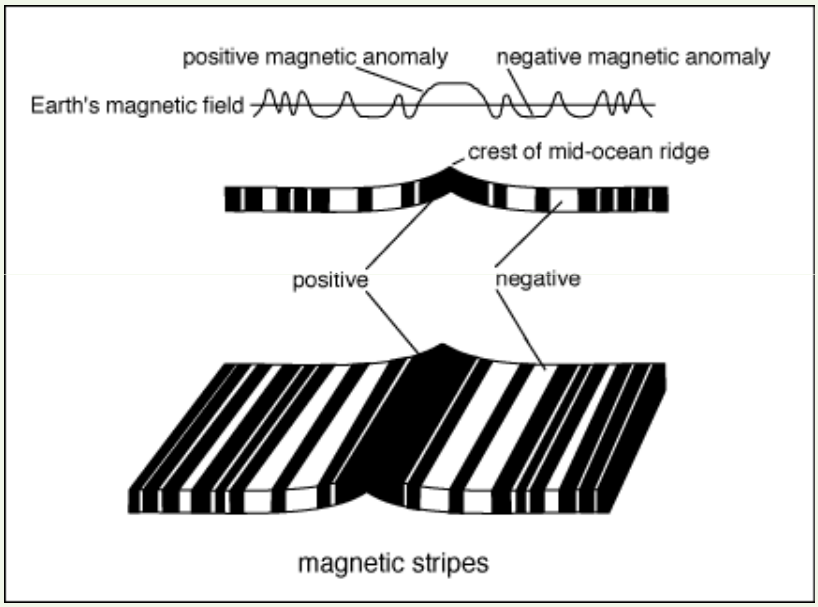
Data used to address problem

- Answer not recognized until mid-1960s although Wegener first proposed "continental drift" at start of 1900s.
- Basic Data used in formulating plate tectonics:
  - Magnetic stripes on the sea-floor
  - Directions of slip vectors during Earthquakes
  - Directions of "transform faults" in sea floor

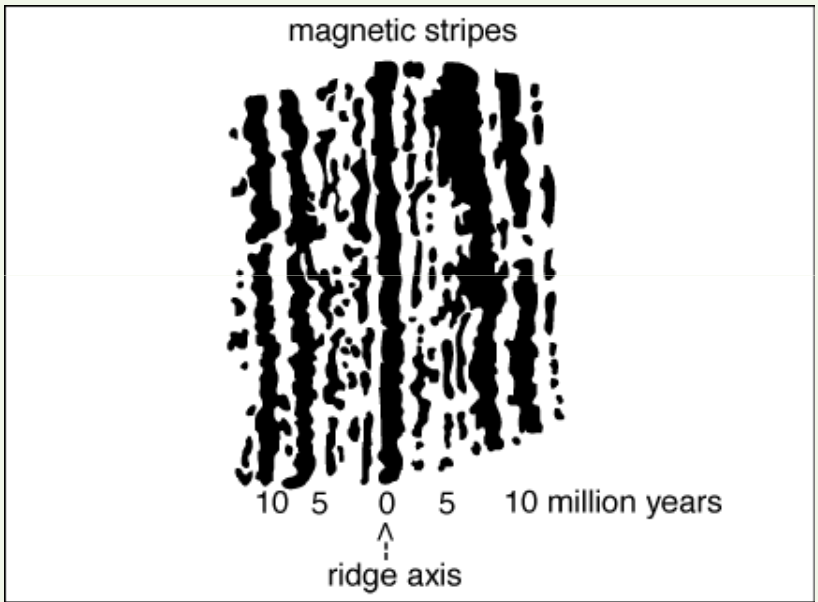
Magnetic reversals

- Observations:
  - Magnetic field of Earth reverses on semi-regular basis
    Short History:
    1.0R, 1.8N, 1.9R, 2.5N, 2.9R?,3.1N,3.4R Myrs.
  - How do we know dates? Radiocarbon dating; fossils
  - "Hot" rocks record the direction of the magnetic field as they cool: Curie Temperature

Magnetic "Stripes" on Seafloor

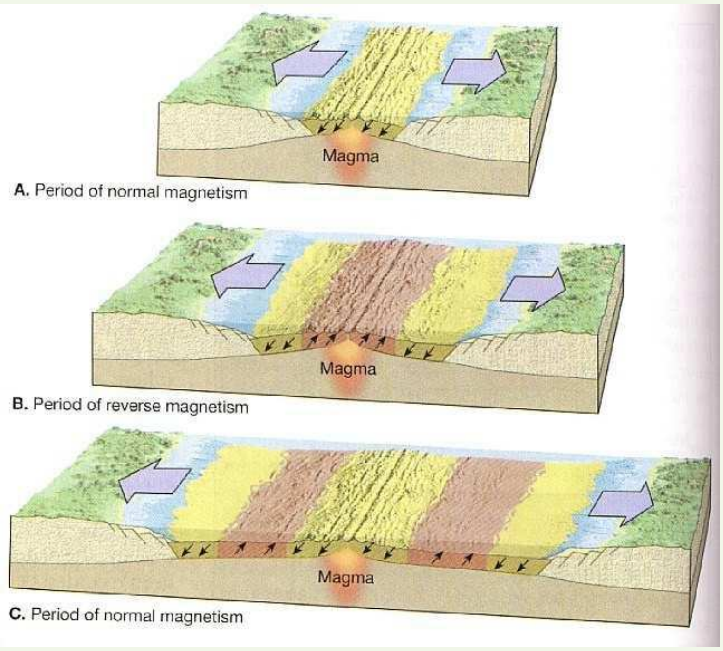


Actual Data (South of Iceland)



Pattern created by magnetic stripes along the Mid-Atlantic Ridge south of Iceland.

Generation of anomalies



Earthquakes: Types of faults

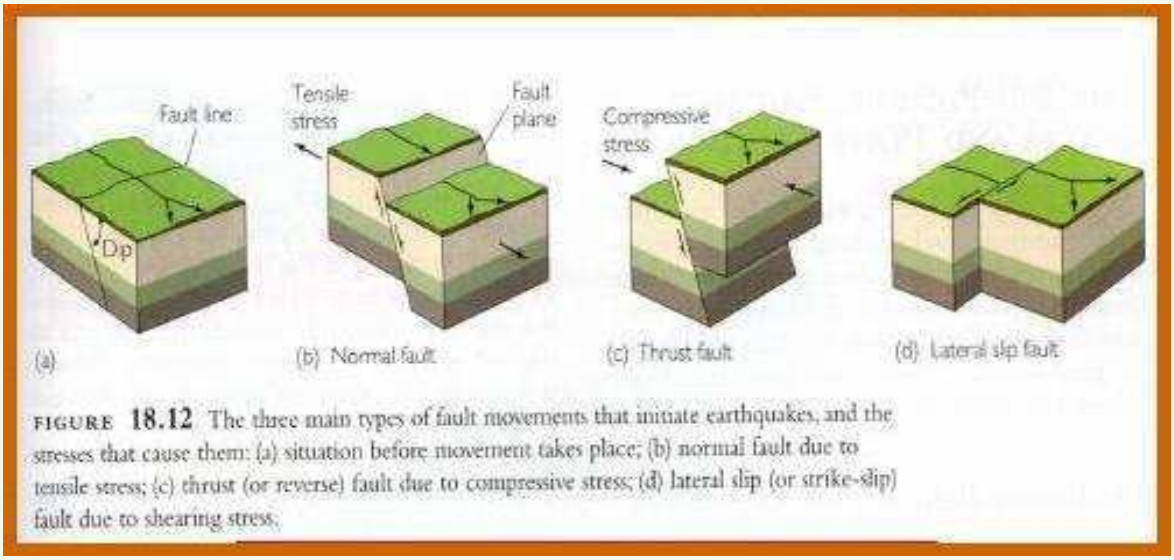
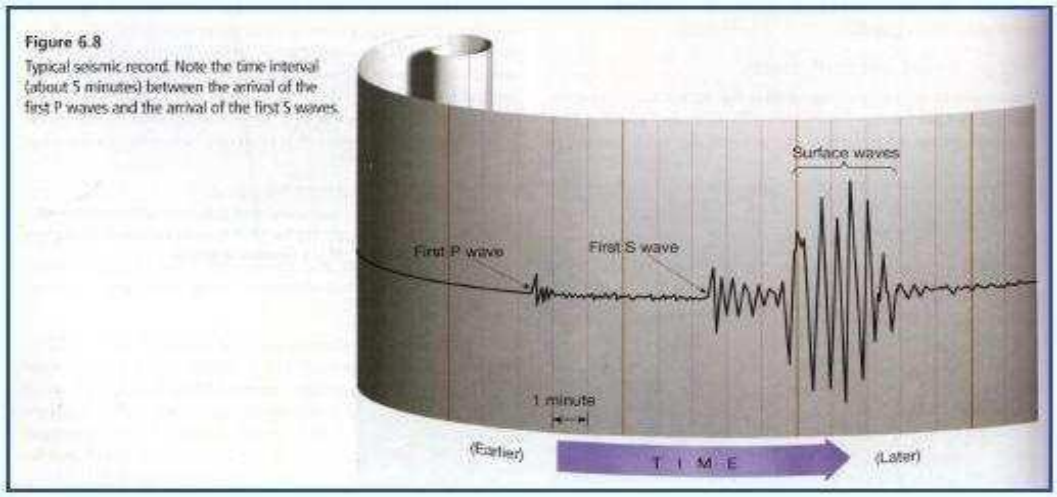


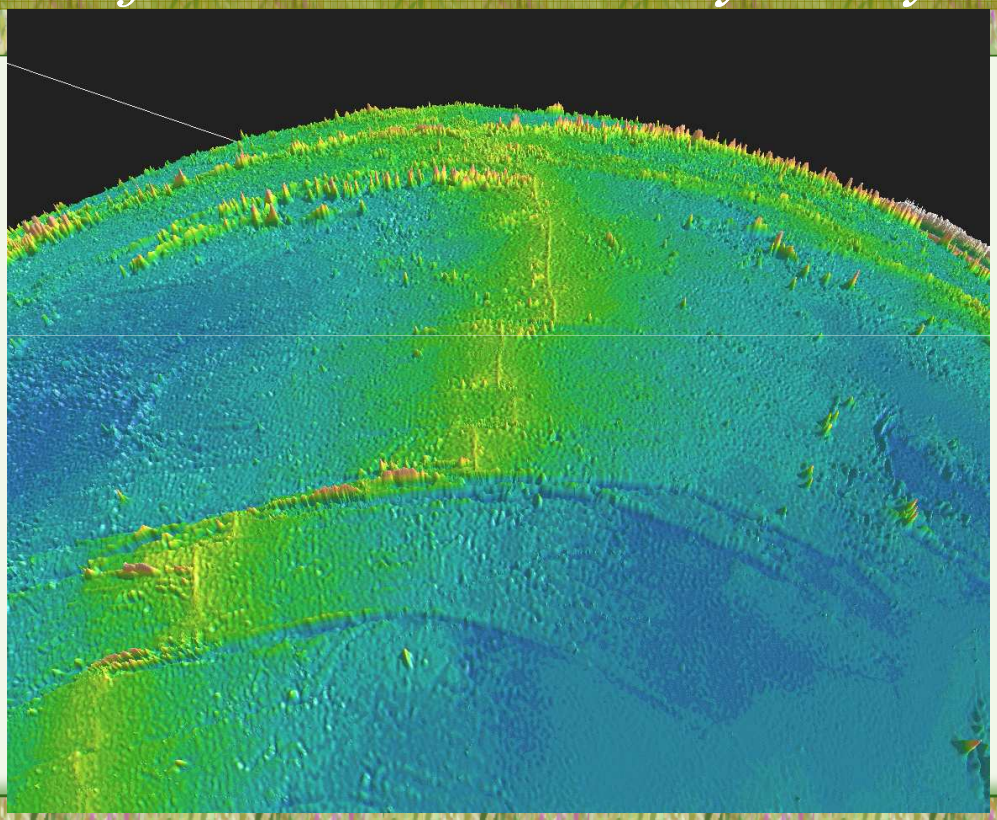
FIGURE 18.12 The three main types of fault movements that initiate earthquakes, and the stresses that cause them: (a) situation before movement takes place; (b) normal fault due to tensile stress; (c) thrust (or reverse) fault due to compressive stress; (d) lateral slip (or strike-slip) fault due to shearing stress.

Earthquakes: Seismology

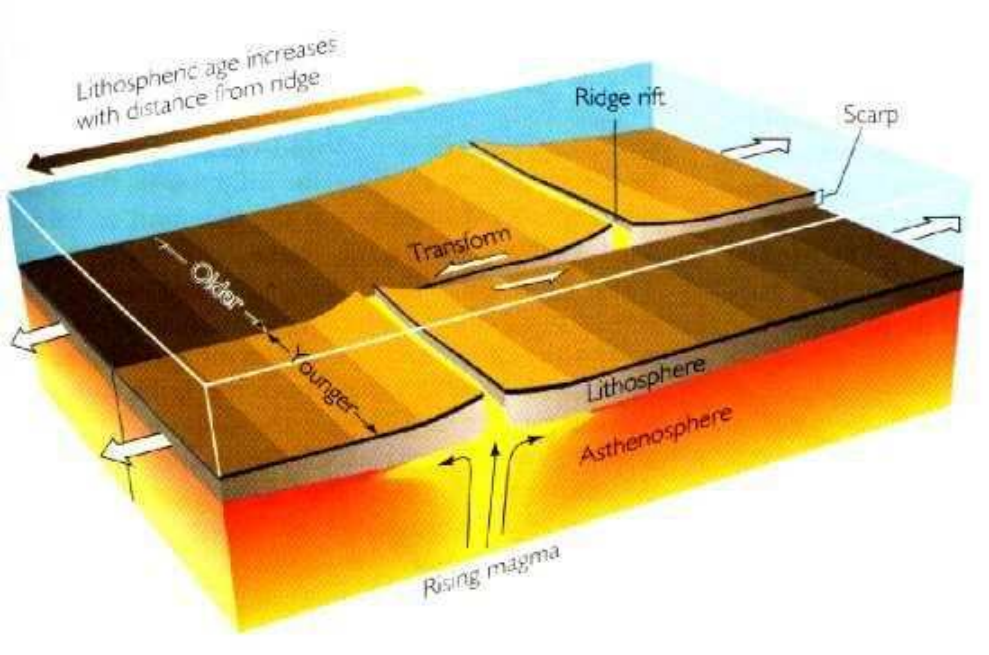
- Measurement of "sound" waves from earthquake



Transform Faults: Bathymetry



Transform Faults: Directions



Synthesis:

- Magnetic anomalies tell us speed of motion
- Transform faults the direction of motion over long periods of time
- Earthquakes the instantaneous direction of motion
- Explanation: Rigid plates moving over surface that interact at their boundaries

What does plate tectonic explain?

- Much of the topography of Earth: Where the high mountains are (Andes, Himalayas etc); Shape of seafloor (mid-ocean ridges, deep trenches)
- Locations of most earthquakes and volcanoes

What does this tell us?

- Future motions of plates
- Where earthquakes are likely to occur
- Importantly: Plate Tectonics gives a framework in which to formulate hypotheses that can be tested.
  - e.g., Interaction between plate tectonics and climate

Is the theory perfect? No!

- Problems:
  - How do we explain earthquakes that occur in the middle of plates?
  - What drives the whole system?
  - Is there another major process occurring?
- Provides a starting point for addressing
  - How variable are the plate motions?
  - Why do have motions changed in the past?

General Issue:

- How do you convey that Science is not absolute?
- None of the theories used in science are complete!
- General Relativity, Quantum Theory, Newtonian Mechanics all have problems at some level
- Does this mean they are useless? No.

Meteorology and Oceanography

- Both fields search to explain the dynamics and evolution of the oceans and atmosphere
- Each seeks predictive capabilities of the dynamics and chemistry of these fluid bodies
- Strong basis in physics, chemistry, mathematics and statistics

Basic principles

- Both use:
  Force = mass x acceleration
  Conservation of mass and energy laws
  Thermodynamics and chemical reactions
- Implementation of these models to the real Earth is complex but there are some simple examples
- Data plays critical role in evaluating models

Measurements in Earth Science

- There really are not that many types
- All fields use similar types
- Classes:
  - *In situ* properties (temperature, composition..)
  - Characteristics of propagated signal (seismic waves, remote sensing, time delay for distance measurement...)
  - Signal interaction (radar, seismic…)

Measurement location

- Where measurements are made varies greatly
- Typical locations:
  - In/under ocean/atmosphere
  - Earth's surface (maybe looking at some other location)
  - From space (either looking down or up)

Summary of Earth Science

- Physics and Chemistry provide the fundamental laws of nature
- Mathematics and statistics provide the methods for solving the laws
- In Earth Science, these are all put together in an attempt to fundamentally understand the workings of our planet.

Relevance:

- There are complex issues facing the future of Earth which are as much political as scientific
- There are typcially no absolute answers to these questions — but in many cases, Earth science provides the framework in which we can evaluate the problem.

Web resources

- EAPS: http://www-eaps.mit.edu
- NASA: http://www.gsfc.nasa.gov
- NASA: http://www.nasa.gov/kids.html
- TOPEX
  http://www.csr.utexas.edu/eqpac/elnino.GIF
- Earth Science course
  http://geo.lsa.umich.edu/~crlb