Introduction to
PLATE TECTONICS

part 2: from Continental Drift to Plate Tectonics

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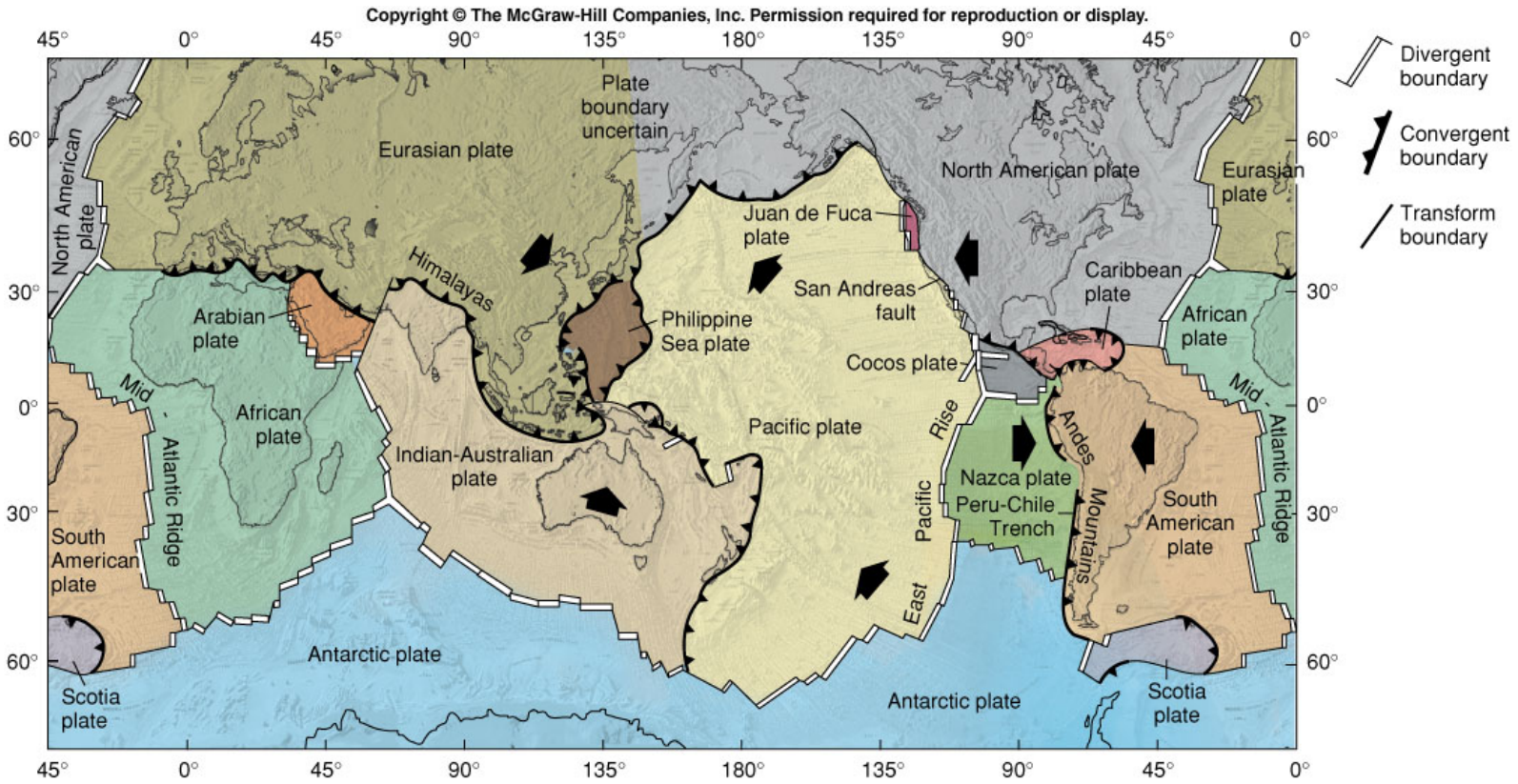
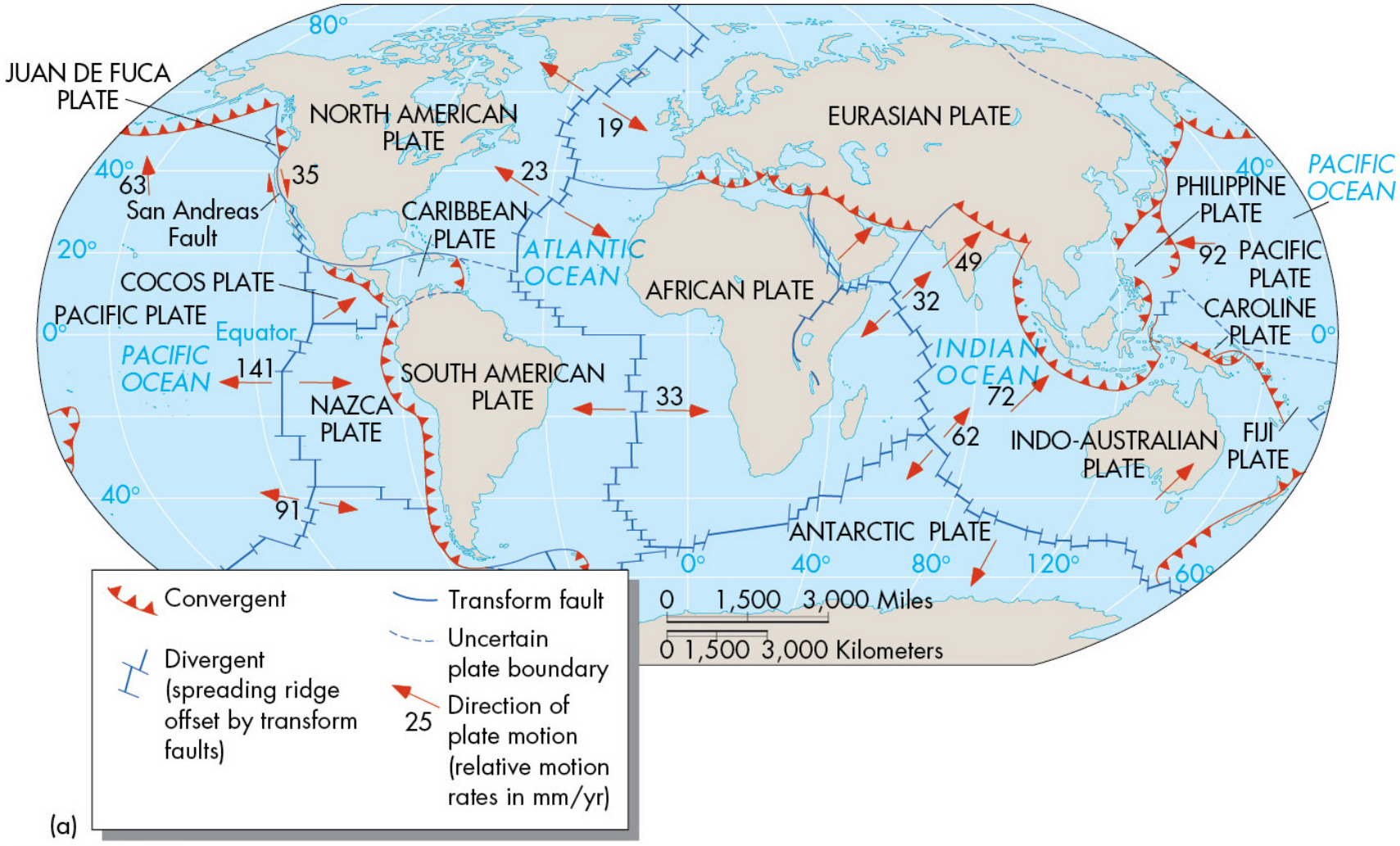
PLATE TECTONICS

Earth's surface is divided in a series of LITHOSPHERIC PLATES

that move passively around the surface,

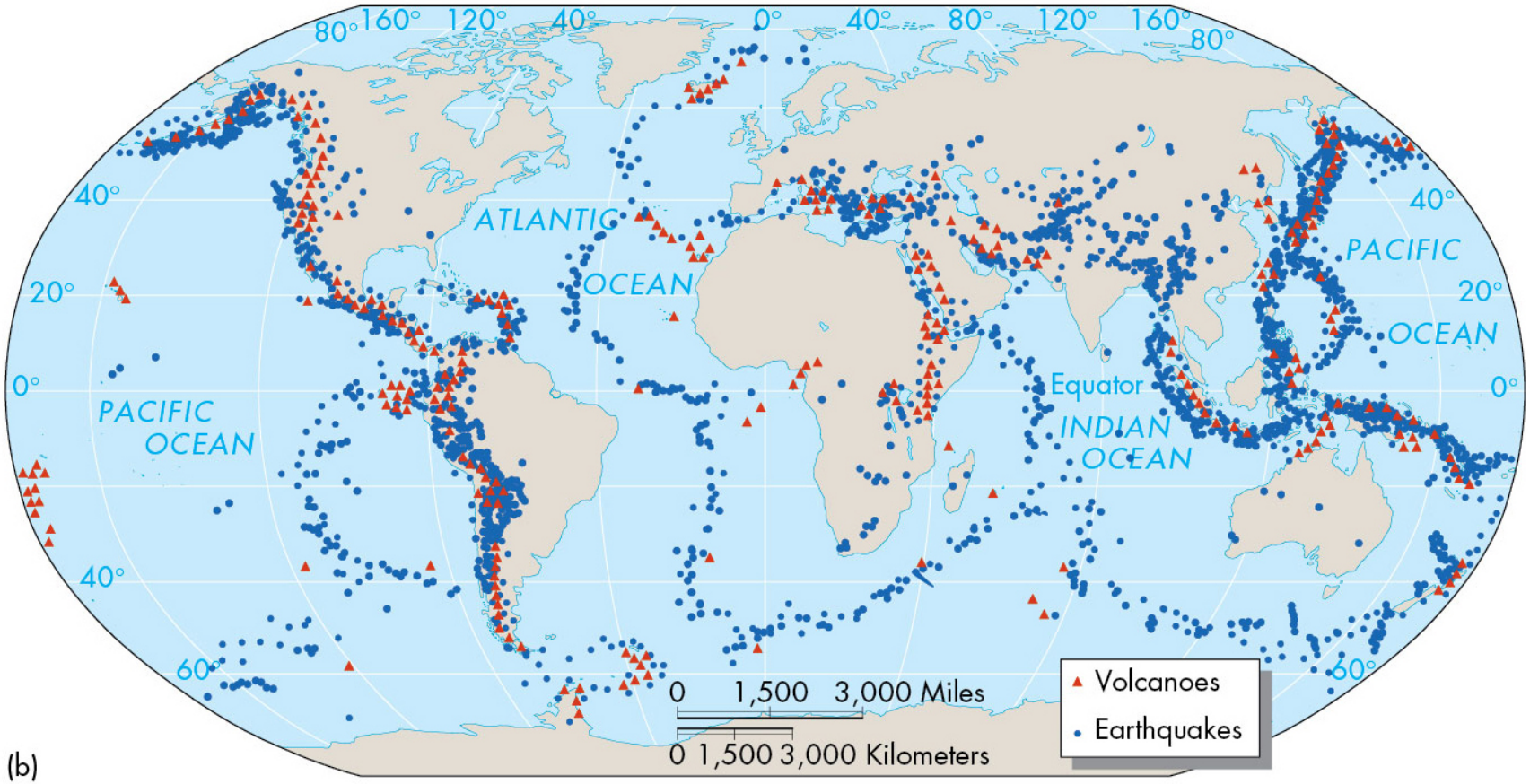
dragged by convection in the ASTHENOSPHERE




JUAN DE FUCA PLATE
NORTH AMERICAN PLATE
EURASIAN PLATE
PACIFIC OCEAN
PHILIPPINE PLATE
PACIFIC PLATE
CAROLINE PLATE
CARIBBEAN PLATE
ATLANTIC OCEAN
AFRICAN PLATE
COCOS PLATE
PACIFIC PLATE
Equator
PACIFIC OCEAN
SOUTH AMERICAN PLATE
NAZCA PLATE
INDIAN OCEAN
INDO-AUSTRALIAN PLATE
FIJI PLATE
ANTARCTIC PLATE
San Andreas Fault
63
35
19
23
49
92
32
141
33
72
62
91
80°
40°
20°
0°
40°
0°
40°
80°
120°
60°
0 1,500 3,000 Miles
0 1,500 3,000 Kilometers
Convergent
Divergent (spreading ridge offset by transform faults)
Transform fault
Uncertain plate boundary
25
Direction of plate motion (relative motion rates in mm/yr)

(a)

- Plate Tectonics
  - Plates move relative to one another, mostly interacting at their edge, or boundary
  - Boundaries between lithospheric plates are geologically active areas
  - Plates are created and destroyed



(b)

History of Plate Tectonics

- Continental Drift (Alfred Wegener, 1912)
  - Continents move freely ("drift") over Earth's surface, changing their position relative to one another

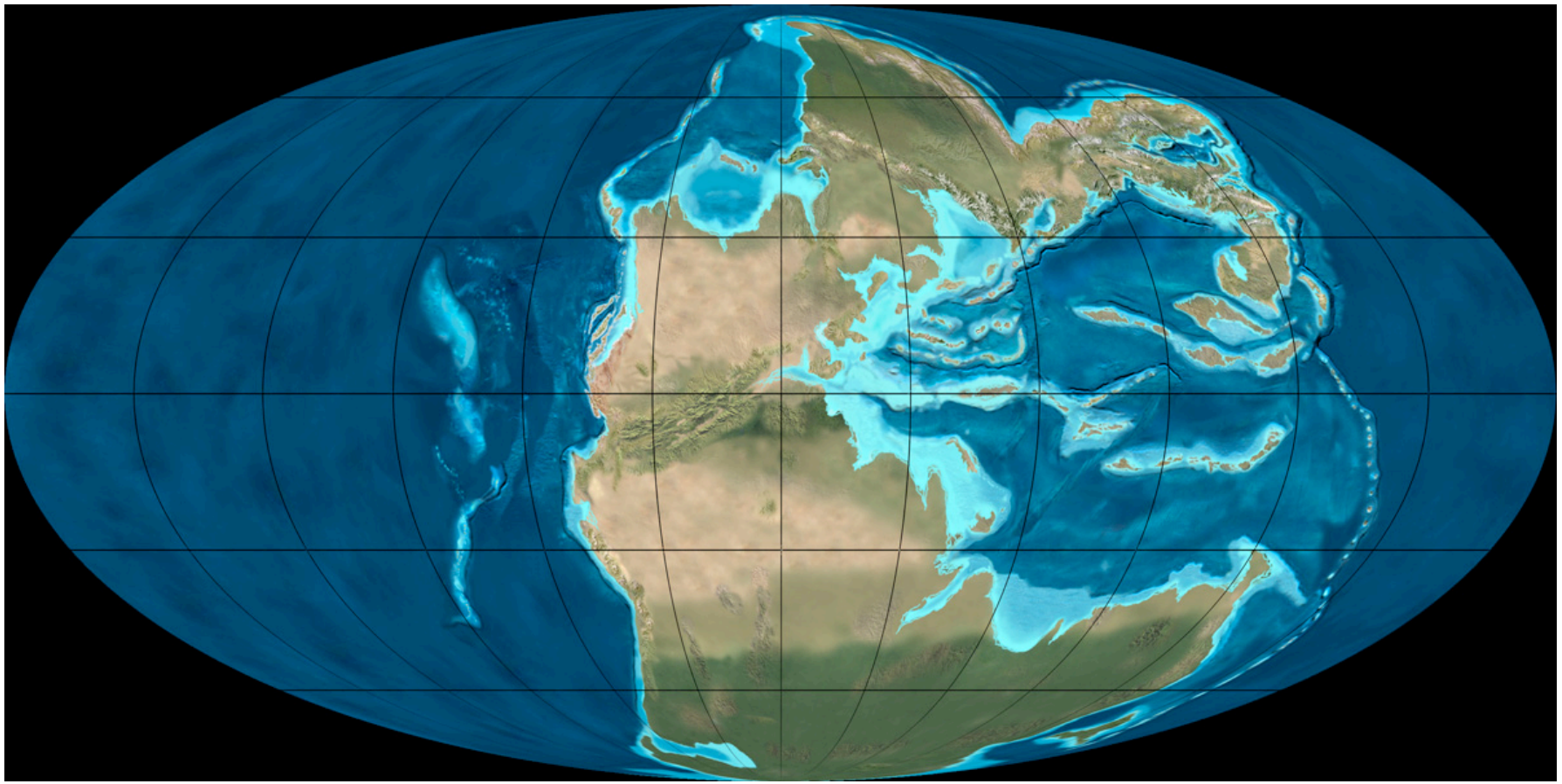
- Sea-floor Spreading (Harry Hess, 1962)
  - Sea floor forms along a mid-ocean ridge crest, then moves horizontally away from it towards an ocean trench

Wegener (1912)

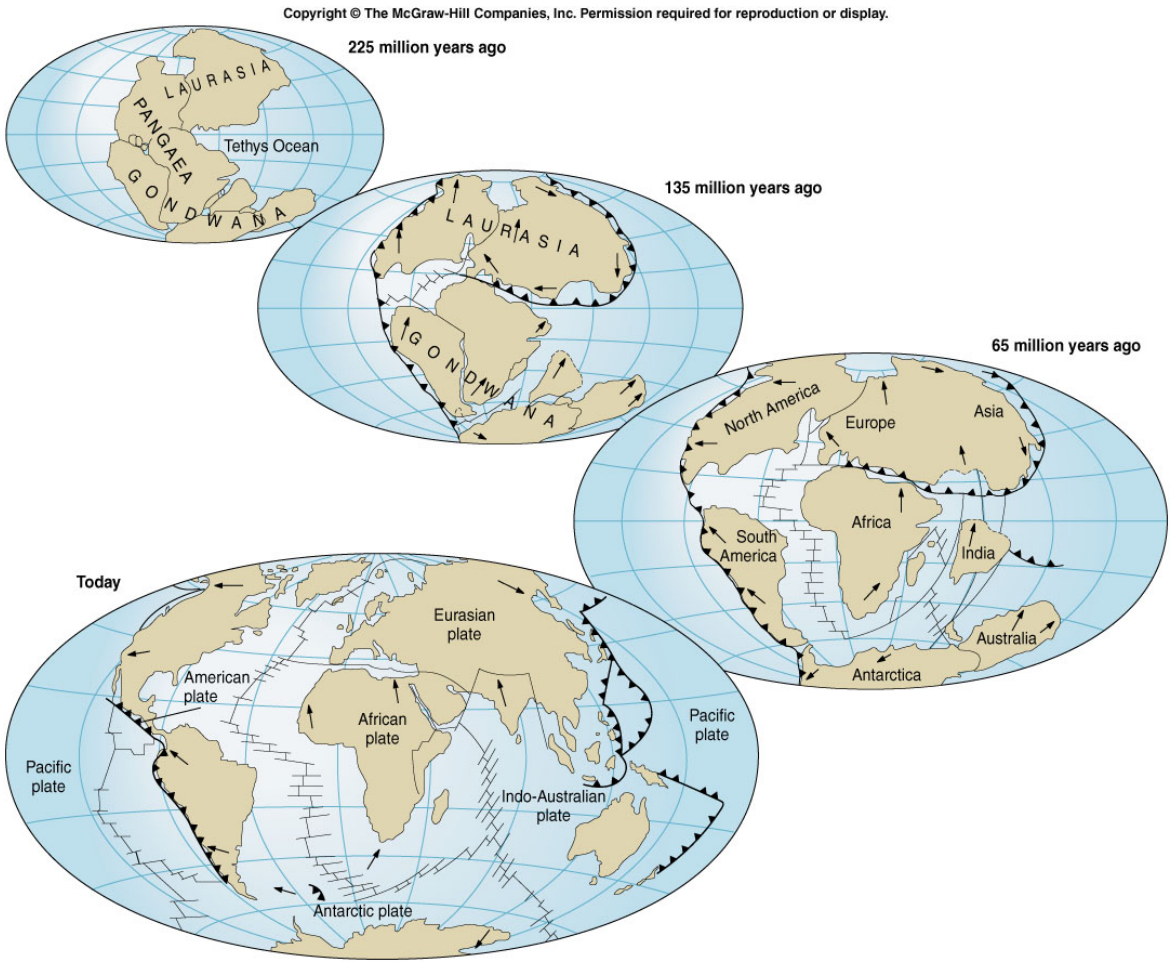
All present-day continents were grouped together in a supercontinent he named Pangea (“all Earth”), surrounded by a global ocean called Panthalassa (“all sea”)

a modern reconstruction of Pangea and Panthalassa in the Early to Mid Triassic, about 240 million years ago

from: jan.ucc.nau.edu/~rcb7/mollglobe.html



Pangea started to split into smaller continents that have been moving apart since then, generating the geography of today



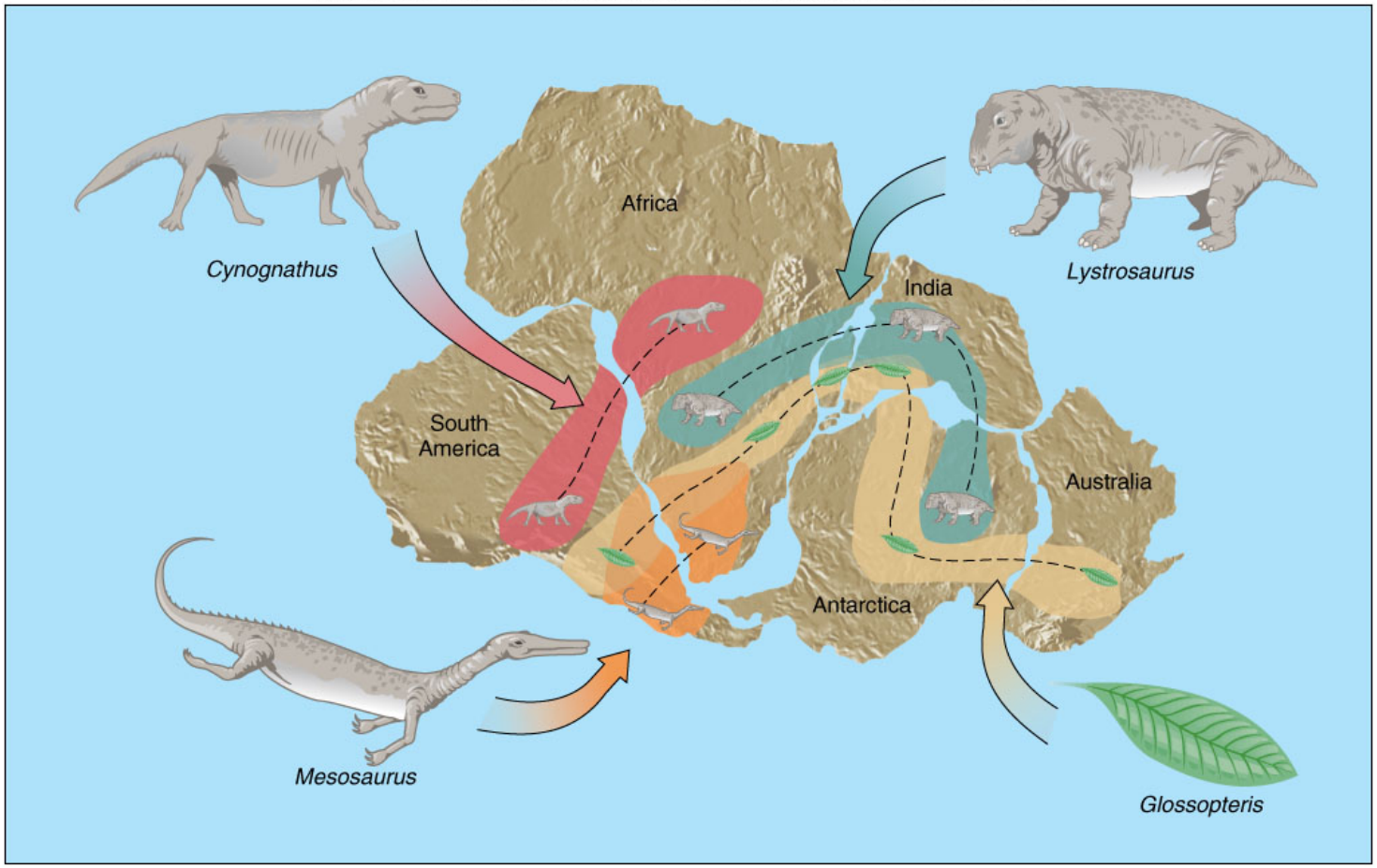
What evidence did Wegener have?

- Four lines of evidence:
  - Fit of the continents
  - Similarity of rock types across oceans
  - Similarity of fossil types across oceans
  - Paleoclimate evidence from glaciations across continents

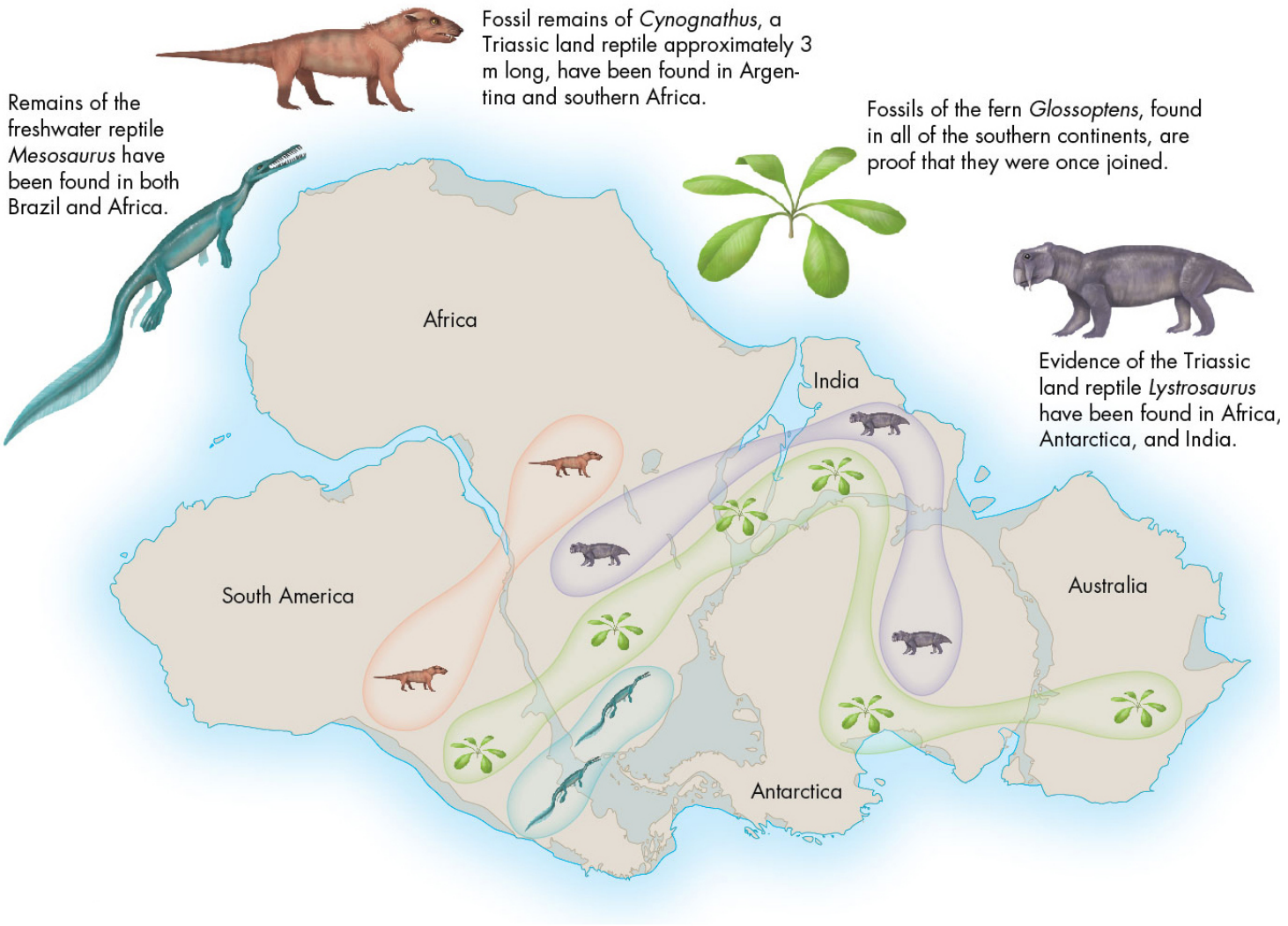
1 - Fit of the continents and 2 - rock similarity

Today's Appalachian Mountains are the remnant of a much longer mountain chain that predated the breakup of Pangea. They continue from Newfoundland (Canada) into Ireland, Scotland, and Norway

3 - Fossil similarity



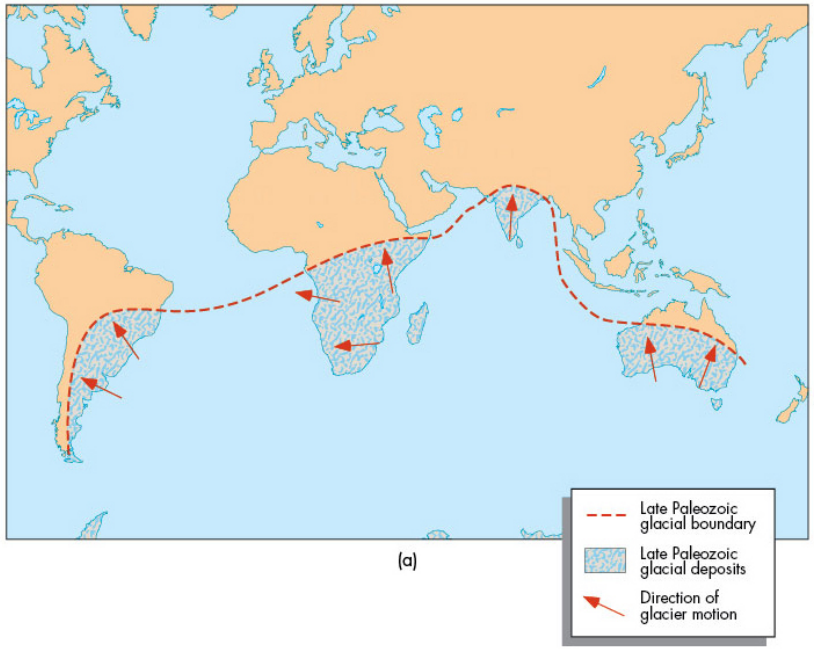
3 - Fossil similarity



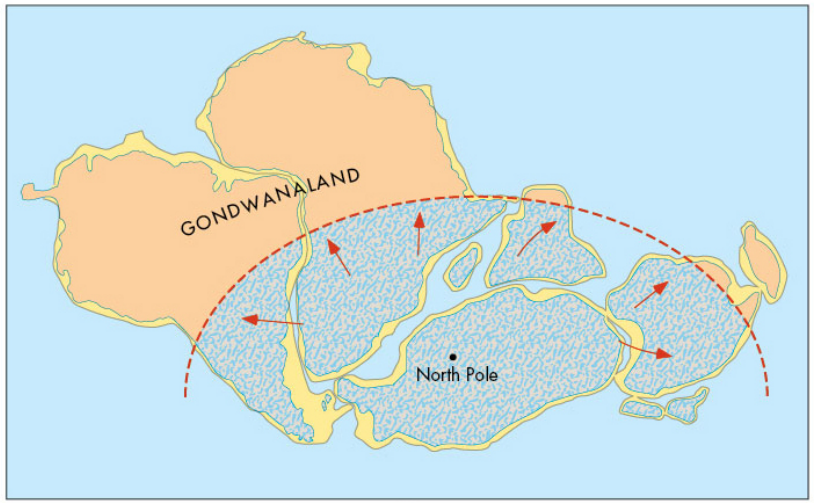
4 - Paleoclimate

– Glacial deposits

– Direction of glacial motion



(a)



(b)

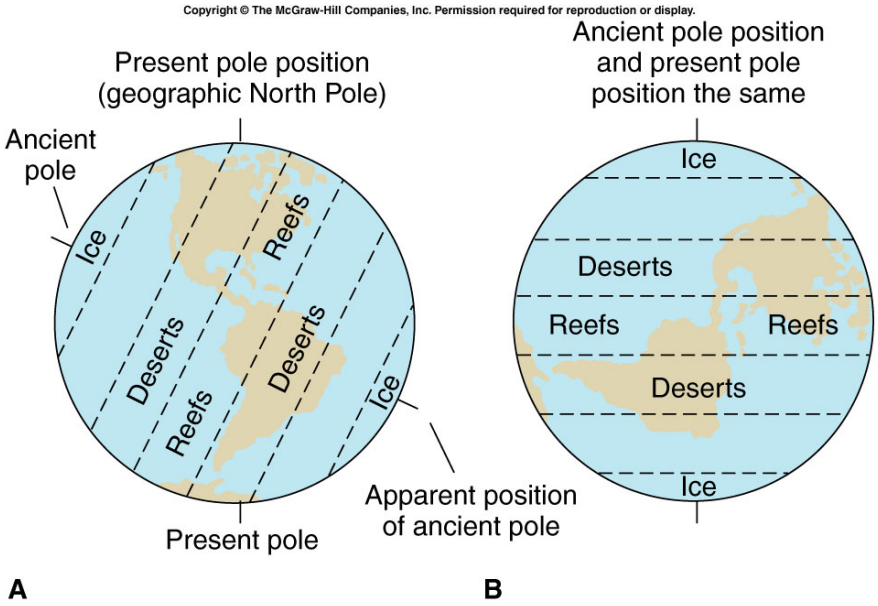
1 – Fit of continents

2 – Rock similarity

4 – Direction of glacial motion

Wegener and Polar Wandering

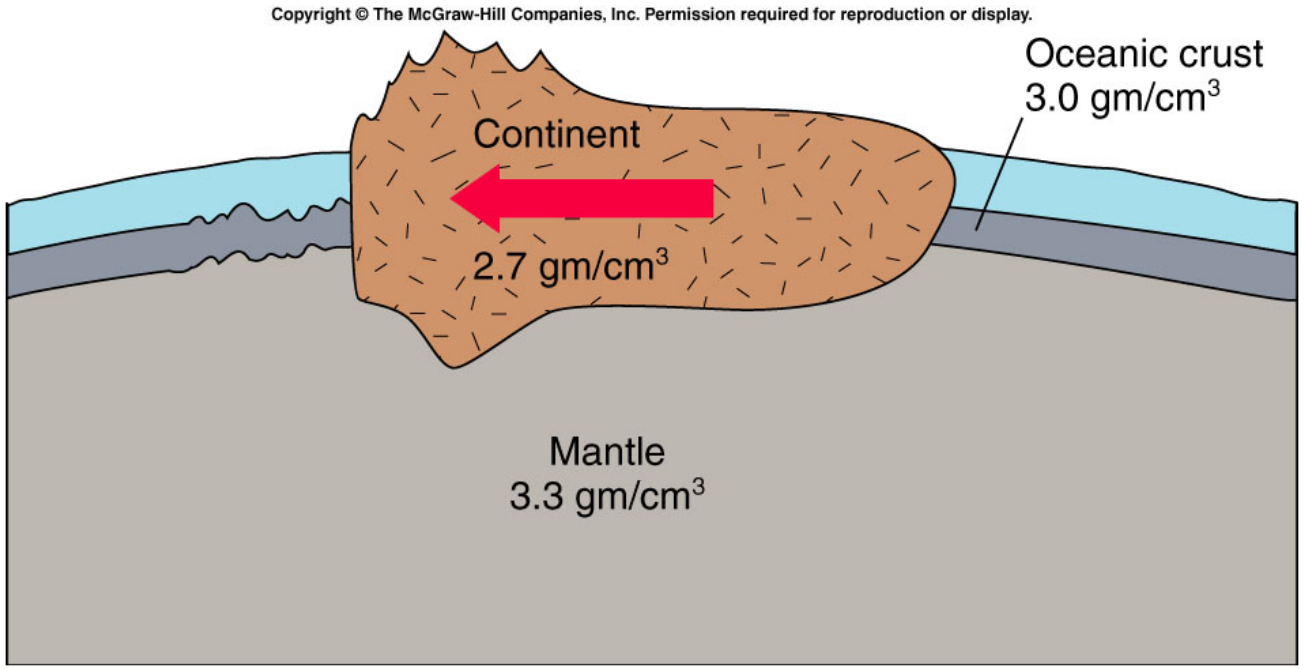
- Rocks indicate climate
- If continents did not move, then the poles did (case A)
- If poles did not move, then the continents drifted (case B)



Wegener then plotted the *apparent* wander of the poles, using that concept as further support for his idea of Continental Drift

Continental Drift was rejected

- Wegener's (and his collaborators such as DuToit) could not explain how continental drift would occur
- They ended up saying that continents were "plowing" through hard crust
- That is not possible
- Their theory was rejected and forgotten



The revival of Continental Drift after World War II

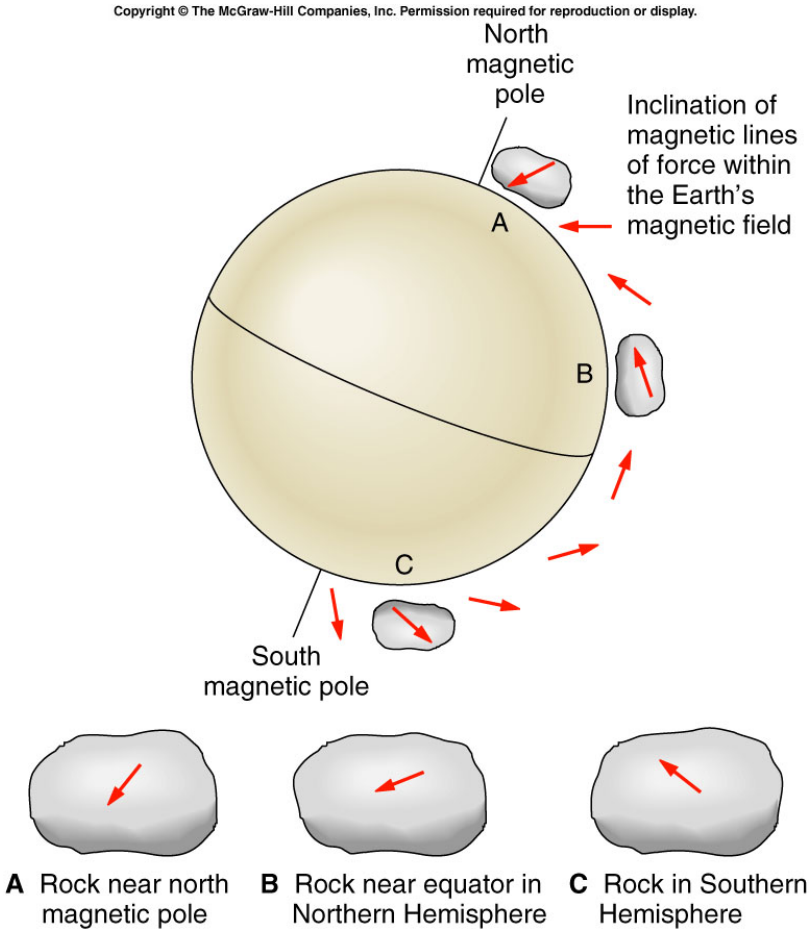
- Military information was collected for submarine warfare during World War II
- Information was declassified soon after war's end
- Two pioneering institutions:
  - Woods Hole Oceanographic Institution (Massachusetts)
  - Scripps Institution of Oceanography (California)
- New investigations were started in:
  - geophysical research (mostly paleomagnetism)
  - the study of the sea floor

Paleomagnetism

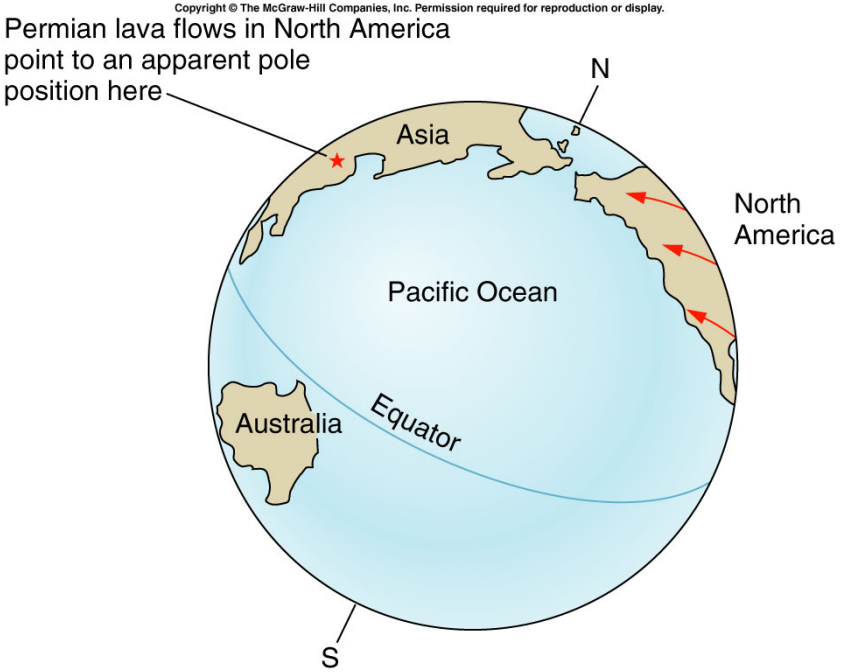
- Paleomagnetism studies ancient magnetic fields recorded in rocks

- The magnetic field and its properties are recorded in rocks"
  - Intensity
    - how strong is the magnetic field
  - Declination
    - the angle between the direction of true North and the direction of a compass needle*
  - Inclination
    - the angle between the horizontal surface and the direction of the compass needle

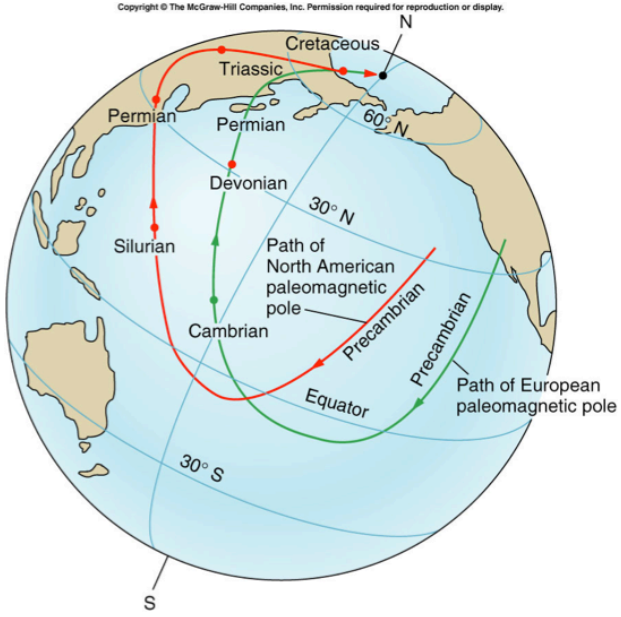
    - the needle of a compass points towards the Magnetic North, which does not coincide with the true Geographic North



Apparent Polar Wandering



Where the North Pole would have been in the Permian, according from today's data



The position of the North Pole in time relative to North America (in red) and Europe (in green)

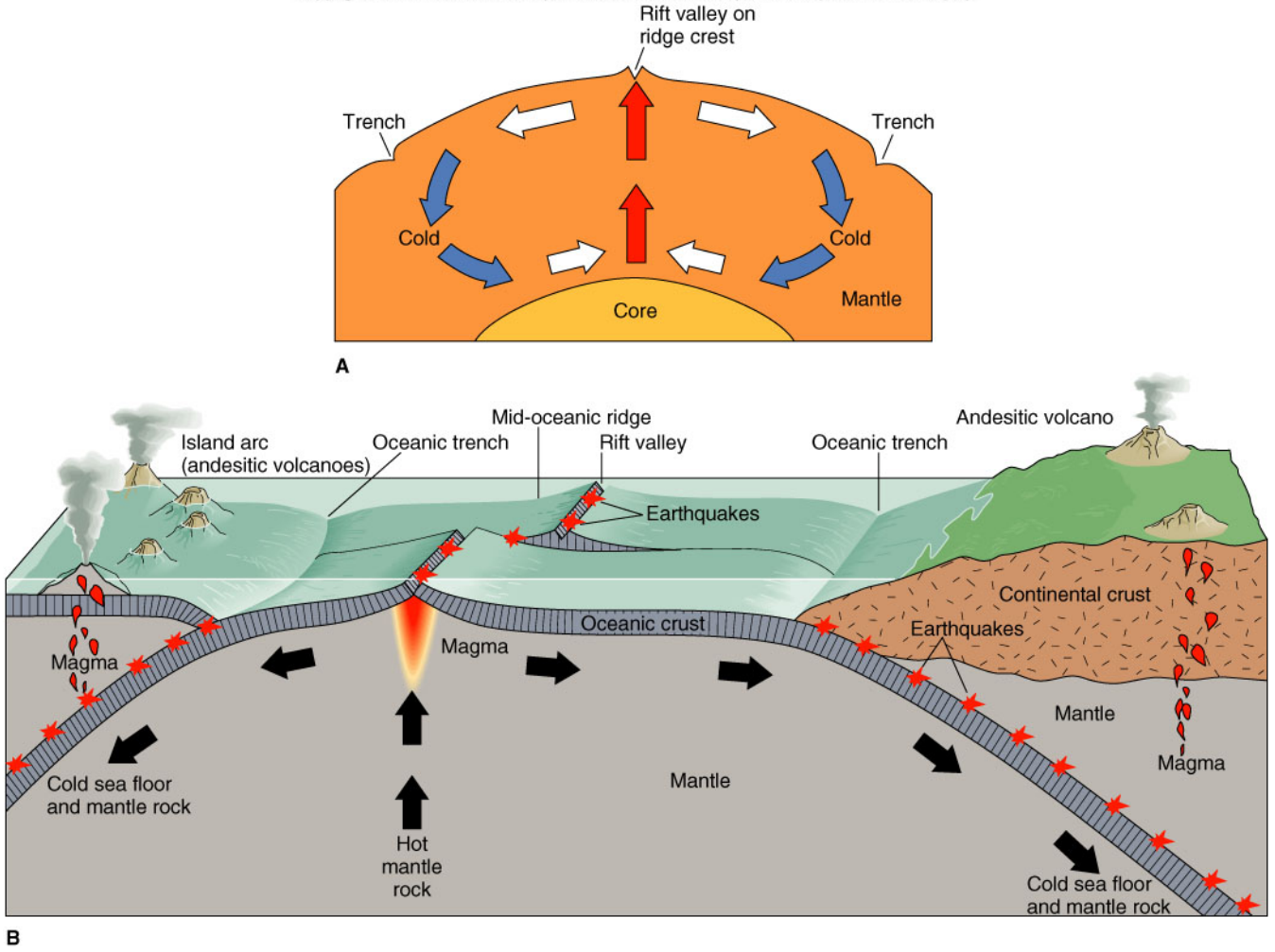
Seafloor Spreading (Hess, 1962)

- Discovery of mid-ocean ridges, trenches, and of sea-floor variable topography (it was not a flat, lifeless ocean after all!)

- Hess said sea-floor moves like a conveyor belt
  - Mid-ocean ridges are the site of spreading
  - Trenches are the site of subduction

- Motion is caused by subduction

Sea-floor Spreading, the conveyor model and the three kinds of Plate Boundaries



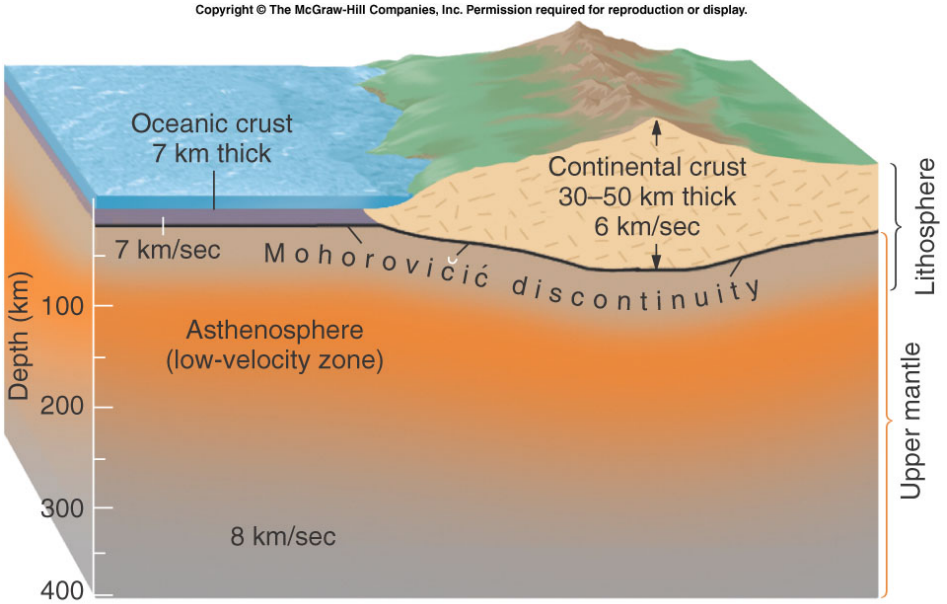
Hess' observations

- Mid-Ocean Ridges
  - High heat flow
  - Basalt eruptions (basalt is an extrusive igneous rock rich in iron, hence called "mafic"
  - Swelling of the ridge because of the heat flow
  - Tension caused by convection breaks the newly formed oceanic crust and creates a rift valley
  - Shallow earthquakes are generated
  -
- Oceanic Trenches
  - Low heat flow
  - Negative gravity anomalies (mass is "missing")
  - Deep-focus earthquakes
  - Andesitic volcanic arcs (island arcs or continental arcs)

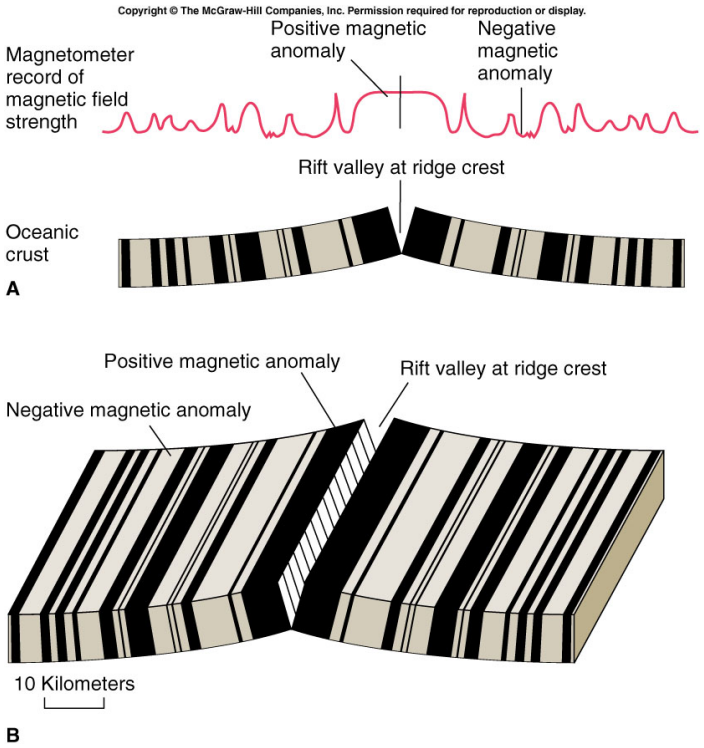
- Age of the Sea-floor
  - Sea-floor is geologically very young
  - Age is increasing symmetrically away from the ridge

combining Continental Drift and Sea-floor Spreading: the theory of **PLATE TECTONICS** is born

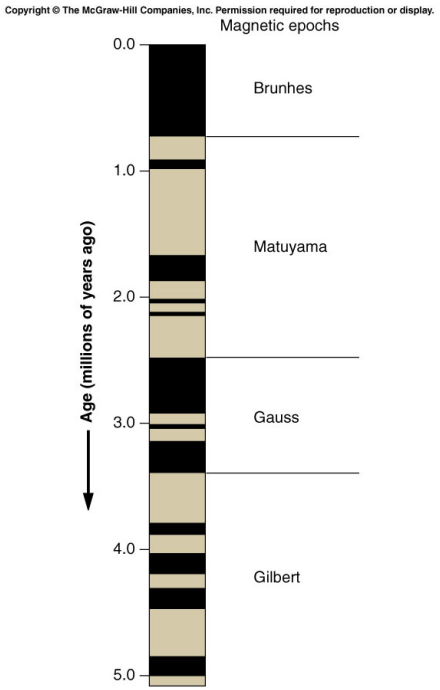
- Plates are lithospheric
- Plates can be big or small
- Plates can be made of oceanic crust, continental crust, or both
- Interactions occur at plate boundaries
- The interior of a plate is relatively stable
- A plate whose leading edge is made of continental crust would not go in subduction because of its low SG (2.7, compared to a SG = 3 for the oceanic crust)



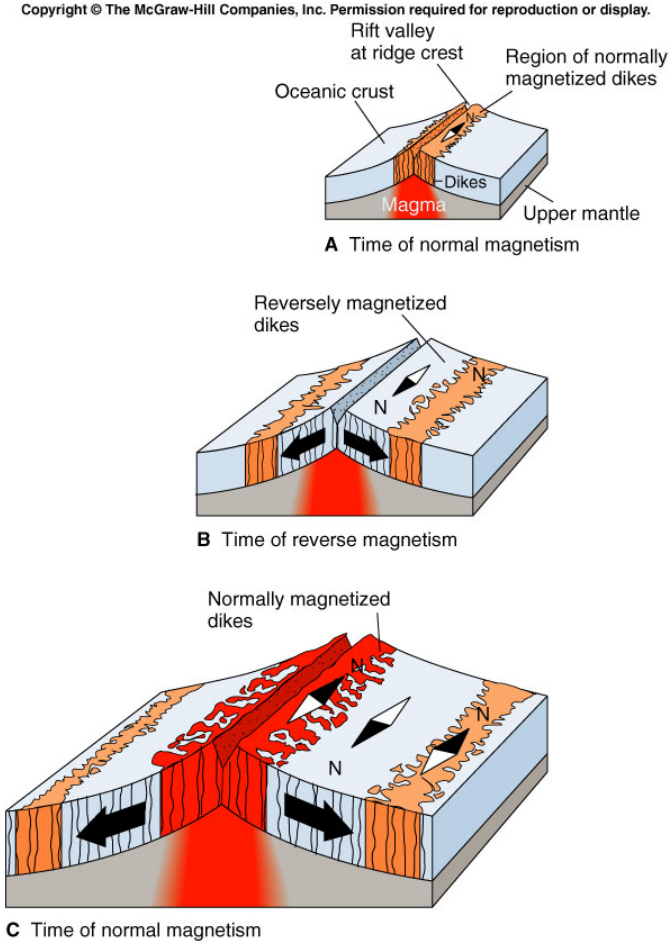
How do we know Plates move?

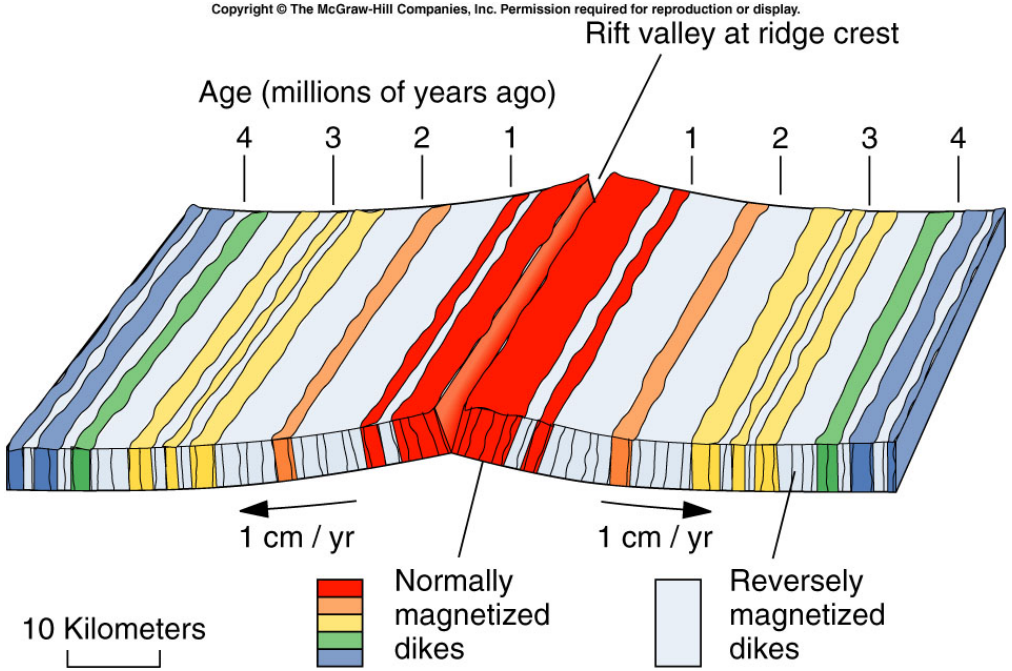


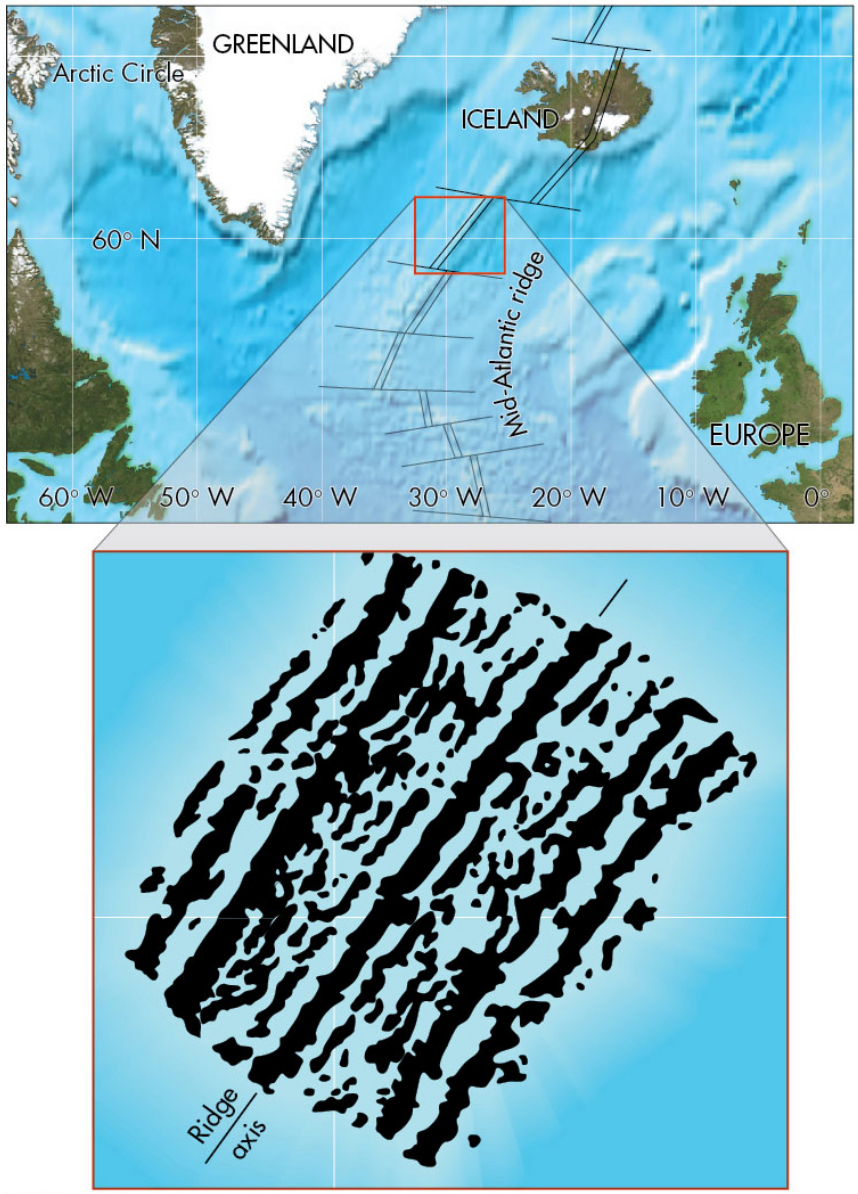
- Vine and Matthews
  - Magnetic anomalies at sea match magnetic reversals on land
- Measuring the rate of Plate motion
  - Matching the age with the magnetic "signature"
- Predicting Sea-floor age
  - Identification of the magnetic "signature"



How are Normal and Reversed magnetizations locked in the basalts on the ocean floor?





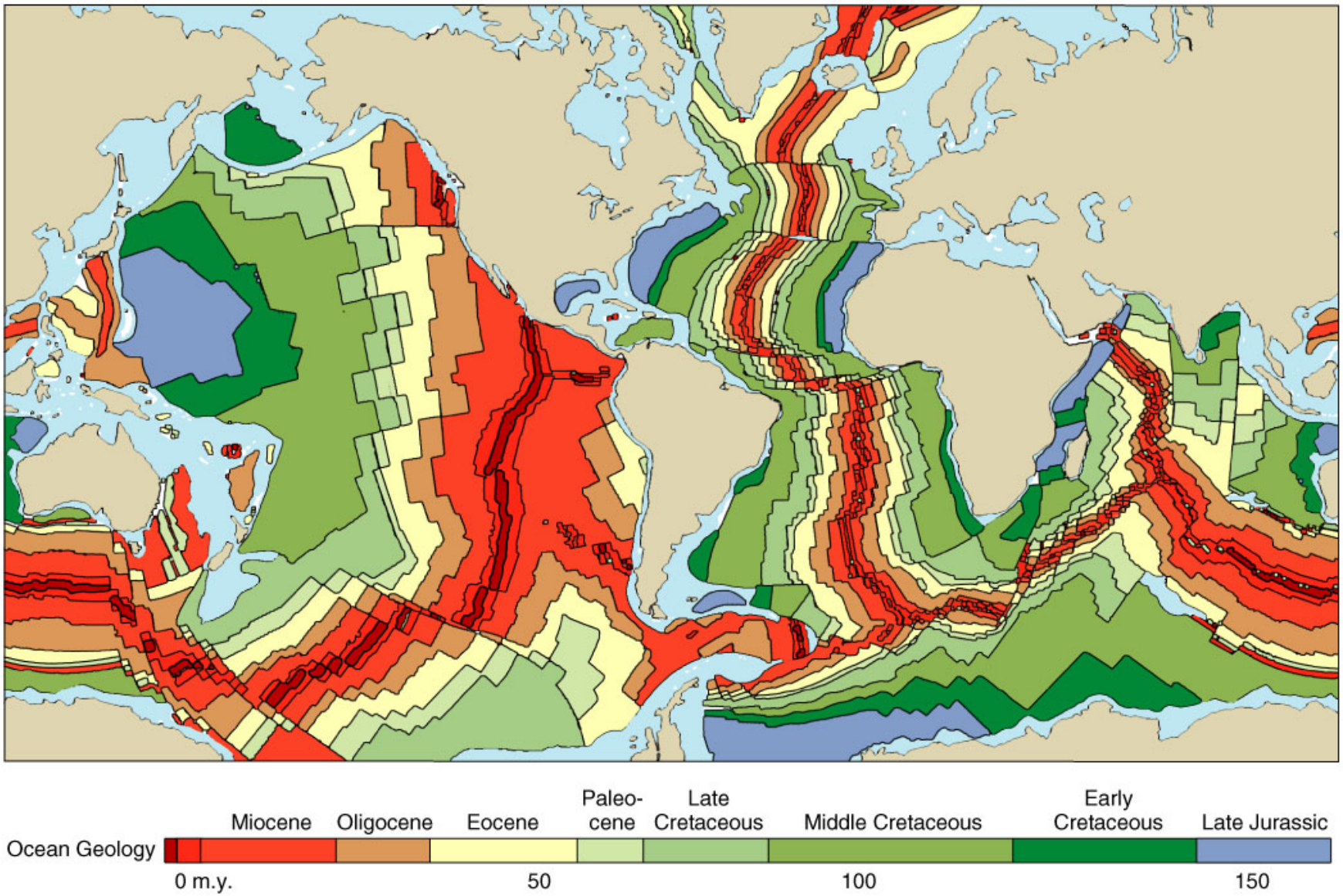


The Mid-Ocean Ridge and paleomagnetism:

the case from Iceland and the Atlantic Ocean

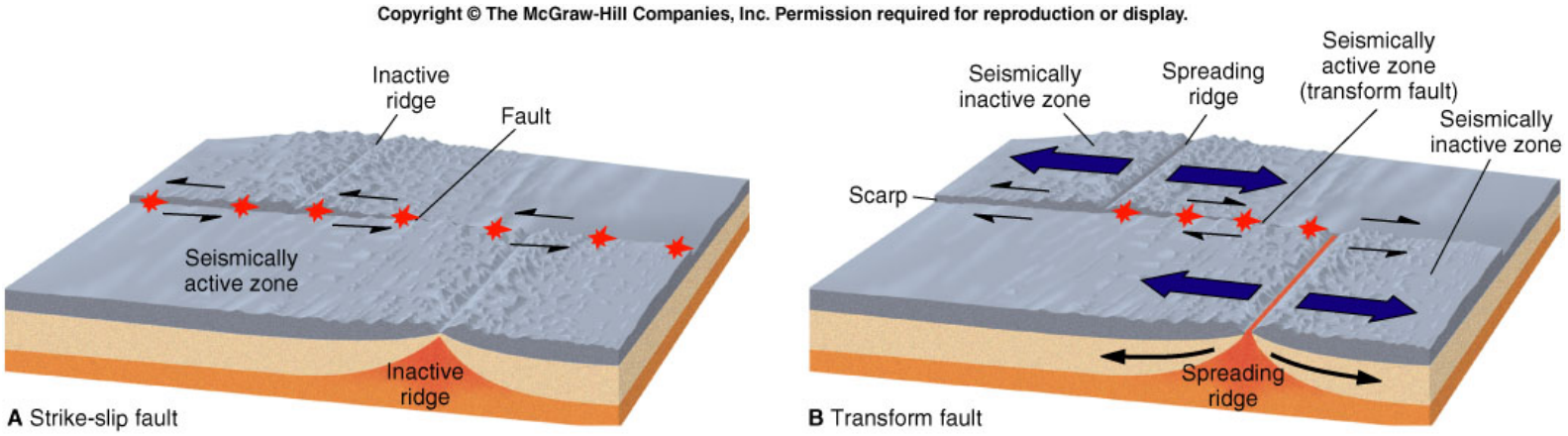
- Magnetic stripes
  - Geologists towed magnetometers along ocean floor to measure magnetic properties of rocks
  - When mapped, the ocean floor had stripes
    - Areas of “regular” and “irregular” magnetic fields
    - Stripes were parallel to oceanic ridges
    - Sequences of stripe width patterns matched the sequences established by geologists on land

The age of the Sea-floor as determined from magnetic anomalies

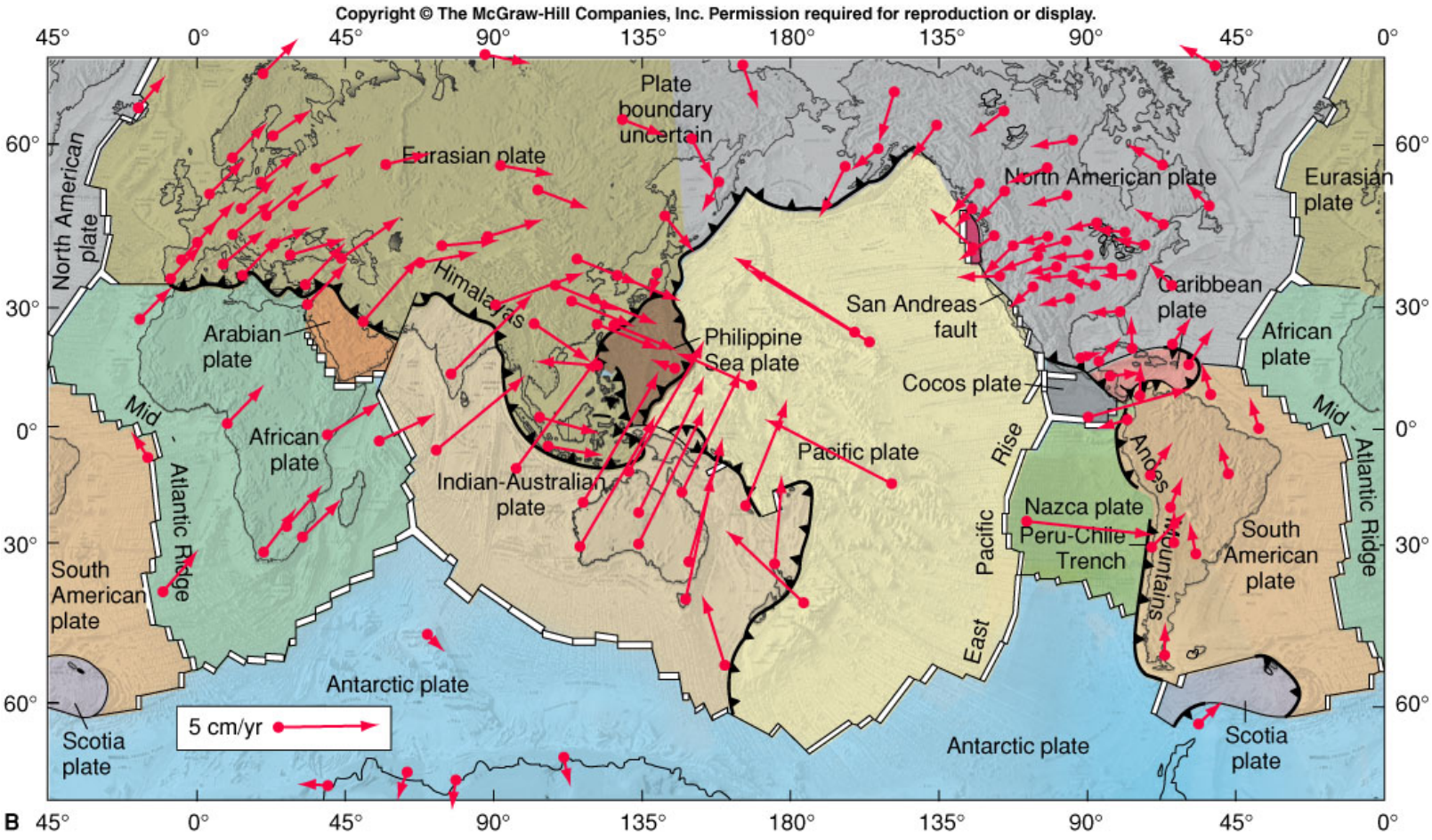


Strike-slip vs. transform faults

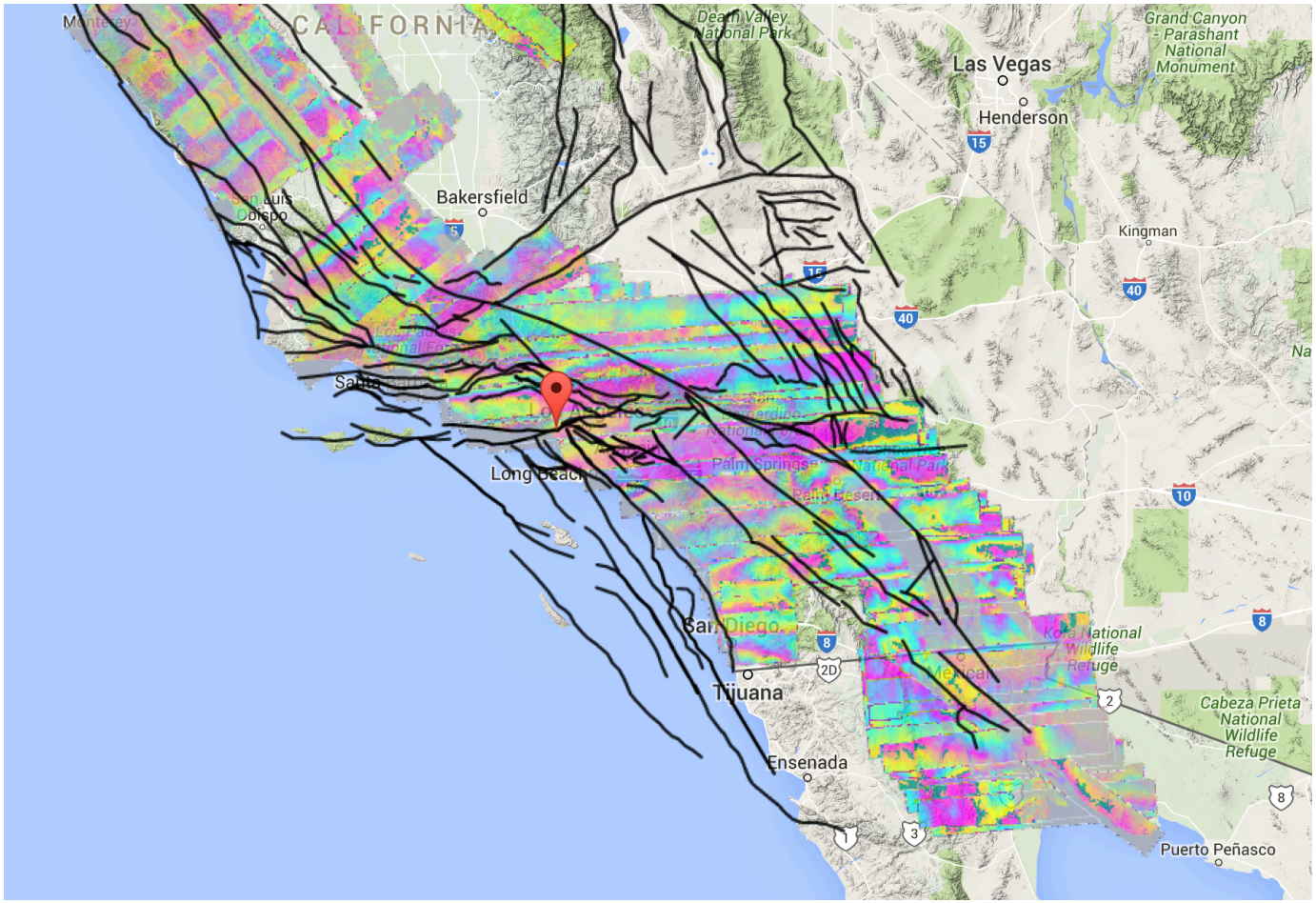
- Further evidence for sea-floor spreading comes from fractures along the mid-ocean ridge
  - A strike-slip fault moves along its entire length
  - A transform fault only moves between two offset portions of the ridge crest



measuring Plate motion: GPS data



measuring Plate motion: UAVSAR data



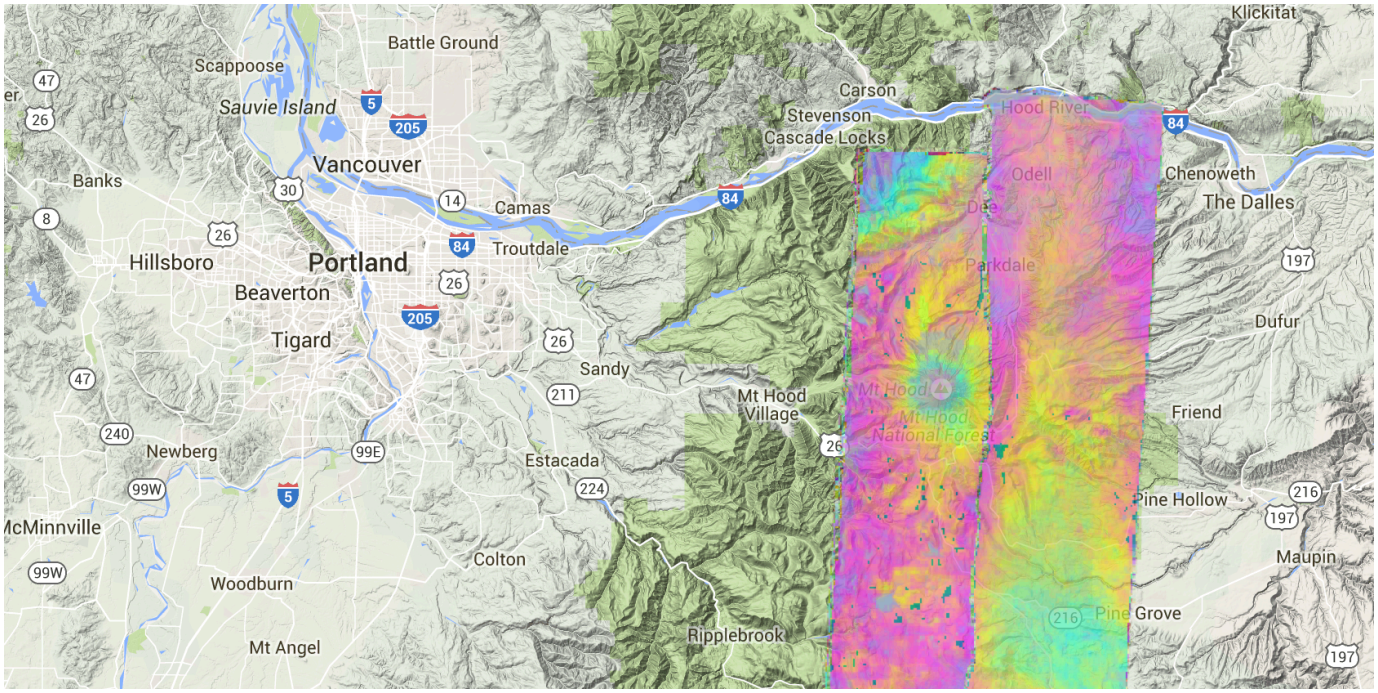


Plate Tectonics

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