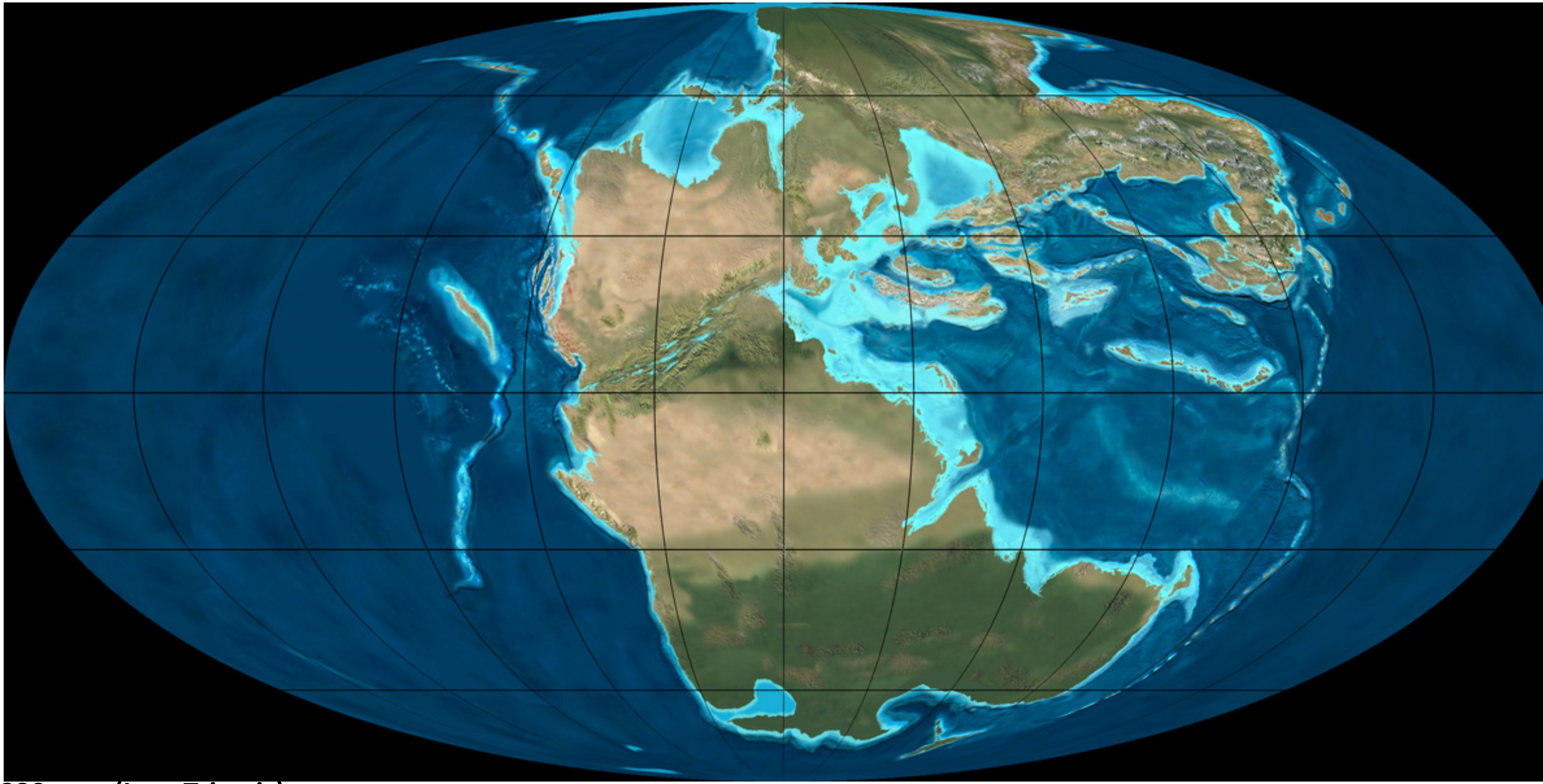
Continental Drift



220 mya (Late Triassic)

map from: http://jan.ucc.nau.edu/~rcb7/globaltext2.html

Continental Drift

The Geological Time Scale

See: http://pubs.usgs.gov/fs/2007/3015/fs2007-3015.pdf

Time scale described by dating stratigraphic layers of rock and fossils of uniform composition that had wide geographic distributions.

Ages of deposits estimated by using knowledge of radioactive element and isotope decay:

Isotopes of uranium decay to lead, half-lives ~500 million years, provided the current estimate of the earth's age of about 4.6 billion years.

^{14}C decays to ^{12}C, half-life ~5800 years, useful for dating more recent events.

Continental Drift

Continental Drift and Plate Tectonics

Continental drift: the indirectly observed pattern of continents and oceans moving around the surface of the globe on fragments of rock (i.e., plates) of varying densities.

Plate tectonics: the processes involved in the origin, movement, and destruction of fragments (i.e., plates) of the earth's crust.

see: http://pubs.usgs.gov/gip/dynamic/dynamic.html

Continental Drift

Outline of topics in this section

1. History and Basic Tenets

2. Evidence for Continental Drift and Hints at Mechanism

3. Current Model of Continental Drift

4. Zoogeographic Consequences of Continental Drift

5. Exploring Earth's Tectonic History (in class Wednesday)

History and Basic Tenets

Alfred Wegener (1880-1930)

Alfred Wegener is credited with laying out principles of continental drift.

Important observations:

Puzzle-like fit of continents

Alignment of rock strata and mountain belts across the Atlantic

Coal beds in polar regions and glacial deposits (e.g., till) in tropical regions

Distribution of related taxa across vastly separate continents
(e.g., marsupials in Australia and S. America)

History and Basic Tenets

Alfred Wegener (1880-1930)

Wegener's Basic Tenets of Continental Drift

(1) Continental bedrock is composed of lighter (less dense) rock than the oceanic bedrock, suggesting that the continents "float" atop a semi-liquid mantle.

(2) All continents were once united as a single supercontinent called Pangaea.

(3) The breakup of Pangea began with the formation of a giant rift valley which, as it widened, became an ocean basin and the progenitor of the Atlantic Ocean. The mid-ocean ridges and trenches, formed as the continents split apart, mark the zones where the continents were once joined.

History and Basic Tenets

Alfred Wegener (1880-1930)

Wegener's Basic Tenets of Continental Drift

(4) The shapes of the continents are more or less as they have always been, allowing historical reconstruction of their margins.

(5) Rates of movement of the continents vary. (Greenland moves at the slowest rate and has only recently separated from Europe in the last 100 000 yrs - Wegener suggested that continents moved at rates of up to 36 m/yr… he was off by quite a bit!)

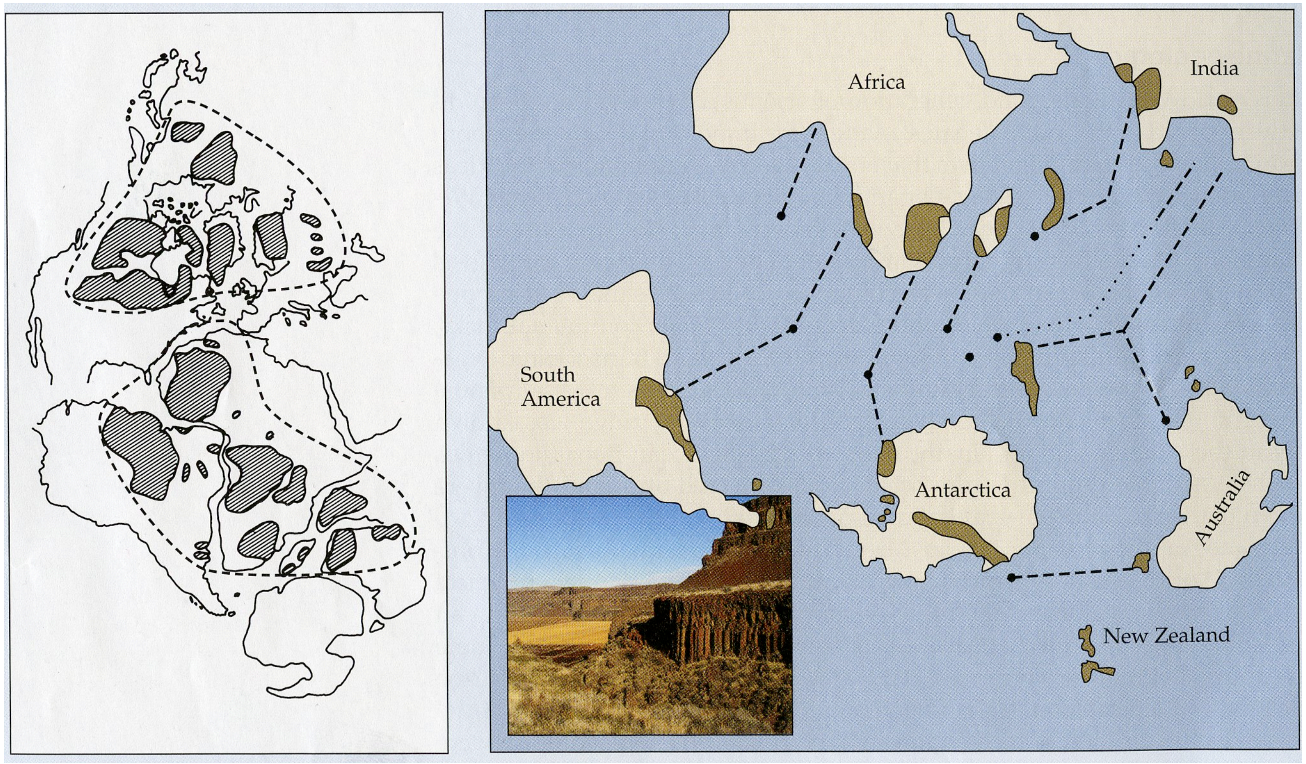
(6) The above processes are gradual and ongoing, and likely have their ultimate causes in heating processes deep in the earth's mantle.

(Tragically Wegener died in 1930 -- he froze to death in Greenland -- 30 years before the acceptance of the theory).

Evidence for Continental Drift and Hints at Mechanism

1) Stratigraphic evidence

Precambrian shield and flood basalt deposits line up with hypothesized arrangement of Pangaea and Gondwana, respectively. Also, in each of the now-isolated southern continents, rock from the late Paleozoic and early Mesozoic occur in the same stratigraphic sequence: glacial sediments, coal beds, desert deposits, and volcanic rock.



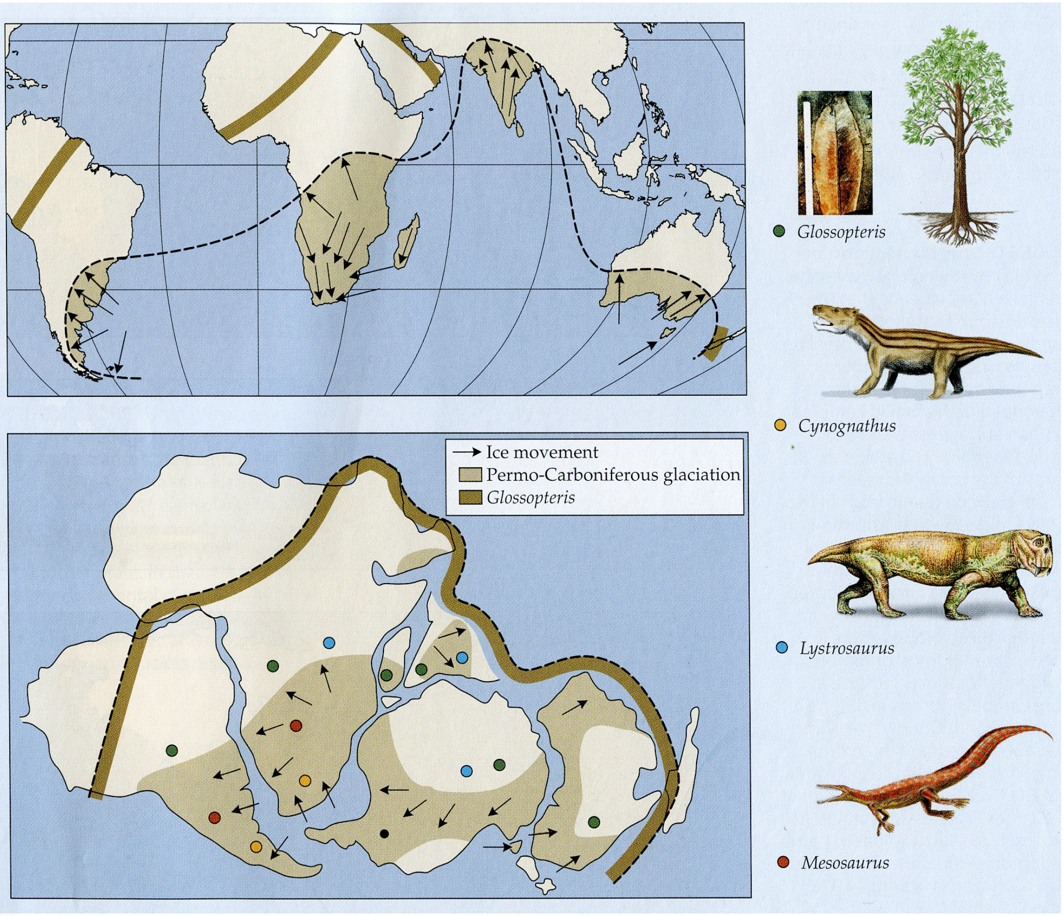
Evidence for Continental Drift and Hints at Mechanism

2) Paleontology and Paleoclimate

Late Paleozoic glacial deposits are common to all continents of the Southern Hemisphere. Also, as glaciers moved they made deep grooves (striations) in underlying rock.

Orientation of grooves makes it possible to determine direction of glacier movement.

Extent of distribution of fossil records of *Glossopteris* flora (tongue ferns) is consistent with a biome around the margins of the Permian glaciers of Gondwana.



Evidence for Continental Drift and Hints at Mechanism

2) Paleontology and Paleoclimate

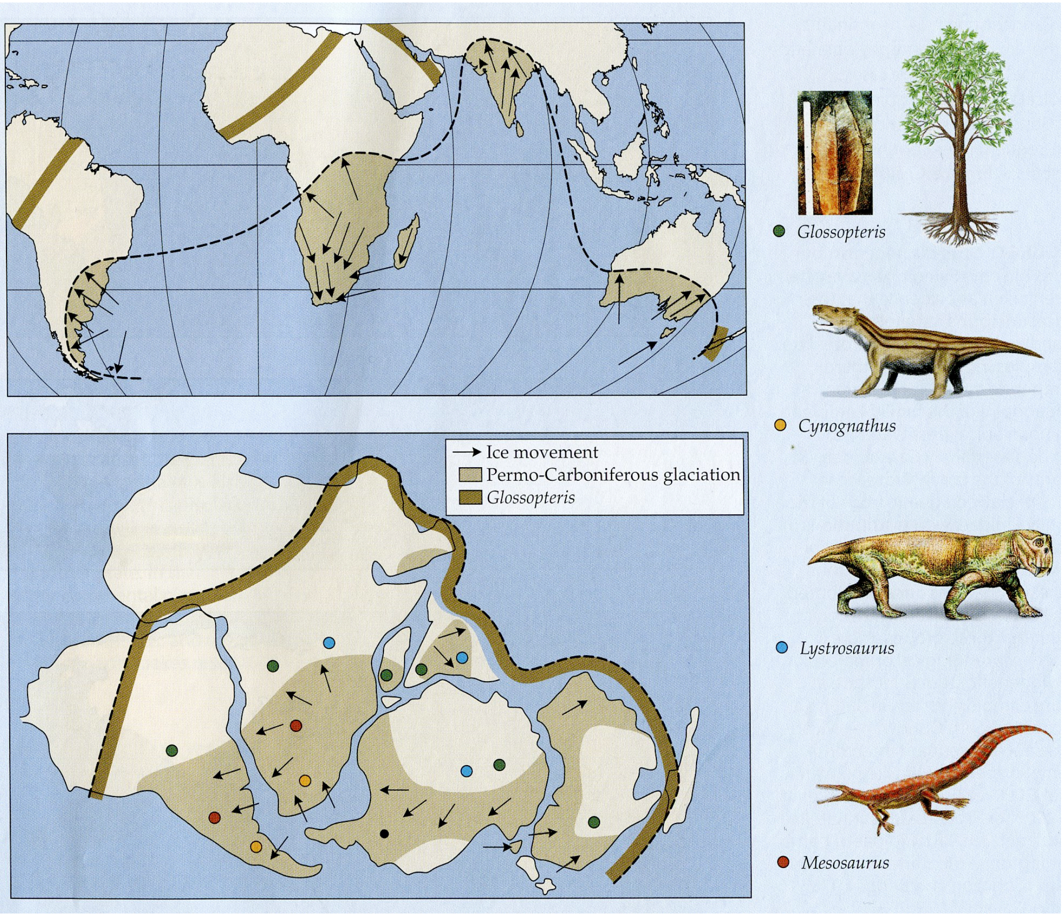
Many animal fossils in the Paleozoic glacial deposits are shared among now separate continents suggesting that continents were one landmass with a similar climate.

e.g.,

Lystrosaurus (mammal-like terrestrial reptile)

Mesosaurus (alligator-like aquatic reptile)

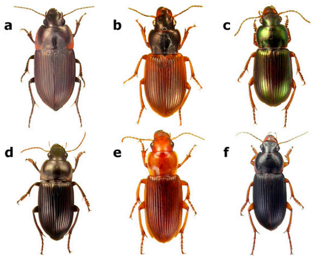
Cynognathus (mammal-like reptile)



Evidence for Continental Drift and Hints at Mechanism

3) Disjunctions in Extant Taxa

Disjunct distributions of a wide diversity of living taxa (especially those not well equipped for long-distance dispersal through the sea) suggest that they were at one time part of a more continuous distribution.



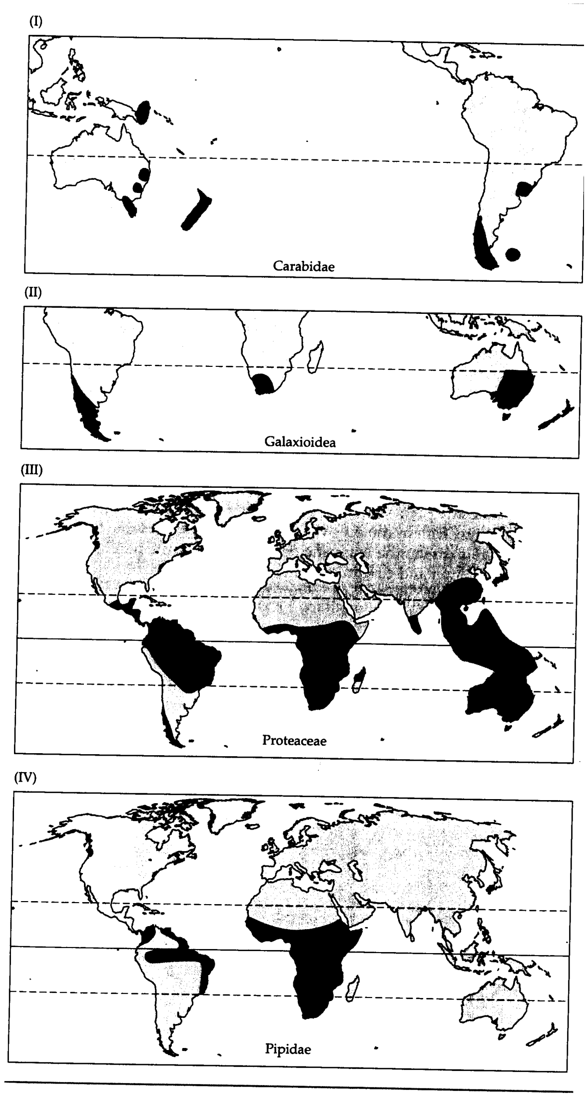
Carabid beetles

Chris Brown, USGS

Clawed frogs

Proteaceae

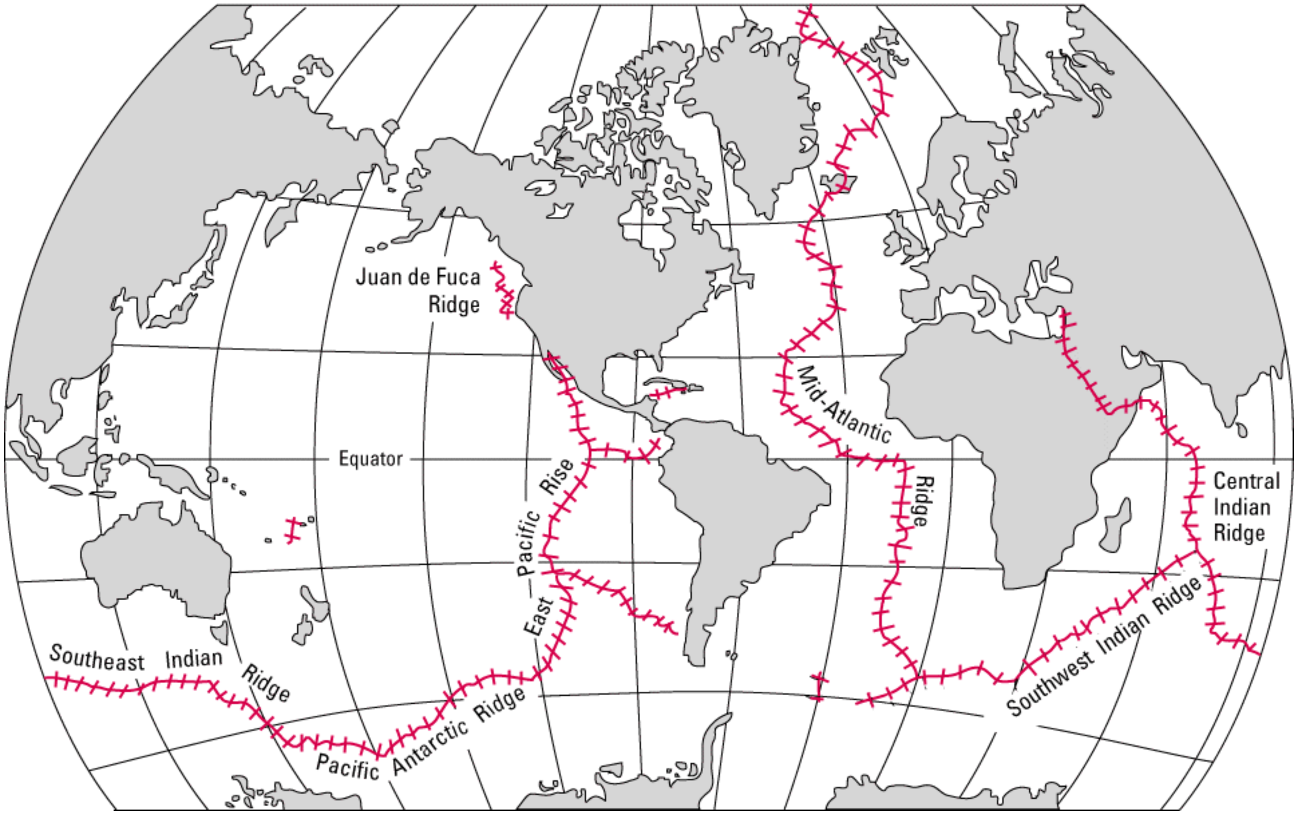
Galaxid freshwater fishes



Evidence for Continental Drift and Hints at Mechanism

4) Sea Floor Mapping

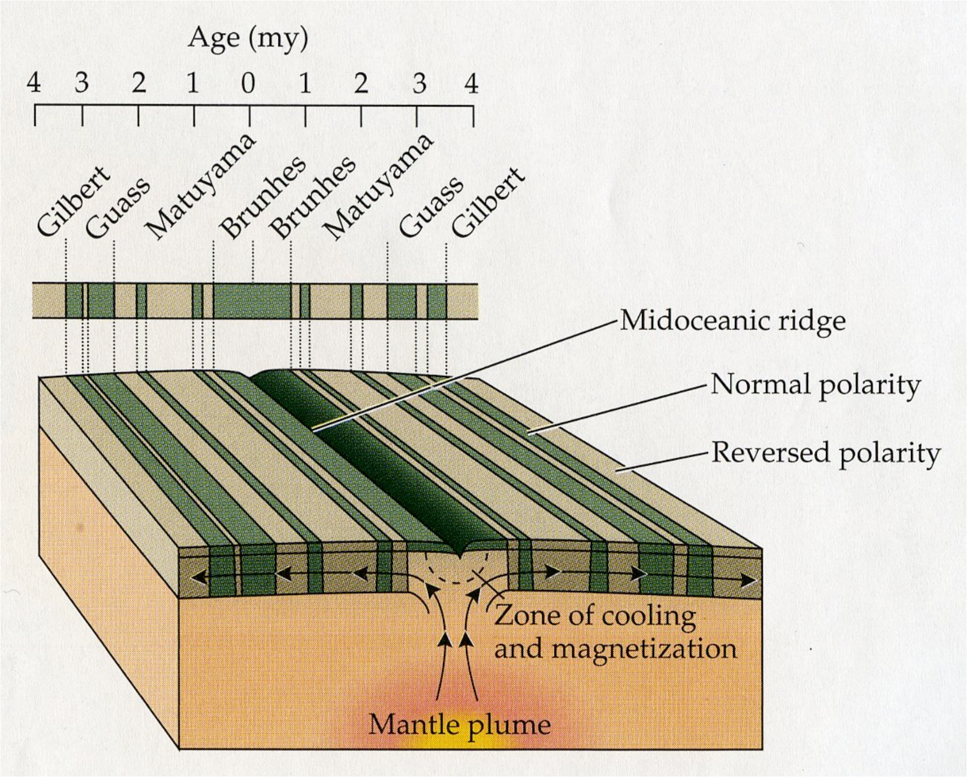
The mid-Atlantic Ridge is part of a 50,000 km long chain of mid-ocean ridges that weaves through all the worlds ocean basins. It's the largest single geographical feature on the earth and is 800 km wide in places and rises to over 4500 m in some areas.



Evidence for Continental Drift and Hints at Mechanism

5) Paleomagnetism, Magnetic Stripes, and Magnetic Reversals

Iron and titanium oxides are sensitive to the polarity of the earth's magnetic field (direction and declination). When magma solidifies, rocks containing these minerals record the polarity and direction of the magnetic field.



Regular patterns of alternating polarity in the rock moving away from the oceanic ridges

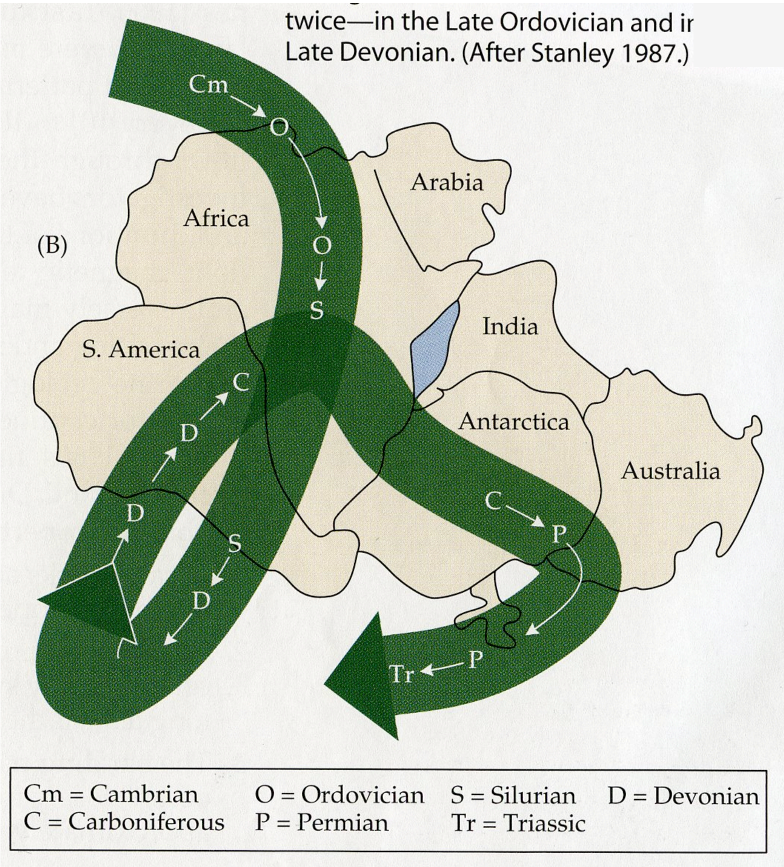
Alternating patterns were symmetrical on either side of the ridges

Age of different strips increased as one moved away from the ridge crests

Evidence for Continental Drift and Hints at Mechanism

5) Paleomagnetism, Magnetic Stripes, and Magnetic Reversals

Iron and titanium oxides are sensitive to the polarity of the earth's magnetic field (direction and declination). When magma solidifies, rocks containing these minerals record the polarity and direction of the magnetic field.



twice—in the Late Ordovician and ir
Late Devonian. (After Stanley 1987.)

Earth's magnetic fields are oriented toward its core and poleward

Also influences crystal orientation during formation of magnetically active rock

Used to reconstruct position and movement of continents

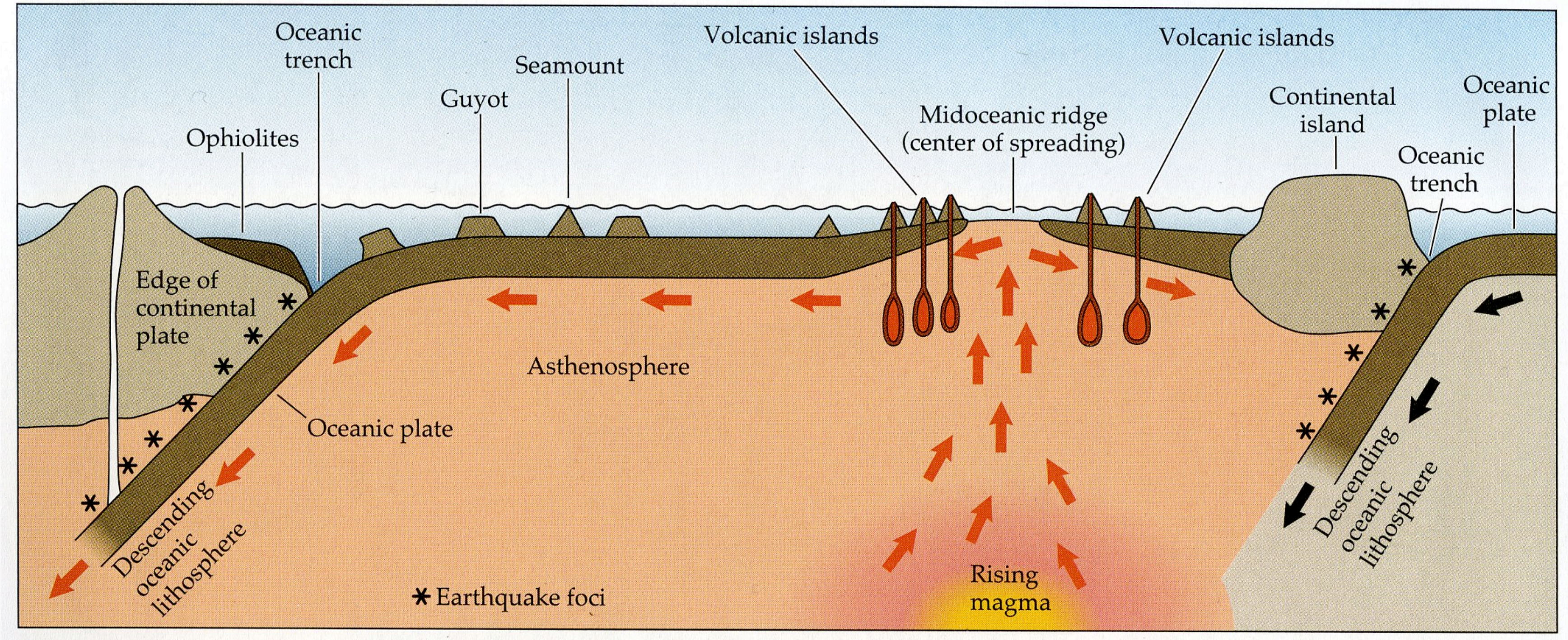
Gondwana drifted over the South Pole!

Evidence for Continental Drift and Hints at Mechanism

6) Sea Floor Spreading

Putting the observations of sea floor terrain and of magnetic striping together prompted various people to propose the idea of *sea floor spreading*.

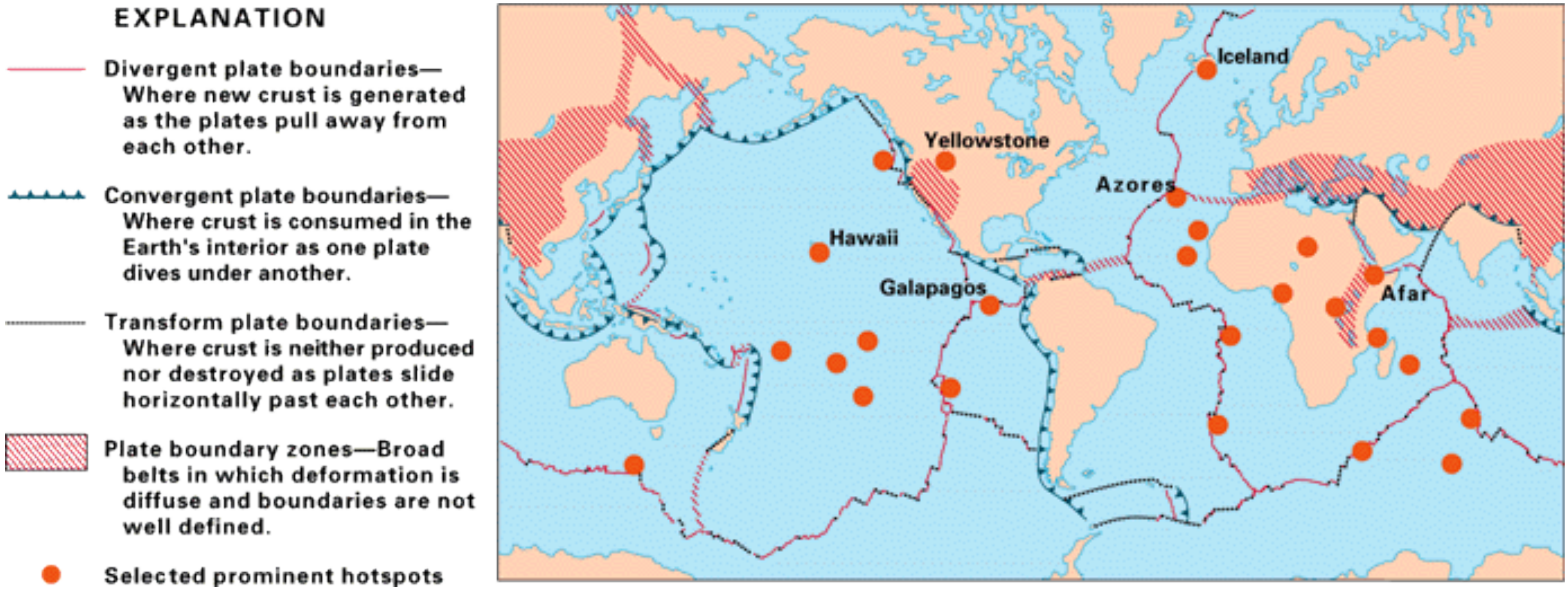
Harry Hess, a Princeton geologist in the U.S. navy during WW2, broadened the idea of sea floor spreading in the early 1960's to include the idea of oceanic crust "recycling".



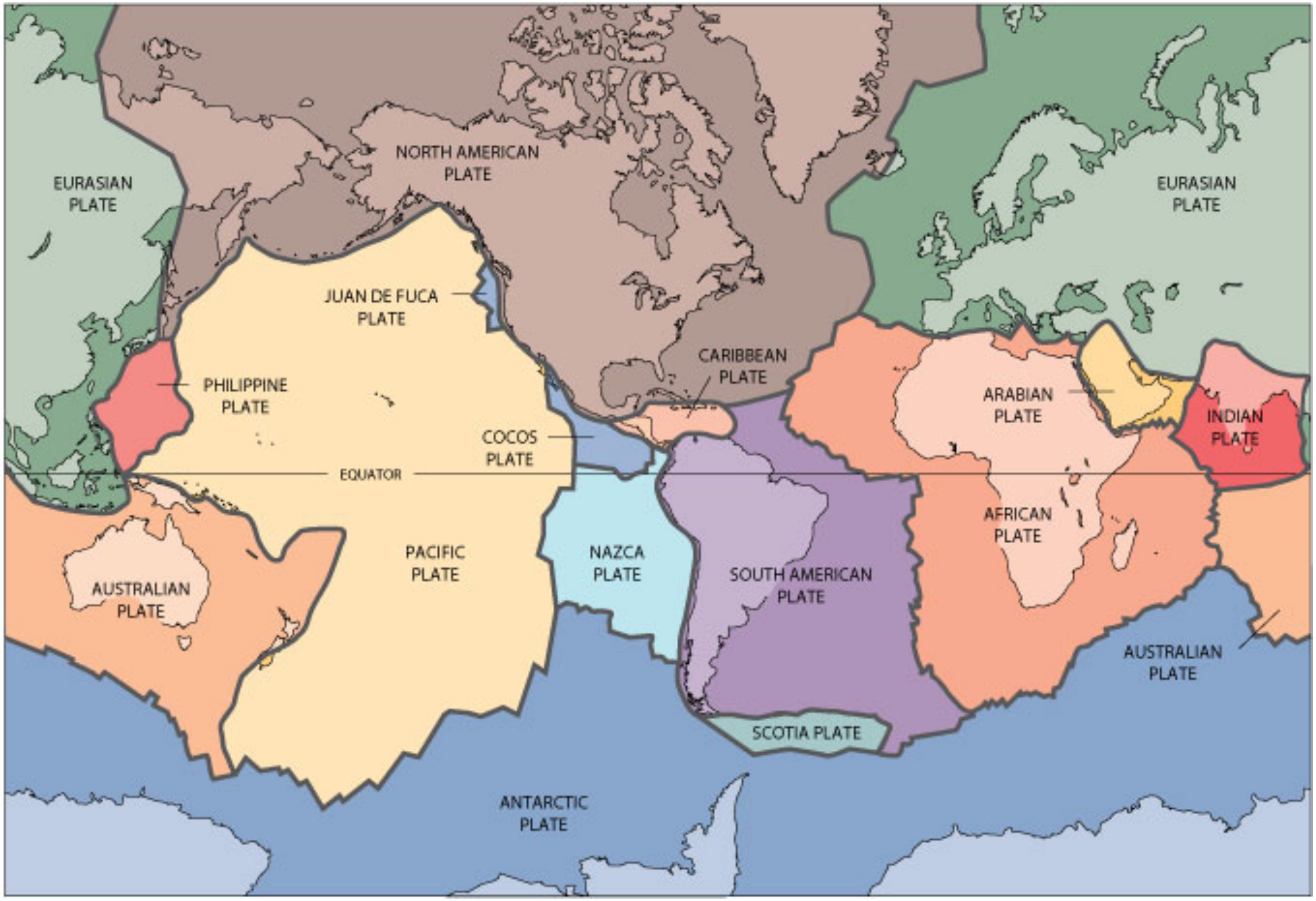
Evidence for Continental Drift and Hints at Mechanism

7) Earthquake Activity Concentration

Most earthquake activity tends to be associated with the meeting or spreading of plates.



Current Model of Continental Drift



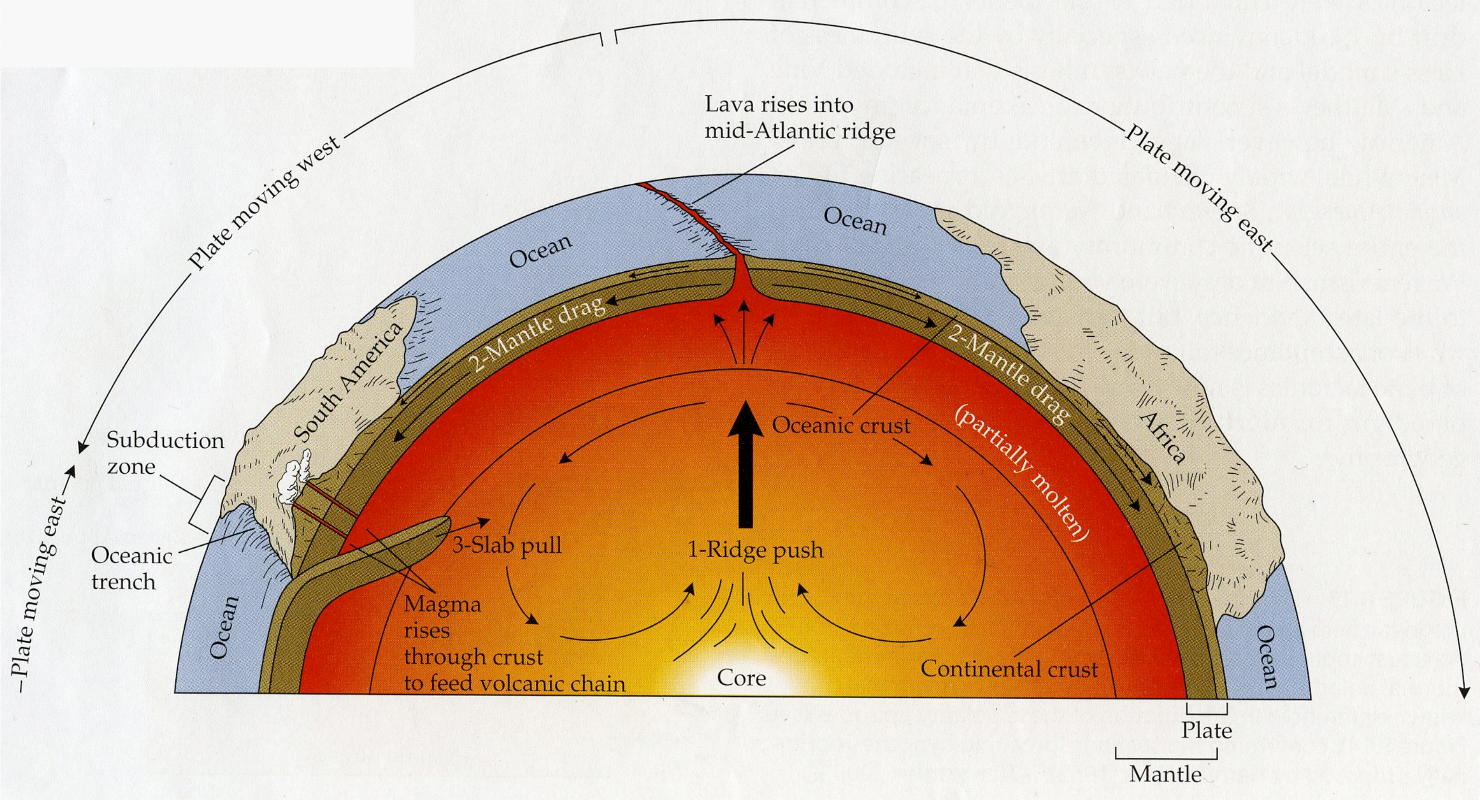
Current Model of Continental Drift

Major Forces of Plate Tectonics

1. Ridge Push: force generated by molten rock rising from the earth's core through the mantle at the mid-oceanic ridges.

2. Mantle Drag: tendency of the crust to ride atop the flowing mantle.

3. Slab Pull: force generated as subducting crust tends to pull trailing crust after it.



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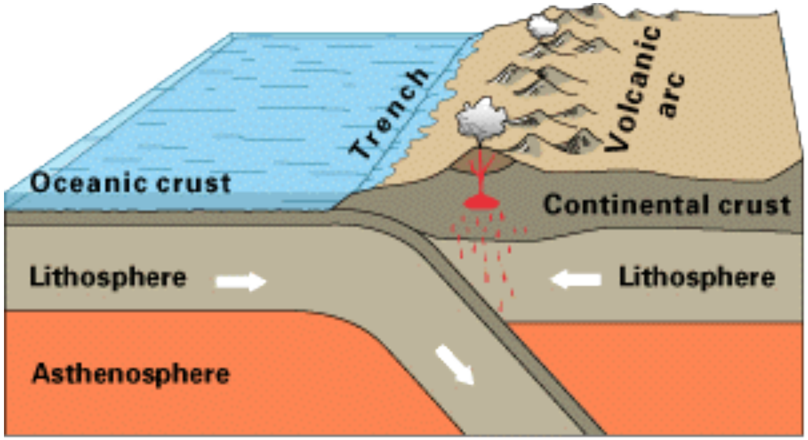

Oceanic-continental convergence

Current Model of Continental Drift

Major Forces of Plate Tectonics

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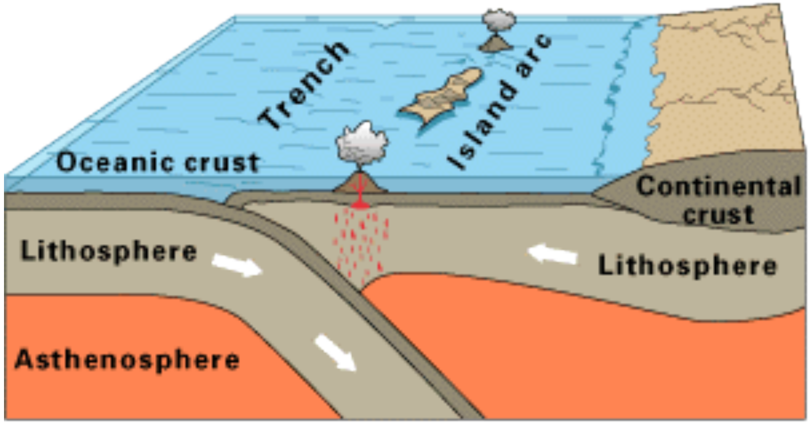

Oceanic-oceanic convergence

Current Model of Continental Drift

Major Forces of Plate Tectonics

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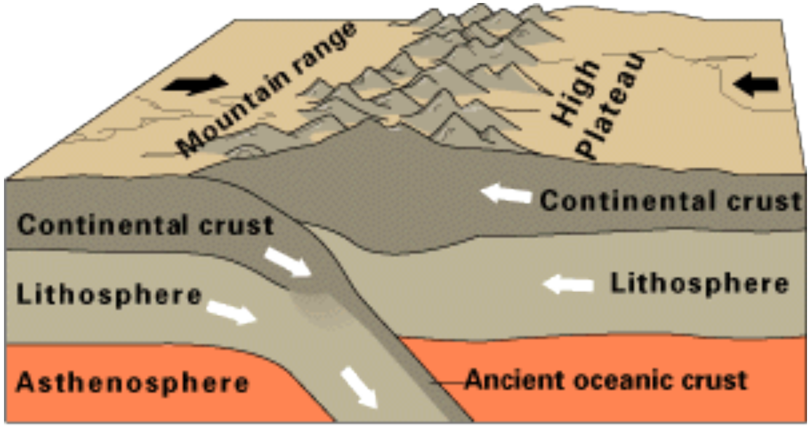
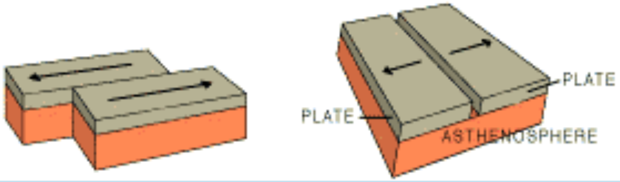


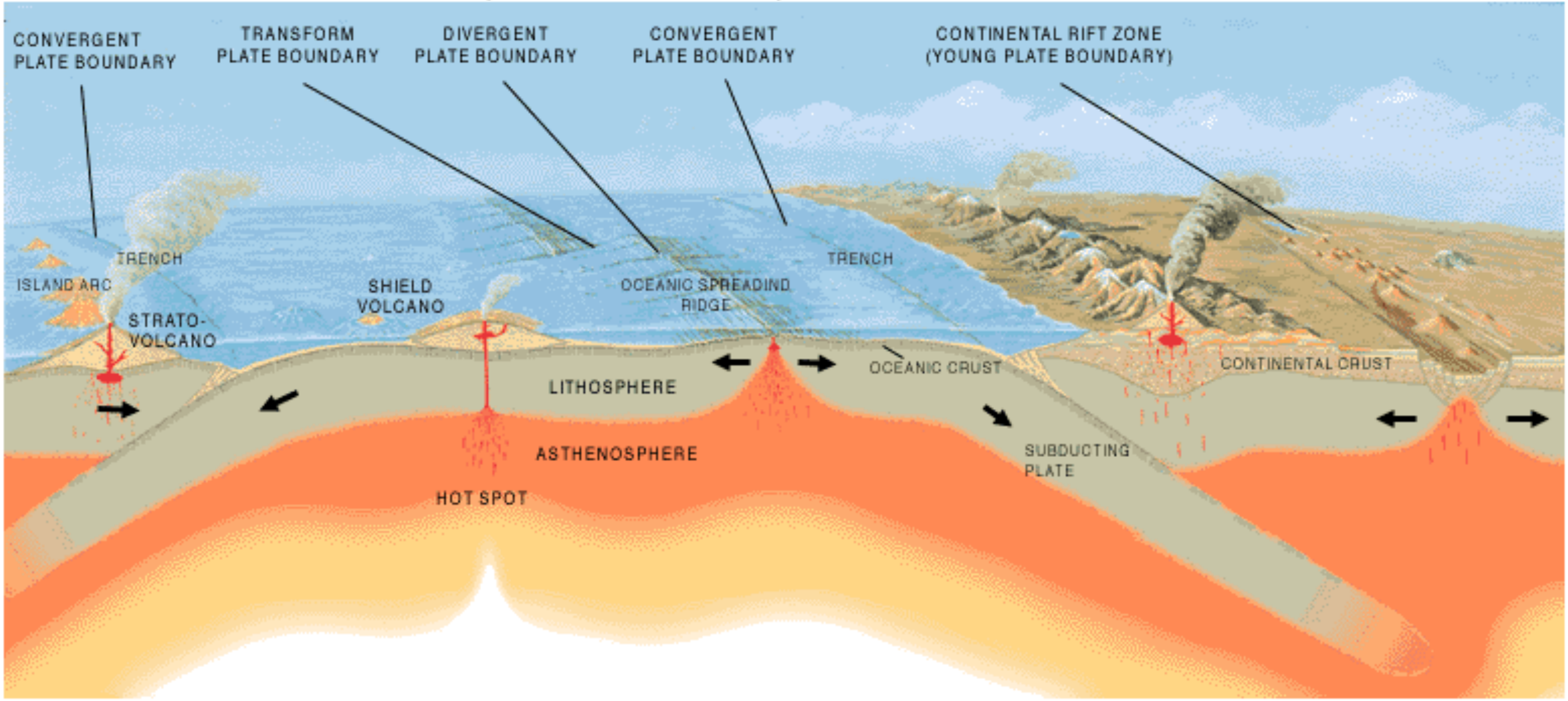
Continental-continental convergence

Current Model of Continental Drift

Major Forces of Plate Tectonics



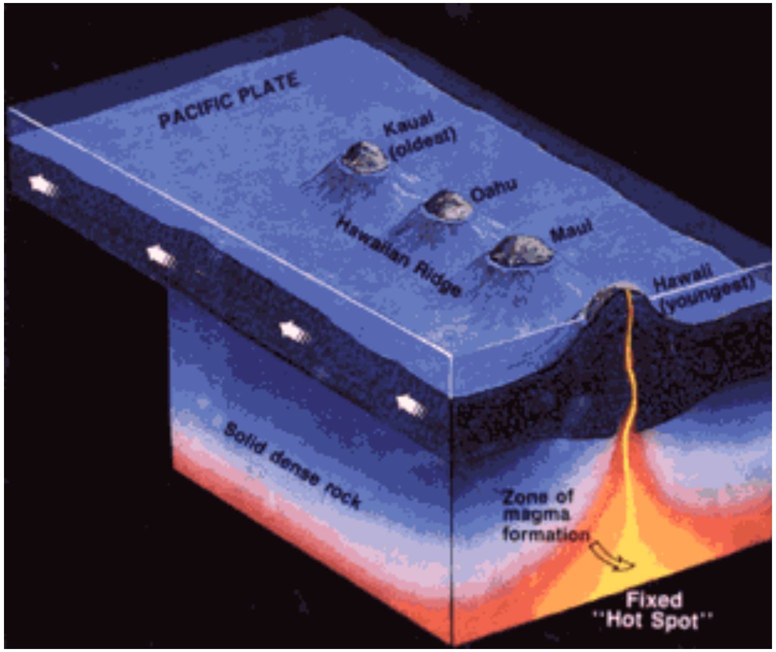
subduction zones
spreading zones
strike-slip faults

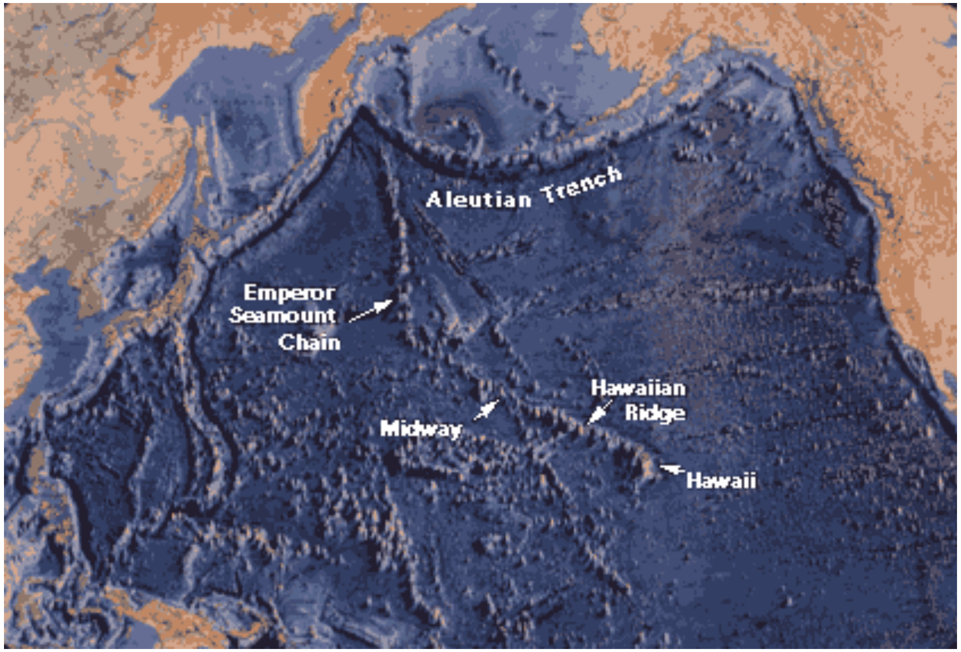


Current Model of Continental Drift

These forces explain many old observations

e.g., age of islands and seamounts along the Hawaiian ridge

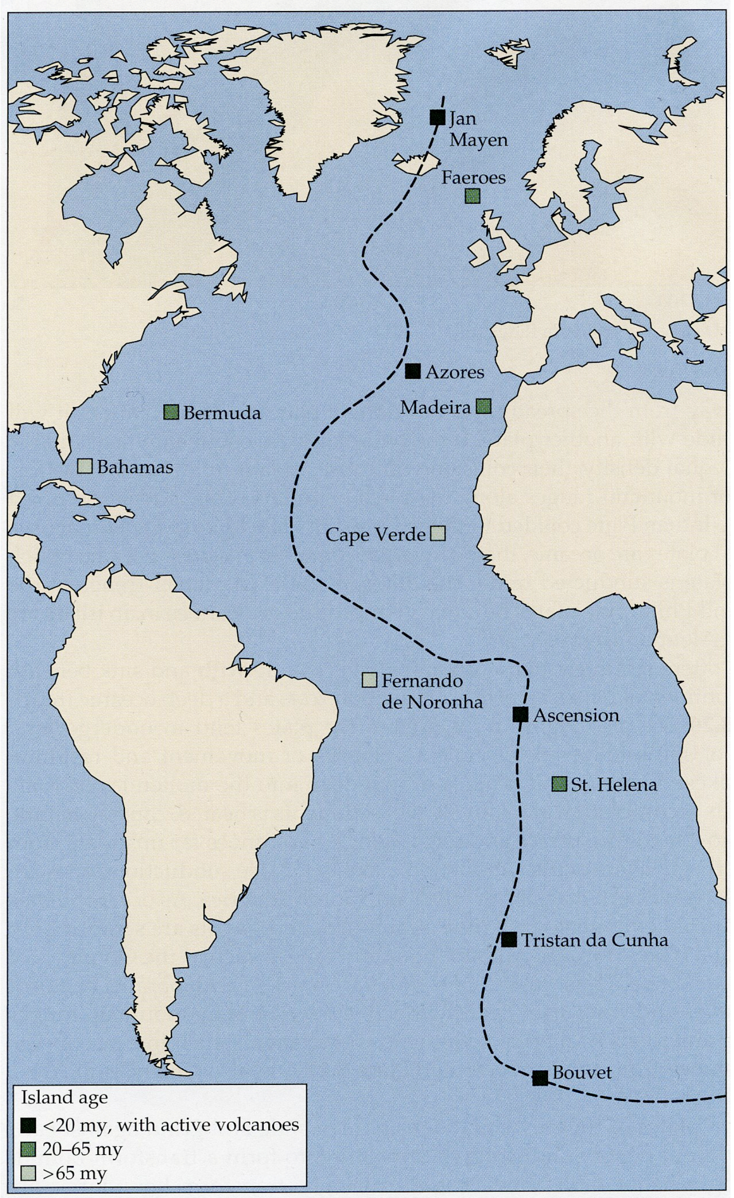




Current Model of Continental Drift

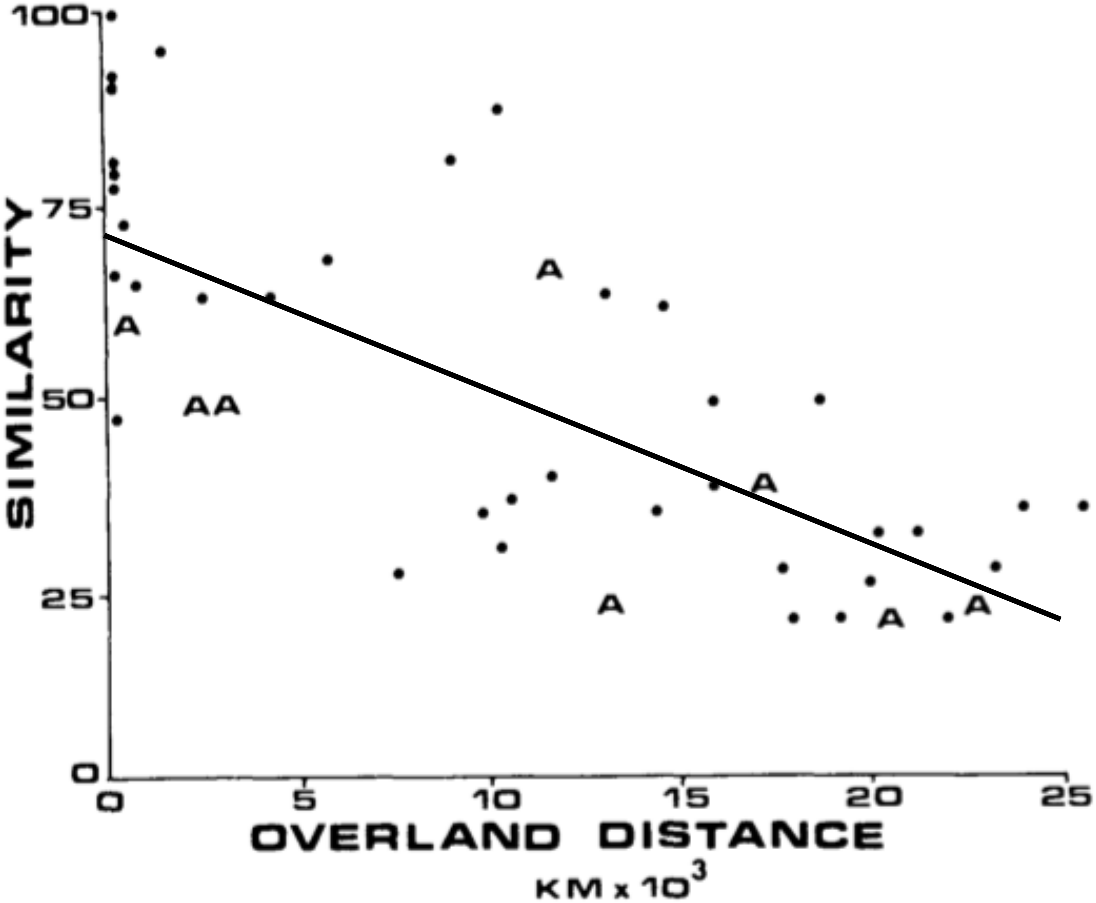
These forces explain many old observations

e.g., volcanic activity on Atlantic islands



Zoogeographic Consequences

1) Shifting Pattern of Isolation and Connectedness



Landmass comparisons of NA, SA, Africa, Eurasia, New Guinea, Madagascar and Australia

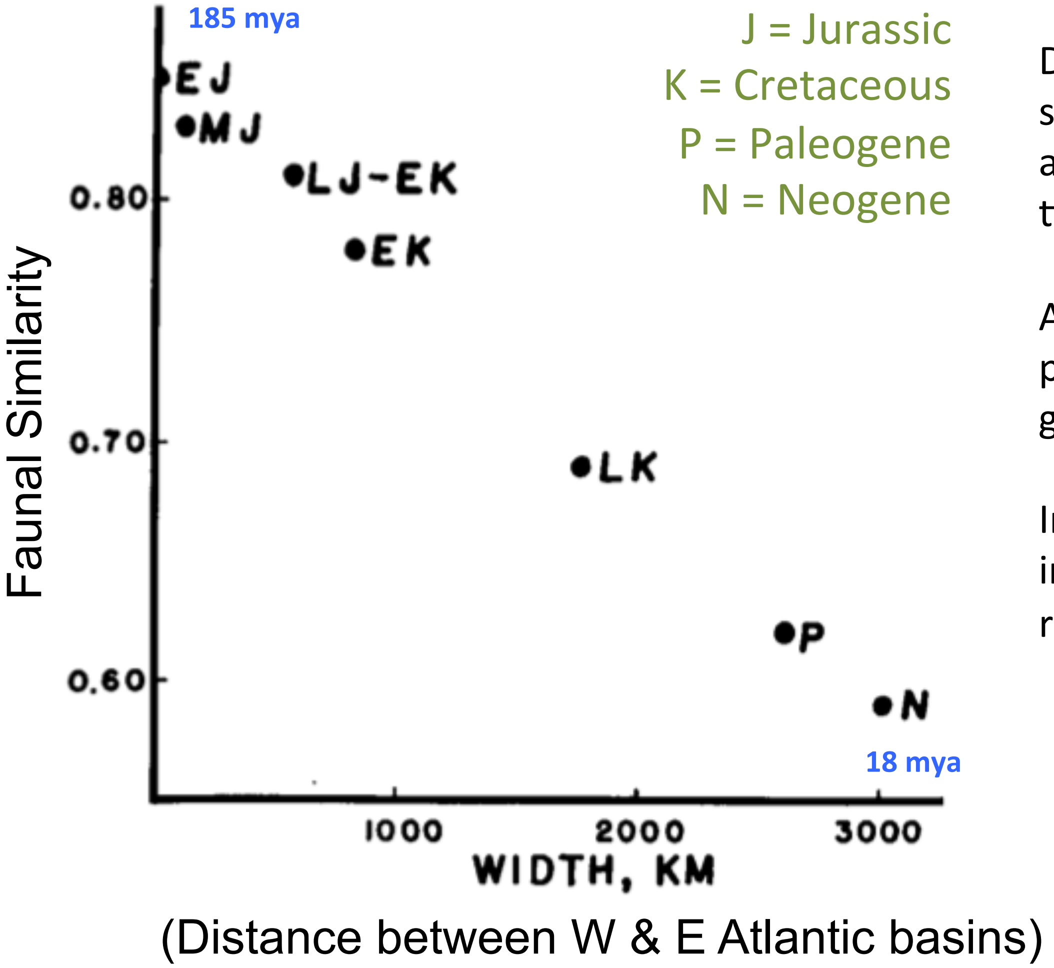
Mammal biotic similarity decreases as overland distance between landmasses increases

Most pairwise comparisons with Australia (A) fall below trend line (more distinct due to long isolation of Australian continent)

(figure from Flessa 1980)

Zoogeographic Consequences

1) Shifting Pattern of Isolation and Connectedness



Decrease in **marine invertebrate fossil** similarity as distance between western and eastern Atlantic basins increase over time (early Jurassic to Neogene)

As mid-Atlantic ridge pushed continental plates apart, Atlantic Ocean formed and got bigger

Increasing isolation of marine invertebrate faunas on either side of ridge with opportunity for divergence

(figure from Flessa 1980)

Zoogeographic Consequences

1) Shifting Pattern of Isolation and Connectedness

Biotic Exchanges

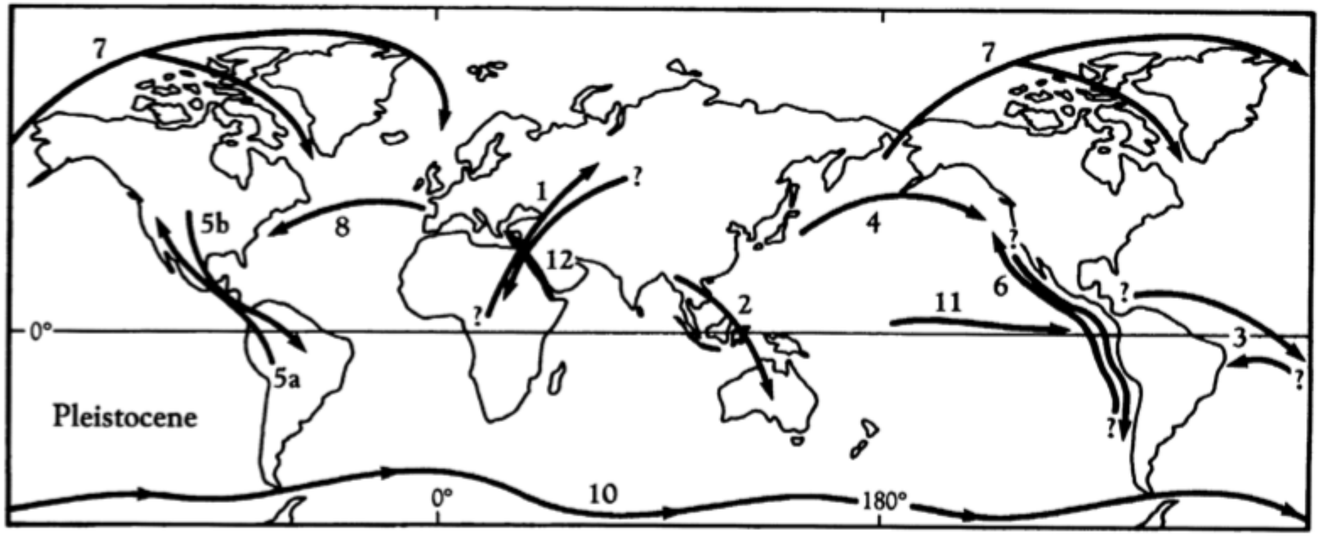
Key

1. Terrestrial interchange between Africa and Asia
2. Terrestrial interchange, chiefly from southeast Asia to Australia and New Guinea
3. Marine interchange across the tropical Atlantic
4. Marine interchange across the North Pacific, mainly from west to east

5a. Great American interchange for lowland rain-forest organisms, chiefly from south to north

5b. Great American interchange for savanna and upland organisms, symmetrical during the Pliocene, mainly north to south subsequently

6. Transequatorial marine interchange in the eastern Pacific, mainly from north to south during the Pliocene, of unknown directionality subsequently
7. Marine trans-Arctic interchange
8. Marine interchange across the North Atlantic, mainly from east to west
9. Transequatorial marine interchange in the eastern Atlantic
10. Circum-Antarctic marine interchange
11. Marine interchange across the tropical Pacific, mainly from west to east
12. Trans-Suez interchange (Recent only)



(from Vermeij 1991)

Zoogeographic Consequences

1) Shifting Pattern of Isolation and Connectedness

Great American Biotic Exchange Timeline of Events:

Jurassic

Cretaceous

Tertiary

Pleistocene

220-160 my BP N. and S. America part of Gondwanaland. Origin, diversification and spread of mammals and birds.

140 my BP Isolation of S. America.

65 my BP N. and S. America approaching present configuration. Major extinctions (including dinosaurs). Meteor impact at Chicxulub (Gulf of Mexico).

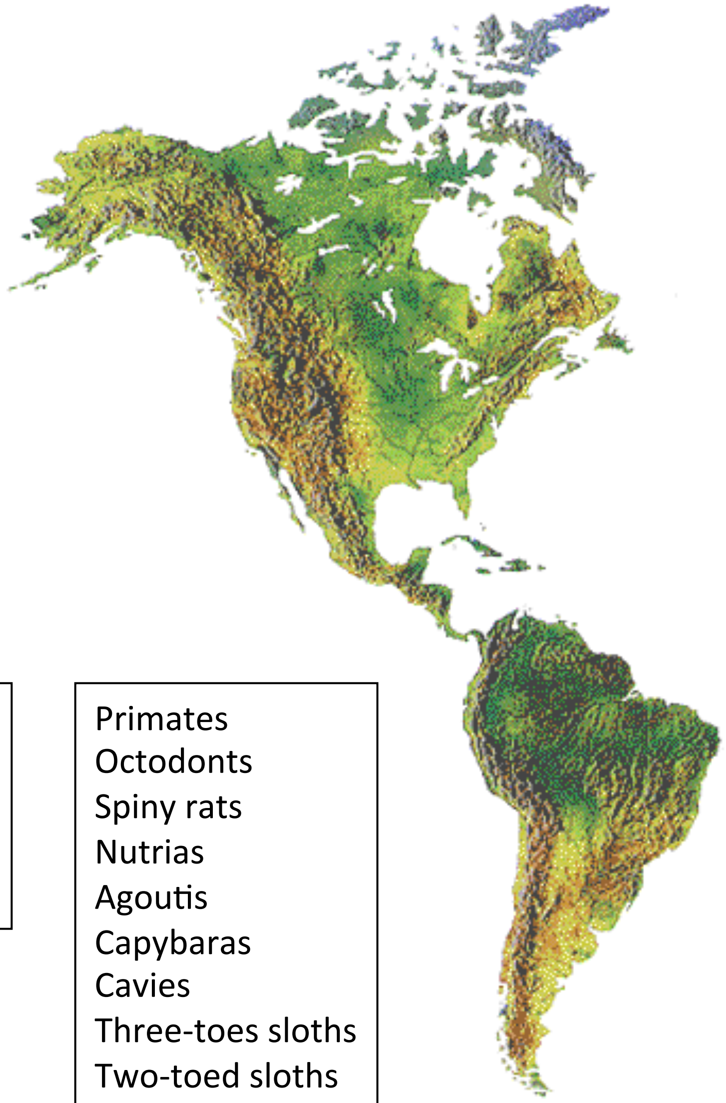
3.5 my BP Emergence of Central American land bridge.

2.5-0.012 my BP Lower sea level and extension of savanna biome in Central America during glacial maxima. Major biotic exchanges between N. and S. America.

Zoogeographic Consequences

1) Shifting Pattern of Isolation and Connectedness

Mammals of N. and S. America before exchange:



Shrews
Pocket mice
Pocket gophers
Beavers
Pronghorns
Bison

Rabbits
Field mice
Foxes
Bears
Raccoons
Weasels
Cats

Mastodons
Horses
Tapirs
Peccaries
Camels
Deer

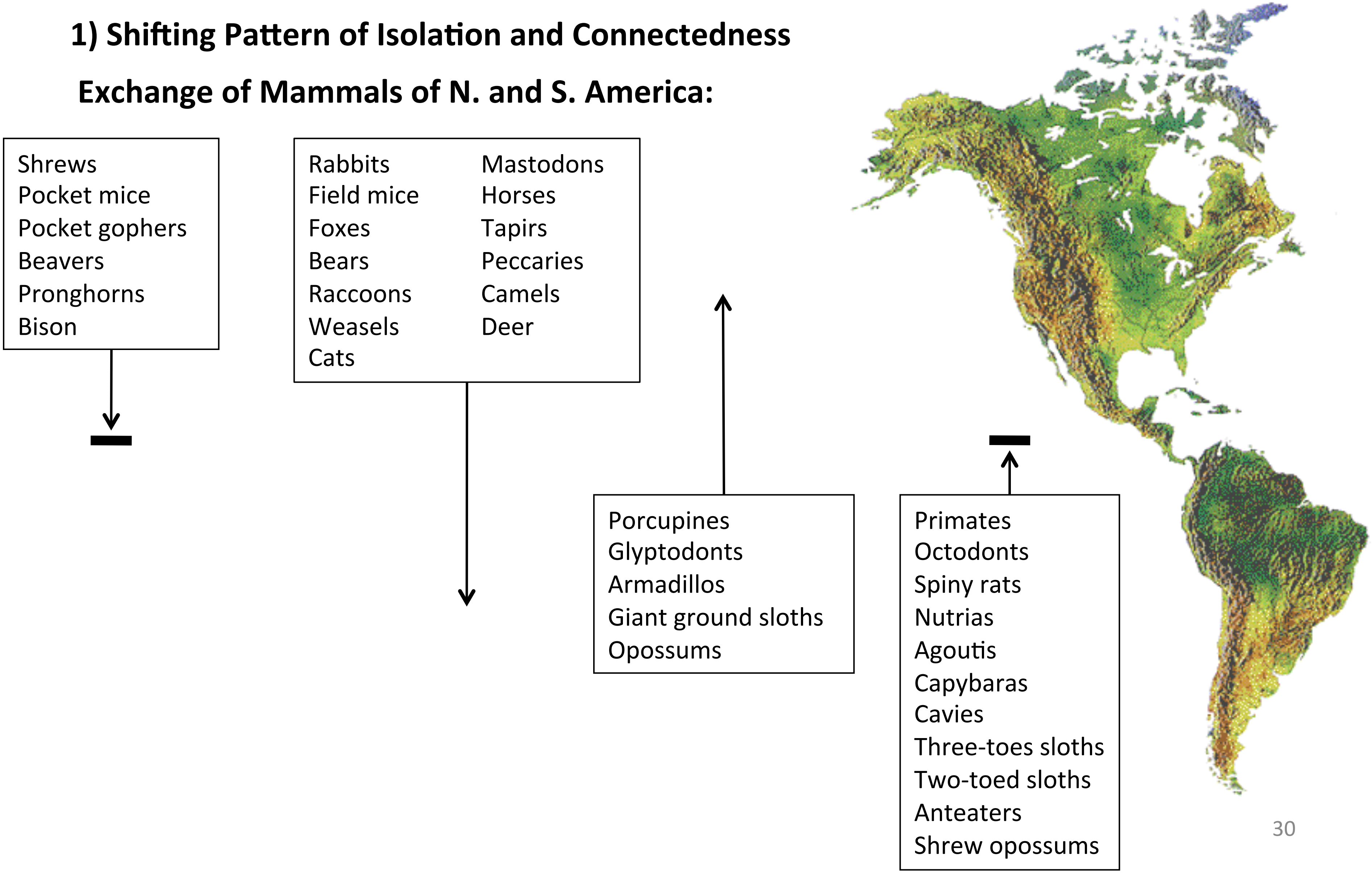
Porcupines
Glyptodonts
Armadillos
Giant ground sloths
Opossums

Primates
Octodonts
Spiny rats
Nutrias
Agoutis
Capybaras
Cavies
Three-toes sloths
Two-toed sloths
Anteaters
Shrew opossums

Zoogeographic Consequences

1) Shifting Pattern of Isolation and Connectedness

Exchange of Mammals of N. and S. America:



Shrews
Pocket mice
Pocket gophers
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Rabbits
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Shrew opossums

Zoogeographic Consequences

1) Shifting Pattern of Isolation and Connectedness

Reasons for asymmetric biotic exchange:

1. N. American mammals were better migrators

   could be due to the fact that there were more savanna specialists in N. America, and continuous savanna through the land bridge.

2. They were better survivors and more readily speciated

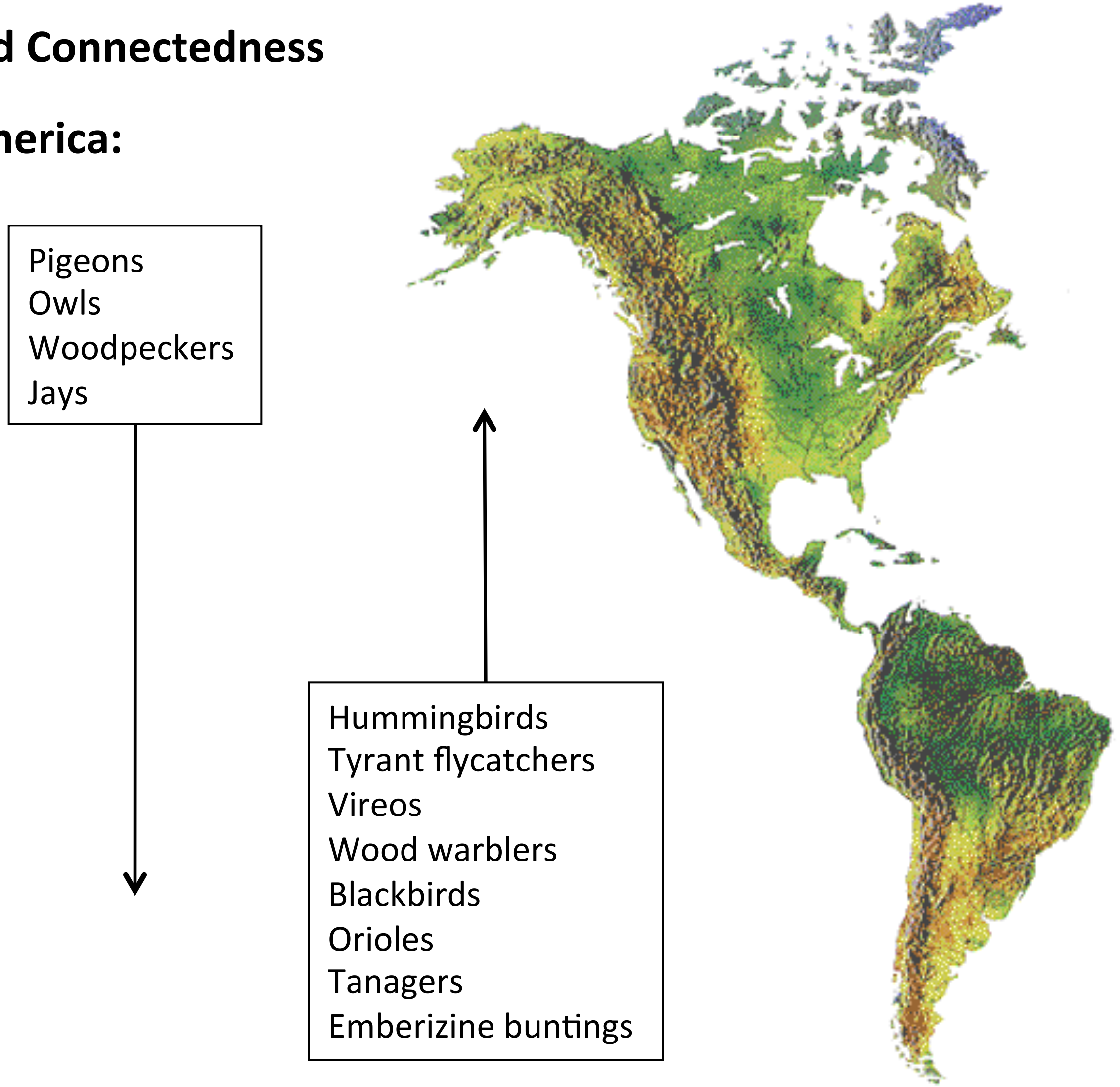
   S. American mammals tended to be closed-forest specialists, and forest habitat became fragmented with climate change (smaller populations, more extinction).

3. They were better competitors.

Zoogeographic Consequences

1) Shifting Pattern of Isolation and Connectedness

Exchange of Birds of N. and S. America:



Pigeons
Owls
Woodpeckers
Jays

Hummingbirds
Tyrant flycatchers
Vireos
Wood warblers
Blackbirds
Orioles
Tanagers
Emberizine buntings

Zoogeographic Consequences

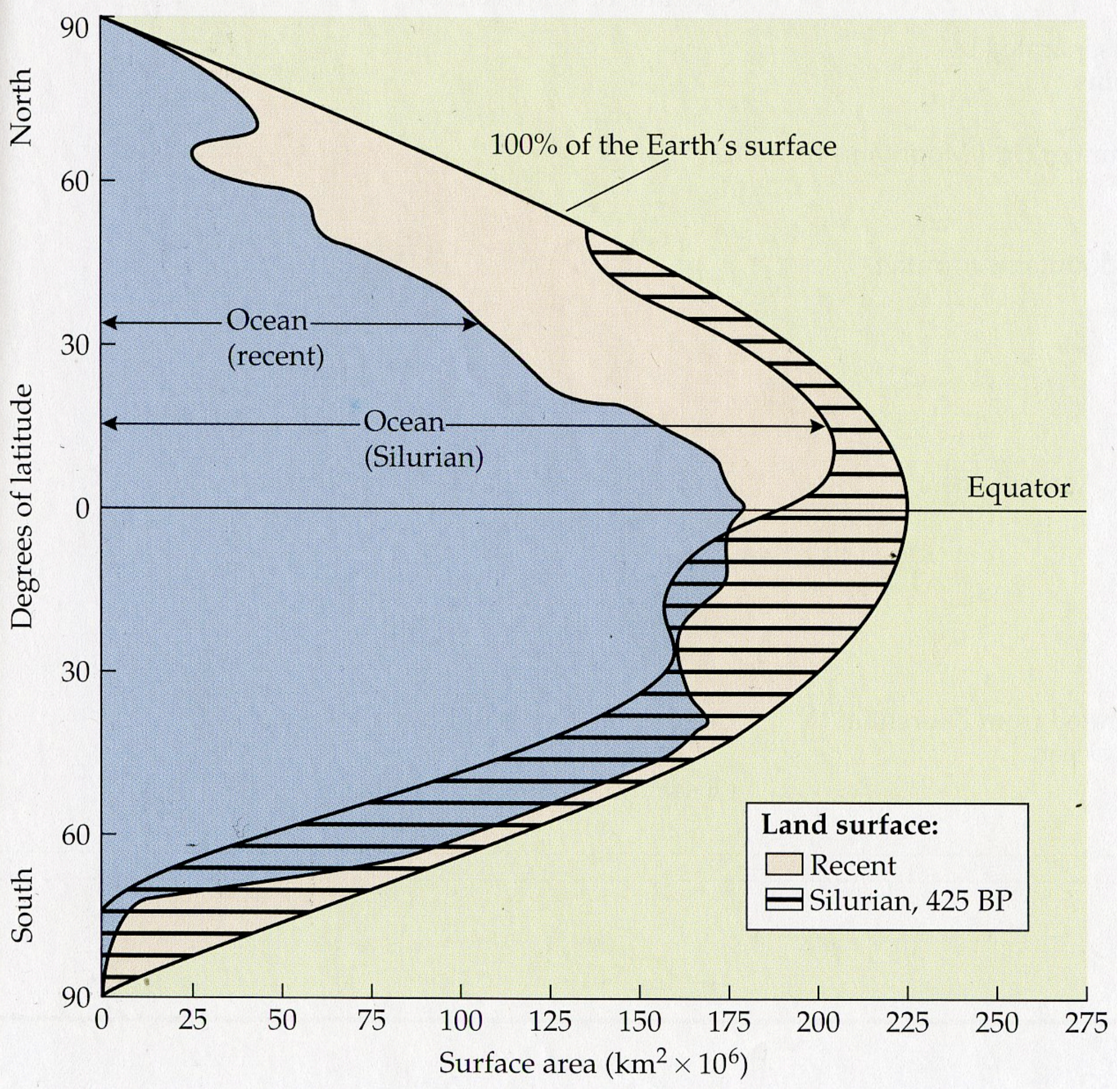
1) Shifting Pattern of Isolation and Connectedness

Other Vertebrates of N. and S. America:

Some show opposing patterns, but almost always with unbalanced exchange.

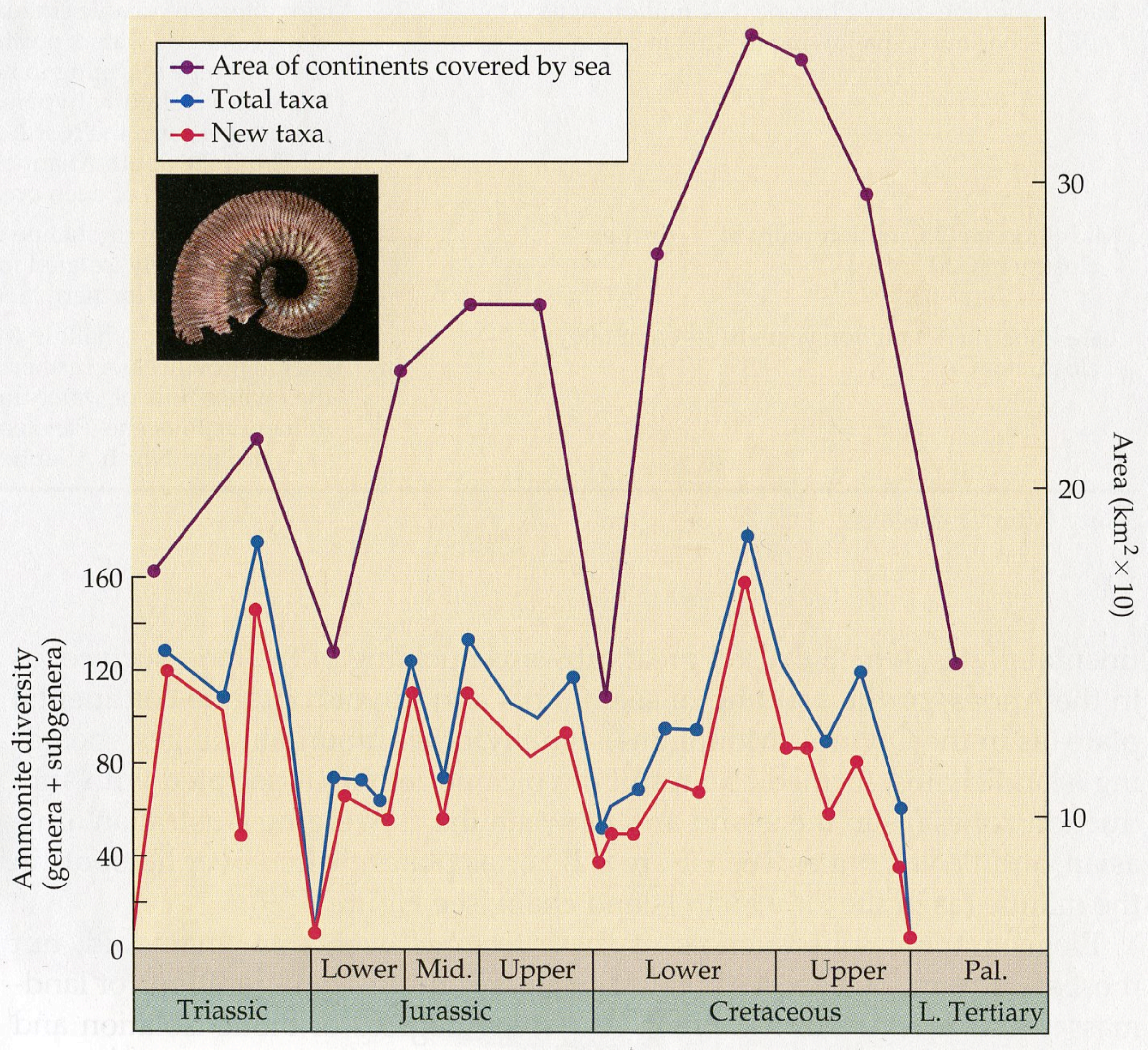
Zoogeographic Consequences

2) Changing Amounts of Land and Sea Area



Zoogeographic Consequences

2) Changing Amounts of Land and Sea Area



Diversity of ammonites

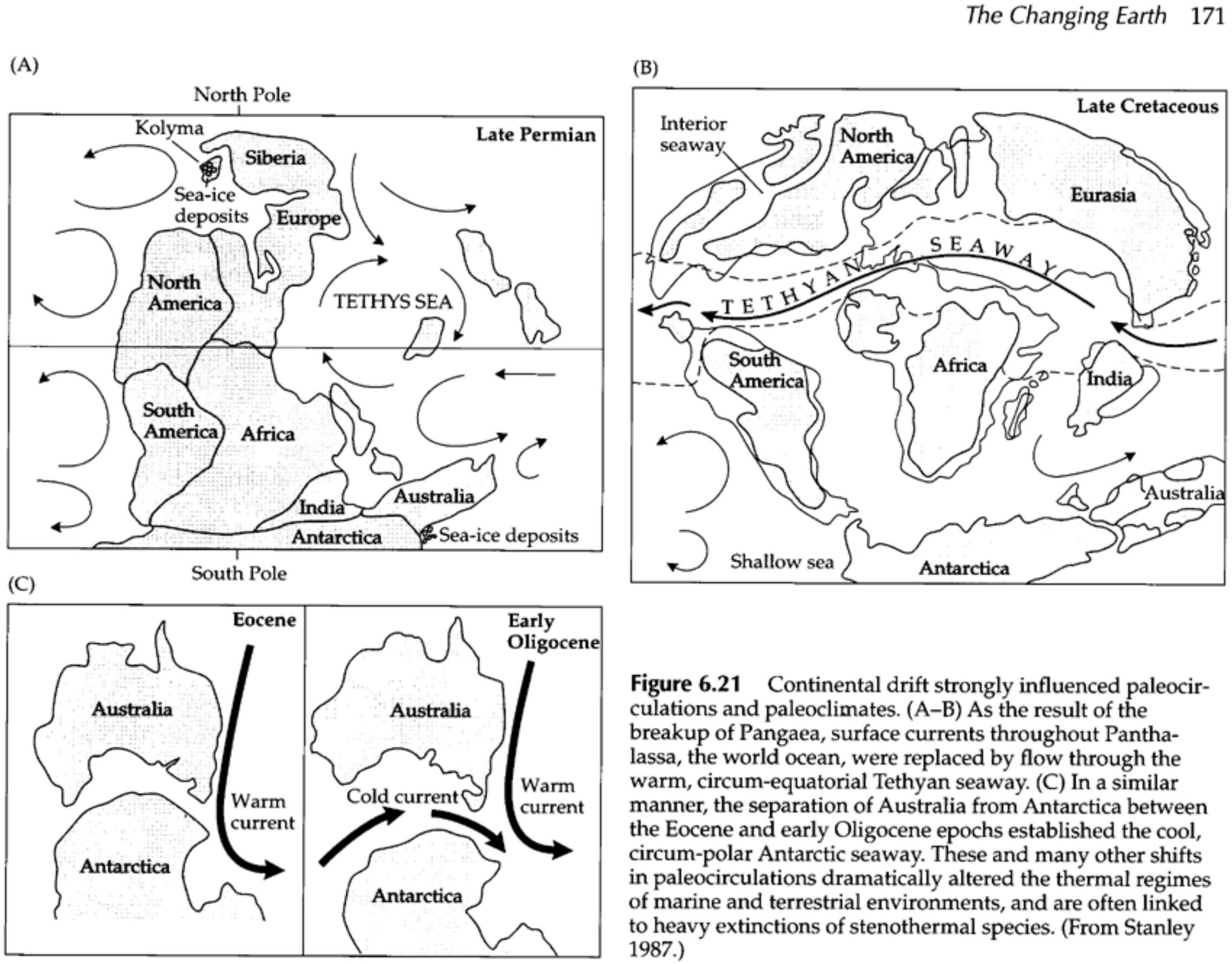
Class Cephalopoda

Spiral shaped fossilized shells

Index fossils – can be used to link the rock layer in which they are found to specific geological time periods

Zoogeographic Consequences

3) Climate Change

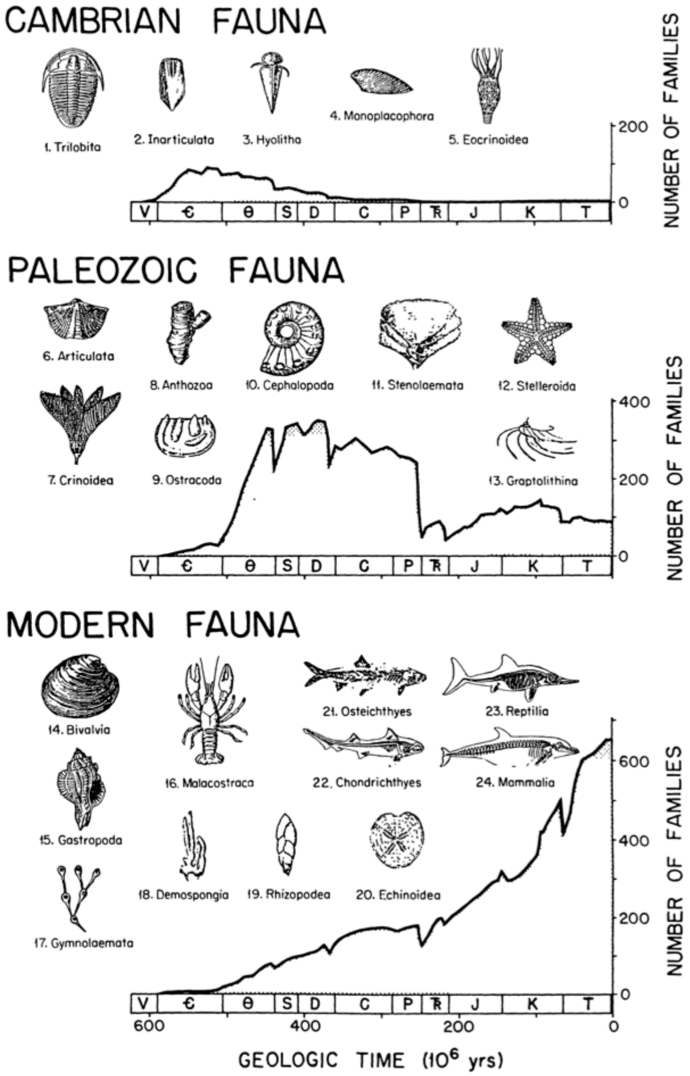


The Changing Earth 171

Figure 6.21 Continental drift strongly influenced paleocirculations and paleoclimates. (A–B) As the result of the breakup of Pangaea, surface currents throughout Panthalassa, the world ocean, were replaced by flow through the warm, circum-equatorial Tethyan seaway. (C) In a similar manner, the separation of Australia from Antarctica between the Eocene and early Oligocene epochs established the cool, circum-polar Antarctic seaway. These and many other shifts in paleocirculations dramatically altered the thermal regimes of marine and terrestrial environments, and are often linked to heavy extinctions of stenothermal species. (From Stanley 1987.)

Zoogeographic Consequences

3) Climate Change



Drop in number of families (extinction) around time of Pangaea formation (between Permain "P" and Triassic "TR" Periods

Rapid increase in number of families (diversification) after beginning of Pangaea breakup in the Jurassic Period "J"

Zoogeographic Consequences

4) Hydrothermal Vents and Tectonically-Derived Faunas

High temperature environments with high hydrogen sulfide concentration around ridges of sea floor spreading. Discovery in 1977 of whole communities based on chemosynthesis.

Highly distinct because:

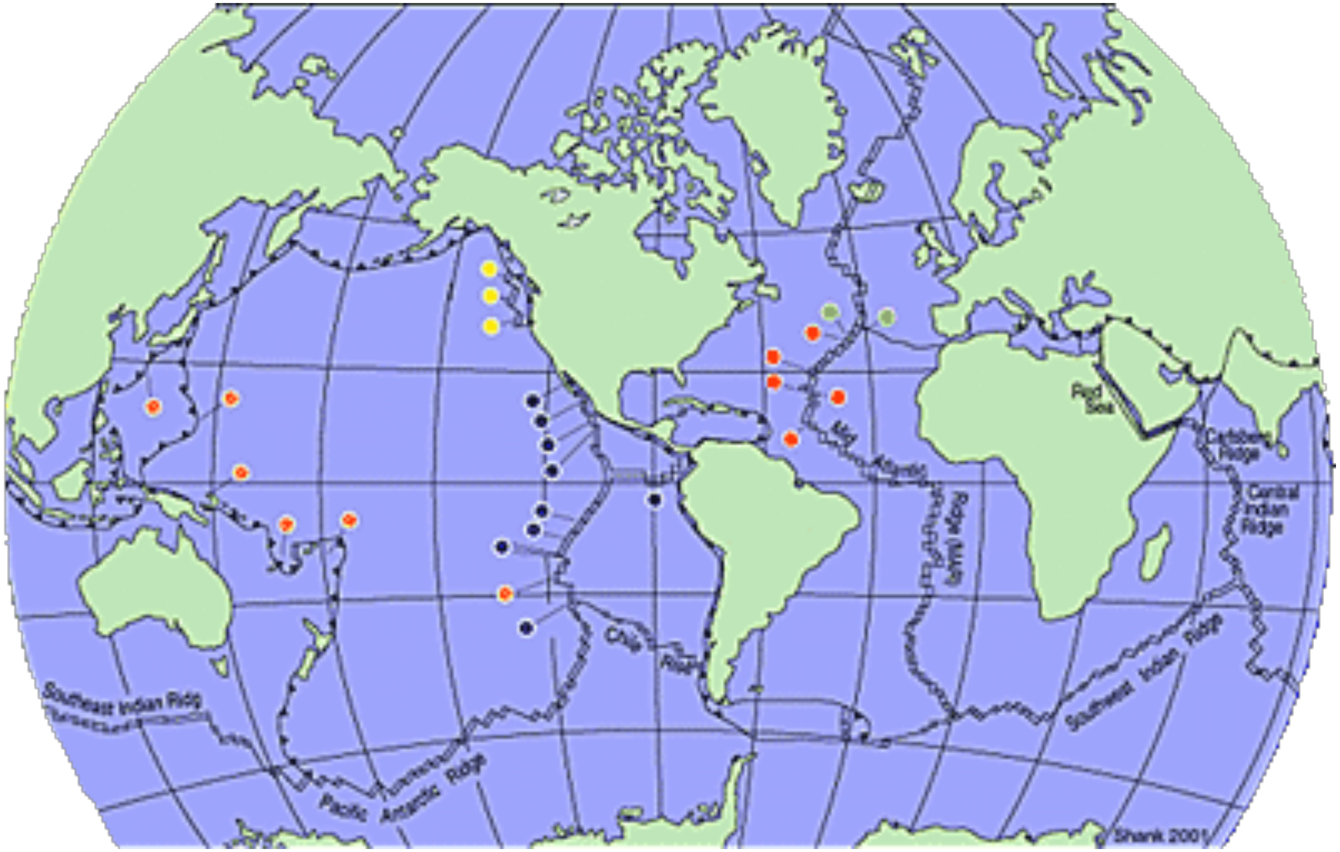
1. very isolated
2. very old (originated over 400 mya)
3. highly specialized adaptations

Discovery resulted in the recognition of a new phylum:
Vestimentifera, with 14 families, and over 50 genera
(includes the highly unusual tube worms)

Deep water communities > 6000m deep

Zoogeographic Consequences

4) Hydrothermal Vents and Tectonically-Derived Faunas



Color circles show vents with similar animal communities
(from http://www.csa.com/discoveryguides/vent/review5.php#n1)

Continental Drift

References for this section:

Flessa, K.W. 1980. Biological effects of plate tectonics and continental drift. *Bioscience* 30: 518-523.

Lomolino, M.V., B.R. Riddle, R.J. Whittaker, & J.A. Brown. 2010. *Biogeography* (4th ed., Chapter 2). Sinauer Associates, Inc., Sunderland, Mass.

USGS website on plate tectonics: http://pubs.usgs.gov/gip/dynamic/dynamic.html