

PHYS 3800

Physical Geology

Chapter 2

The Way the Earth Works: Plate Tectonics

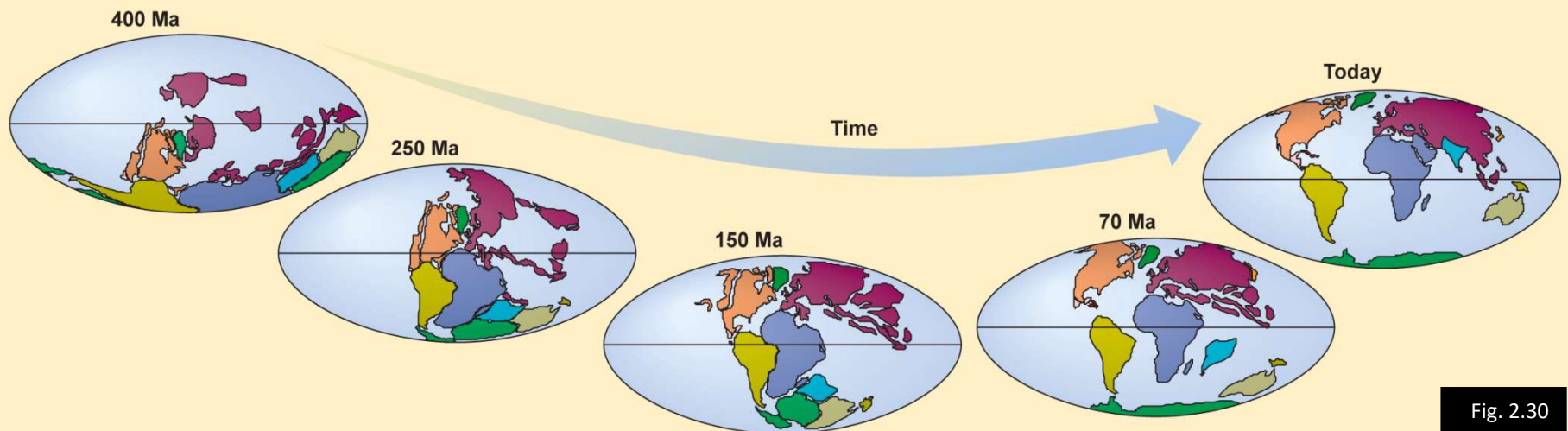


Your Government in Action



In this Chapter

- What were Wegener's observations?
- Paleomagnetism: the key proof of continental drift
- Observations that led Harry Hess to sea-floor spreading
- Three kinds of plate boundaries
- Plate interactions and rates of plate movement



Alfred Wegener

- German meteorologist and polar explorer.
- Wrote *The Origins of the Continents and Oceans* in 1915.
 - He hypothesized a former supercontinent, Pangaea.
 - He suggested that land masses slowly move (continental drift).
 - These were based on strong evidence.
 - ▶ “Fit” of the continents
 - ▶ Glacial deposits far from polar regions
 - ▶ Paleoclimatic belts
 - ▶ Distribution of fossils
 - ▶ Matching geologic units



Fig. 2.1a

Plate Tectonics

- Wegener's idea was the basis of a scientific revolution.
 - Earth continually changes.
 - ▶ Continents move, split apart, and recombine.
 - ▶ Ocean basins open and close.
- His hypothesis was met with strong resistance:
 - “What force could possibly be great enough to move the immense mass of a continent?”

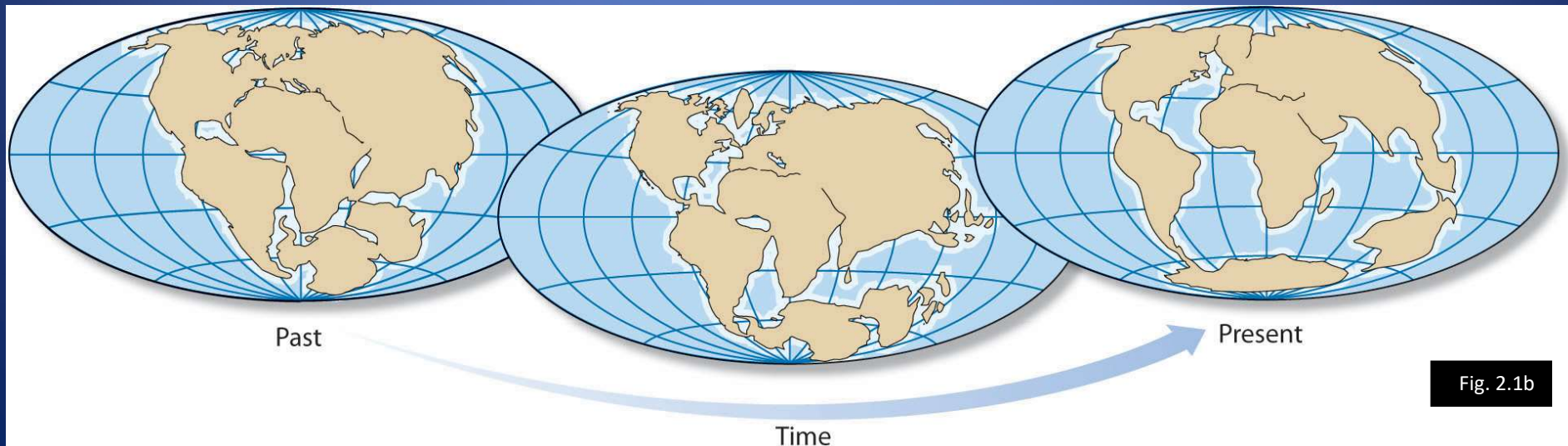


Fig. 2.1b

Plate Tectonics

- The scientific revolution began in 1960.
 - Harry Hess (Princeton) proposed sea-floor spreading.
 - ▶ As continents drift apart, new ocean floor forms between.
 - ▶ Continents converge when ocean floor sinks into the interior.
- By 1968, a complete model had been developed.
 - Continental drift, sea-floor spreading, and subduction.
 - Earth's lithosphere is broken into ~20 plates that interact.

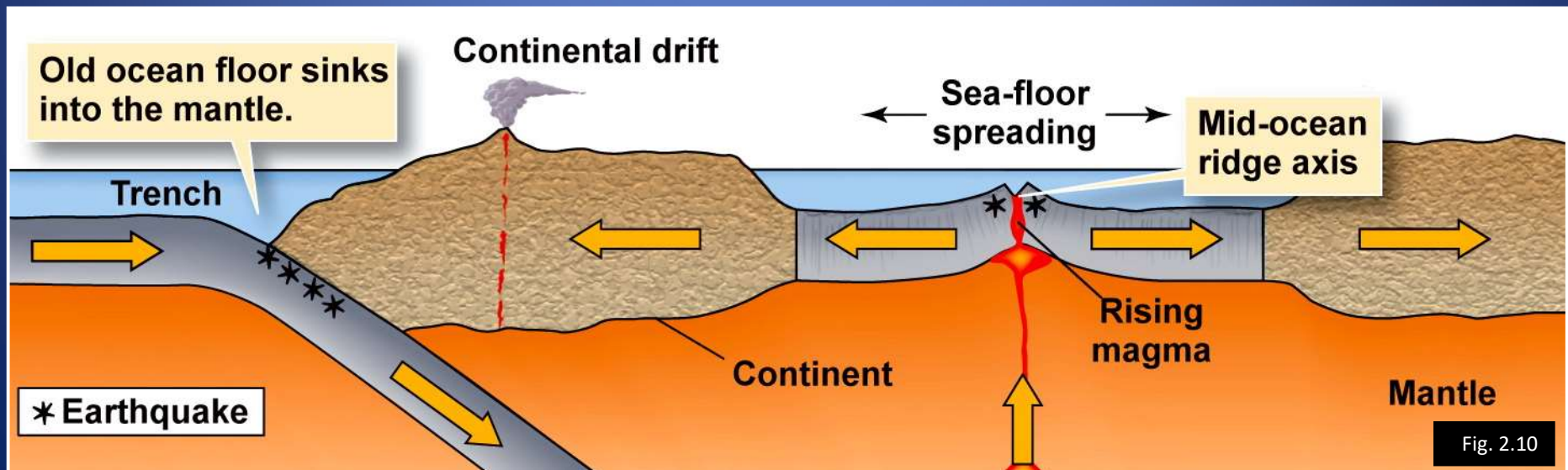
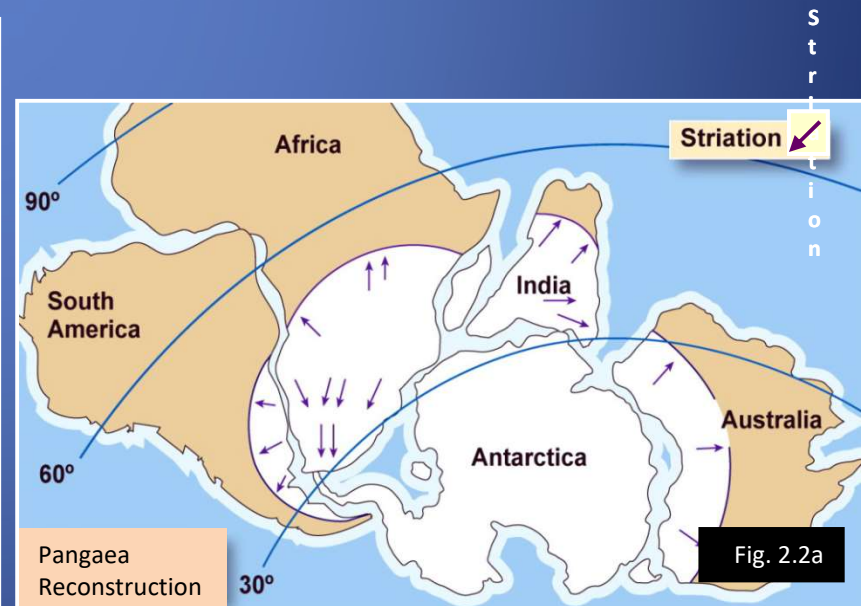
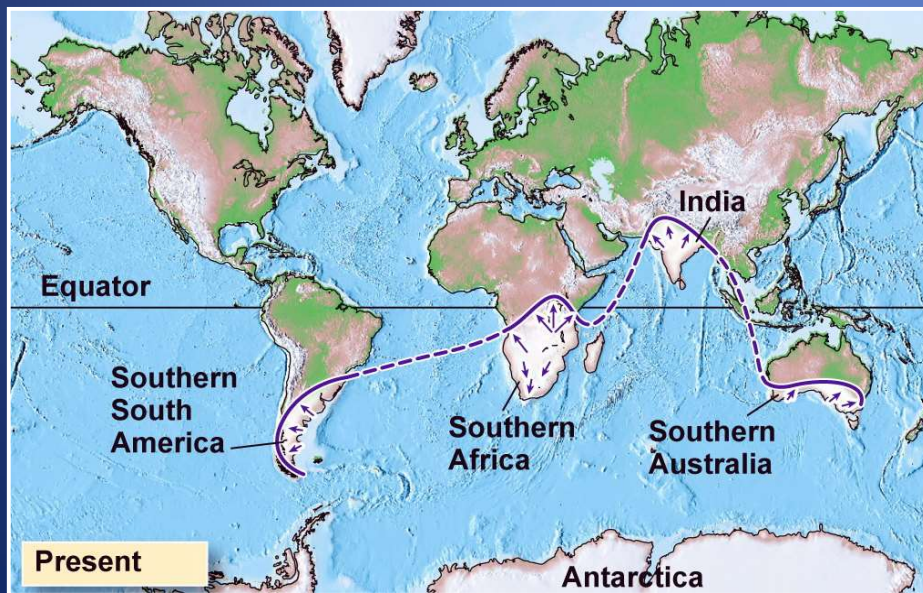


Fig. 2.10

Glacial Evidence

- Evidence of Late Paleozoic glaciers found on five continents.
- Some of this evidence is now far from the poles.
- These glaciers could not be explained unless the continents had moved.



Paleoclimatic Evidence

- Placing Pangaea over the Late Paleozoic South Pole:
- Wegener predicted rocks defining Pangea climate belts.

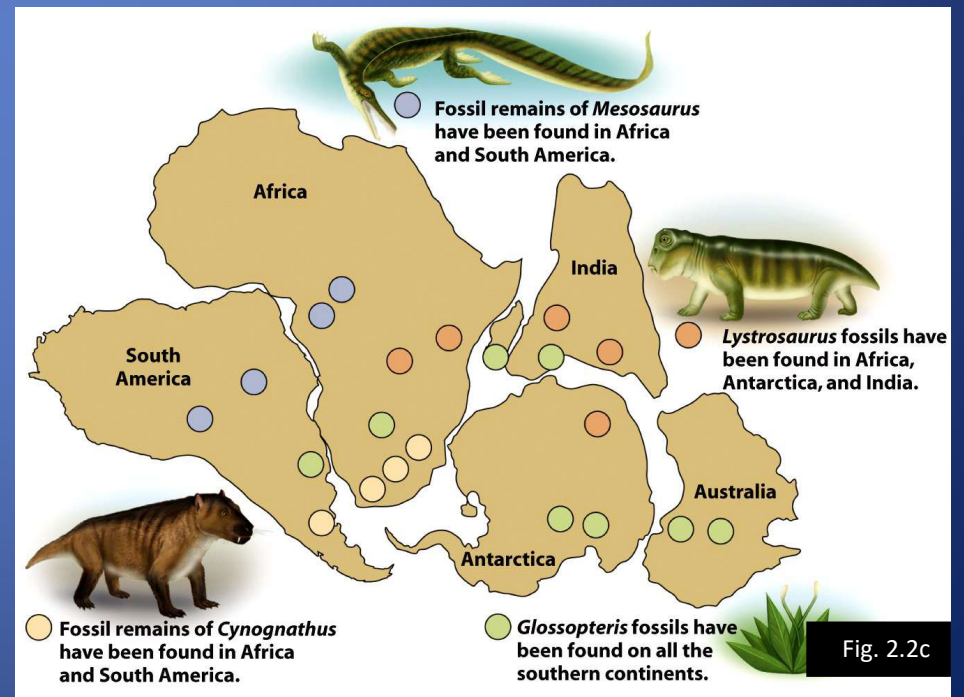
- Tropical coals
- Tropical reefs
- Subtropical deserts
- Subtropical evaporites



Fig. 2.2b

Fossil Evidence

- Identical fossils found on widely separated land masses.
 - *Mesosaurus*—a freshwater reptile
 - *Glossopteris*—a subpolar plant with heavy seeds



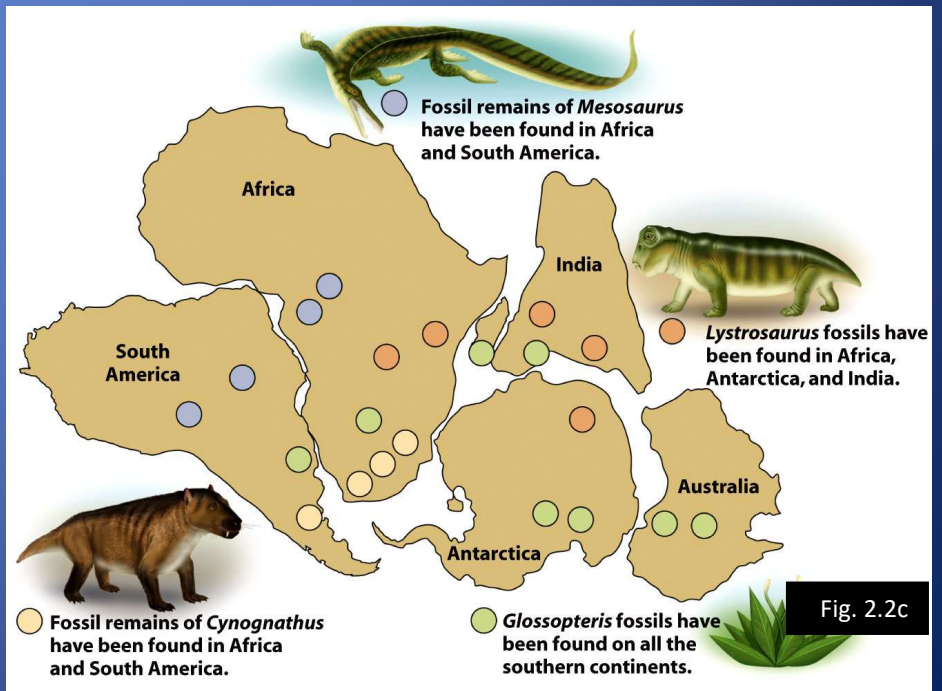
Fossil Evidence

■ Identical fossils found on widely separated land.

- *Lystrosaurus*—A nonswimming, land-dwelling reptile.
- *Cynognathus*—A nonswimming, land-dwelling mammal-like reptile.

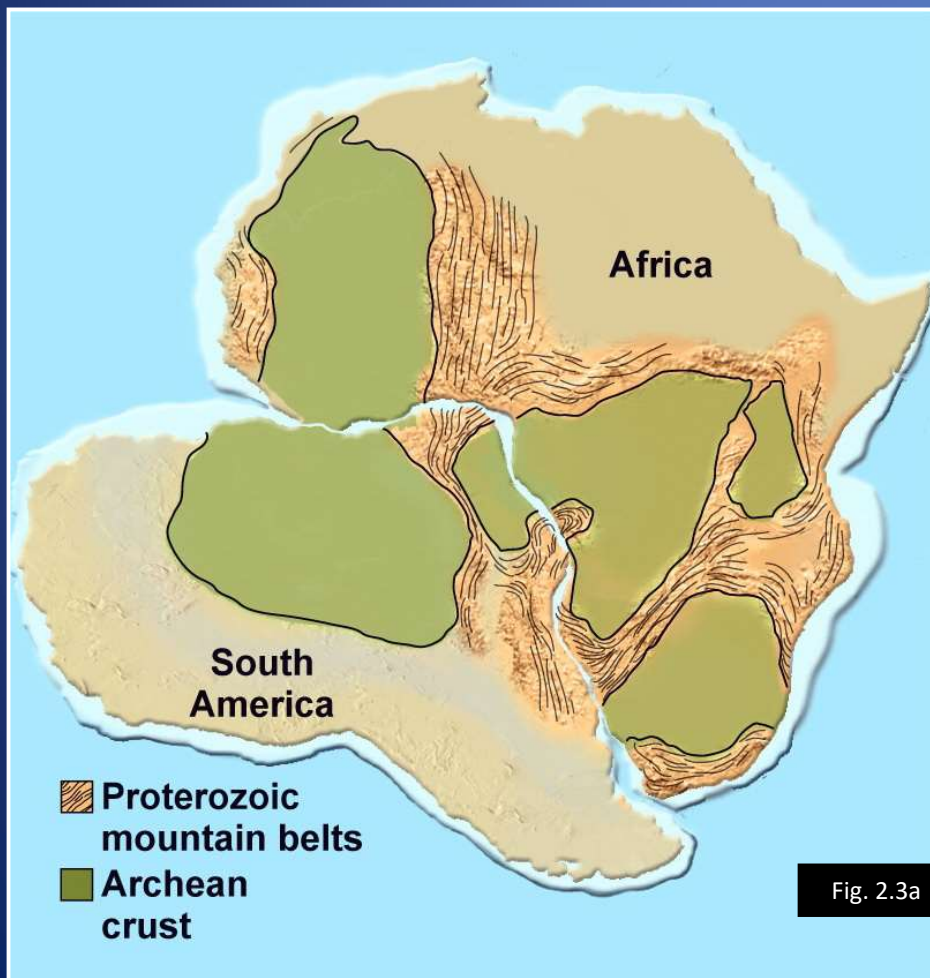
■ These organisms could not have crossed an ocean.

■ Pangaea explains the distribution.



Matching Geologic Units

- Distinctive rock assemblages and mountain belts match across the Atlantic.



Criticisms of Wegener's Ideas

- Wegener had multiple lines of strong evidence.
- Yet, his idea was debated, ridiculed, and ignored. WHY?
 - He couldn't explain *how* or *why* continents moved.
 - Wegener died in 1930 on a Greenland expedition.
 - Over the next three decades, new research, new technology, and new evidence from the oceans revived his hypothesis.



Evidence from beneath the sea was key to proving that Alfred Wegener's ideas were correct.

Earth's Magnetic Field

- Flow in the liquid outer core creates the magnetic field.
 - It is similar to the field produced by a bar magnet.
 - The magnetic pole is tilted $\sim 11.5^\circ$ from the axis of rotation.

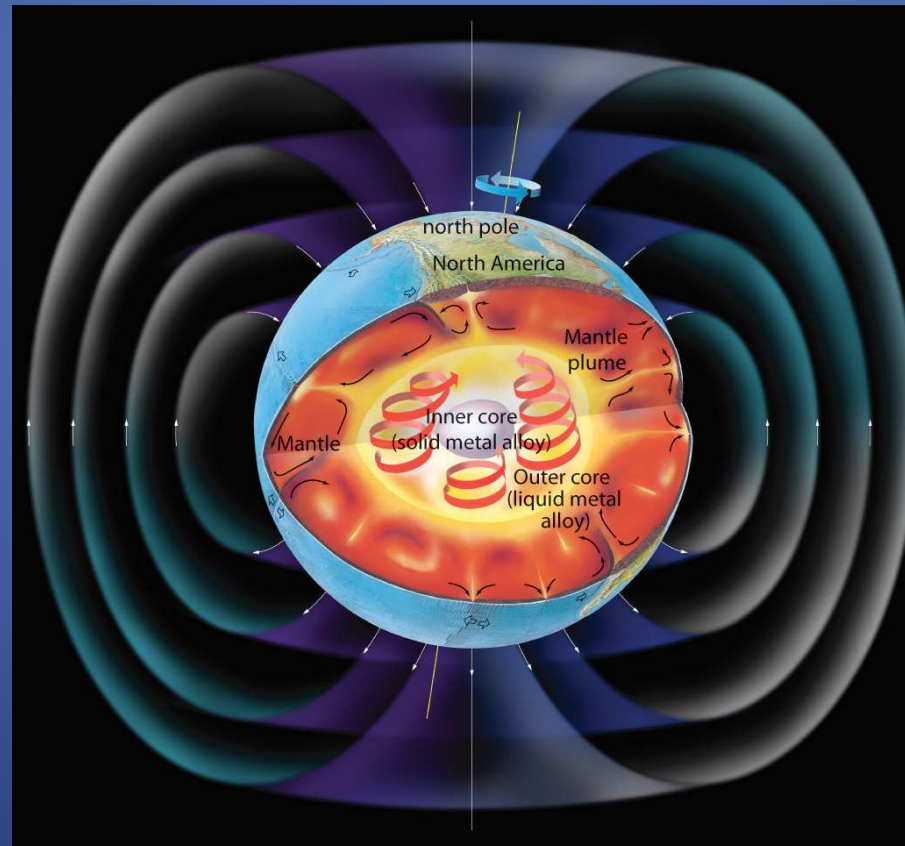
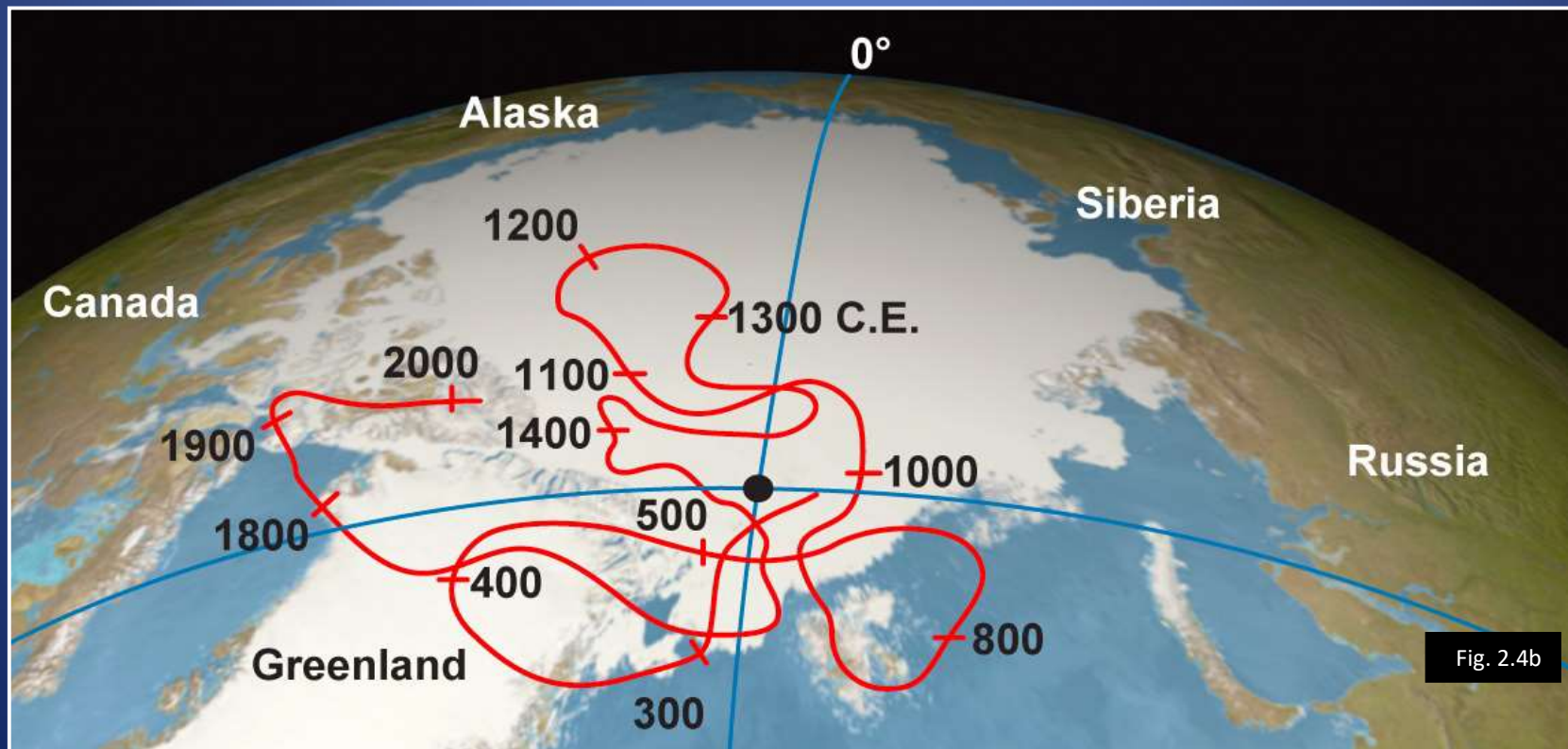


Fig. 2.4a

Magnetic Poles

- The magnetic pole intersects Earth's surface just like the geographic pole does.
 - Magnetic N pole and magnetic S pole both exist.
 - Magnetic poles are located near geographic poles.
 - Magnetic poles move constantly.



The Earth's Magnetic Field

- Geographic and magnetic poles are not parallel.
- A compass points to magnetic N, not geographic N.
- The difference between geographic N and magnetic N is called *declination*. It depends on:
 - Absolute position of the two poles
 - ▶ Geographic north
 - ▶ Magnetic north
 - Longitude

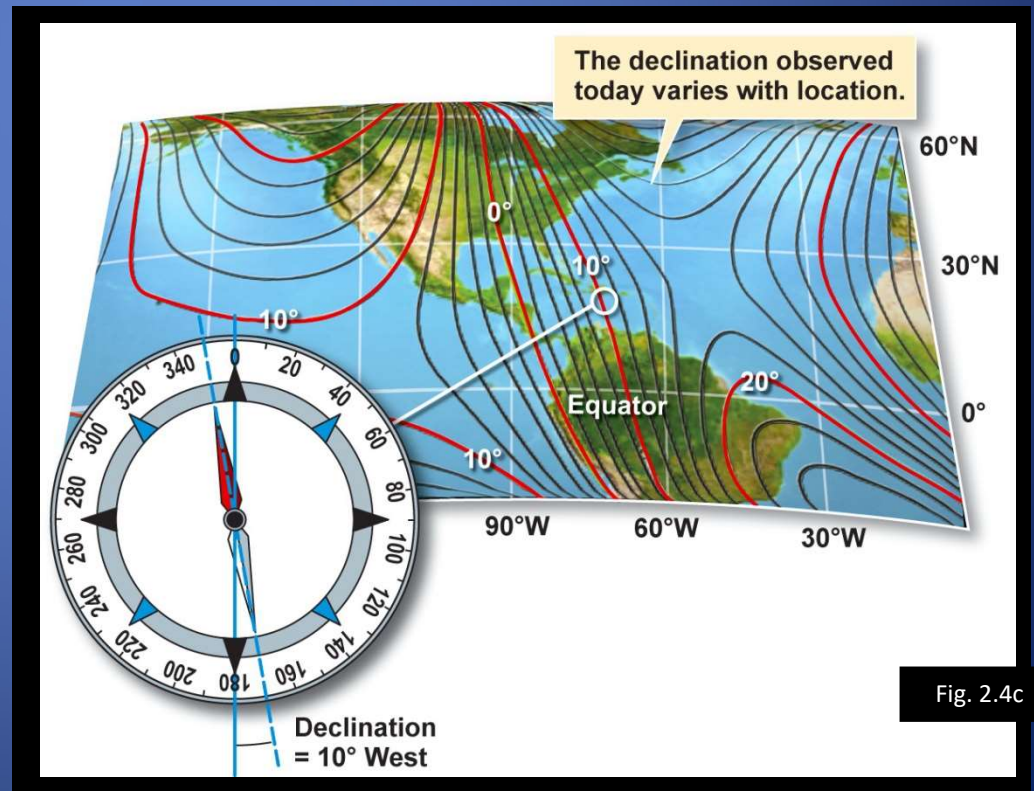
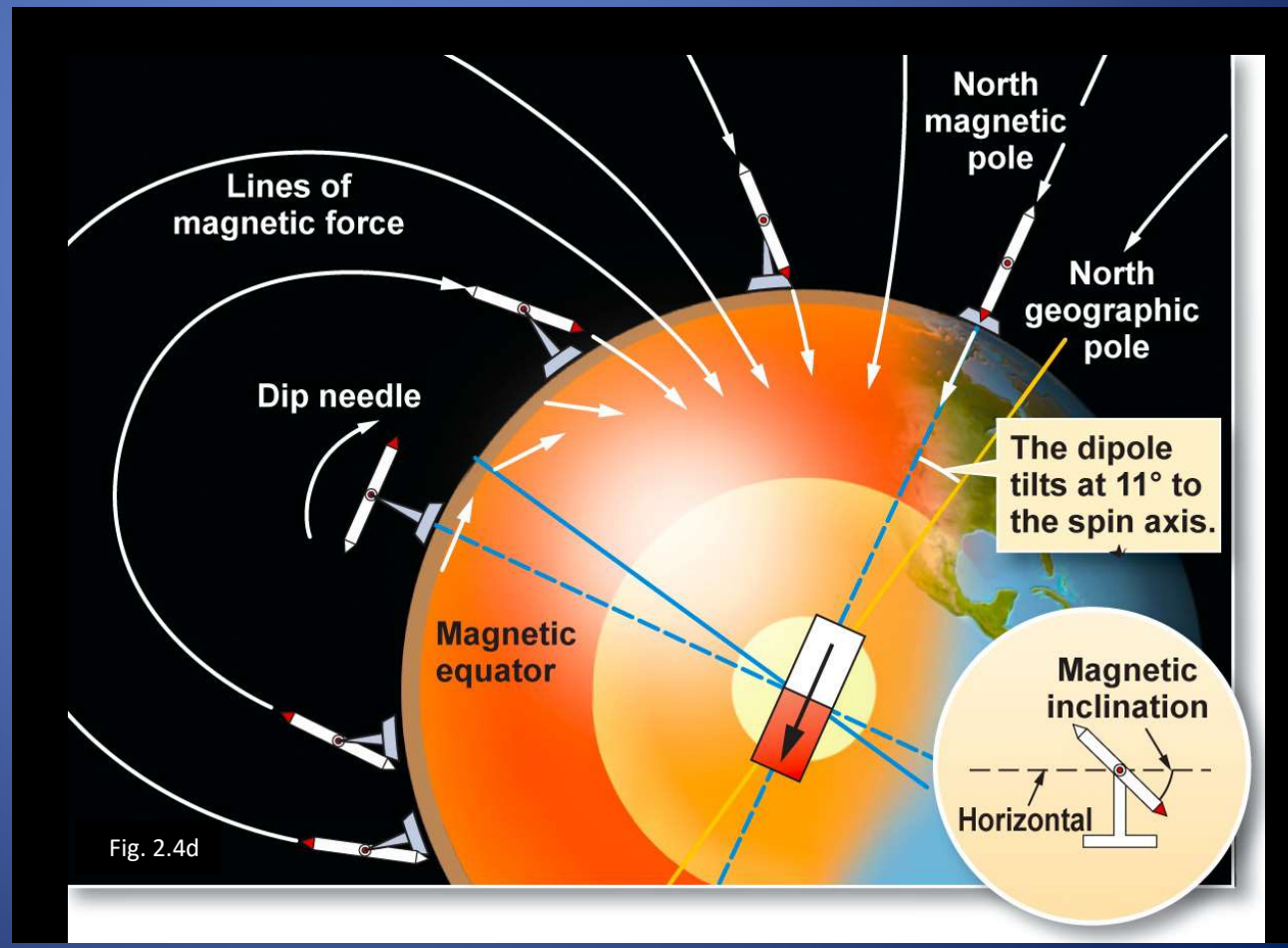


Fig. 2.4c

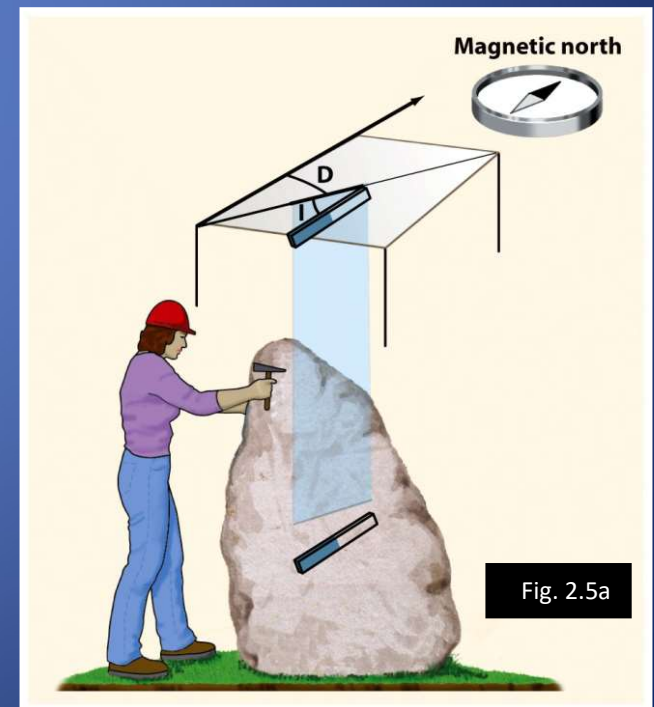
The Earth's Magnetic Field

- Curved field lines cause a magnetic needle to tilt.
- Angle between magnetic field line and surface of the Earth is called *inclination*. It depends on:
 - Latitude



Paleomagnetism

- Rock magnetism can be measured in the laboratory.
- The study of fossil magnetism is called paleomagnetism.
- Iron (Fe) minerals in rock preserve information about the magnetic field at the time the rocks formed.
 - Declination and inclination preserved in rocks often vary from present latitude / longitude.
 - Instruments used in paleomagnetism record changes in position.
 - These data are used to trace continental drift.



Paleomagnetism

- Iron minerals archive the magnetic signal at formation.
- Hot magma
 - High Temp—no magnetization
 - ▶ Thermal energy of atoms is very high.
 - ▶ Magnetic dipoles are randomly oriented.

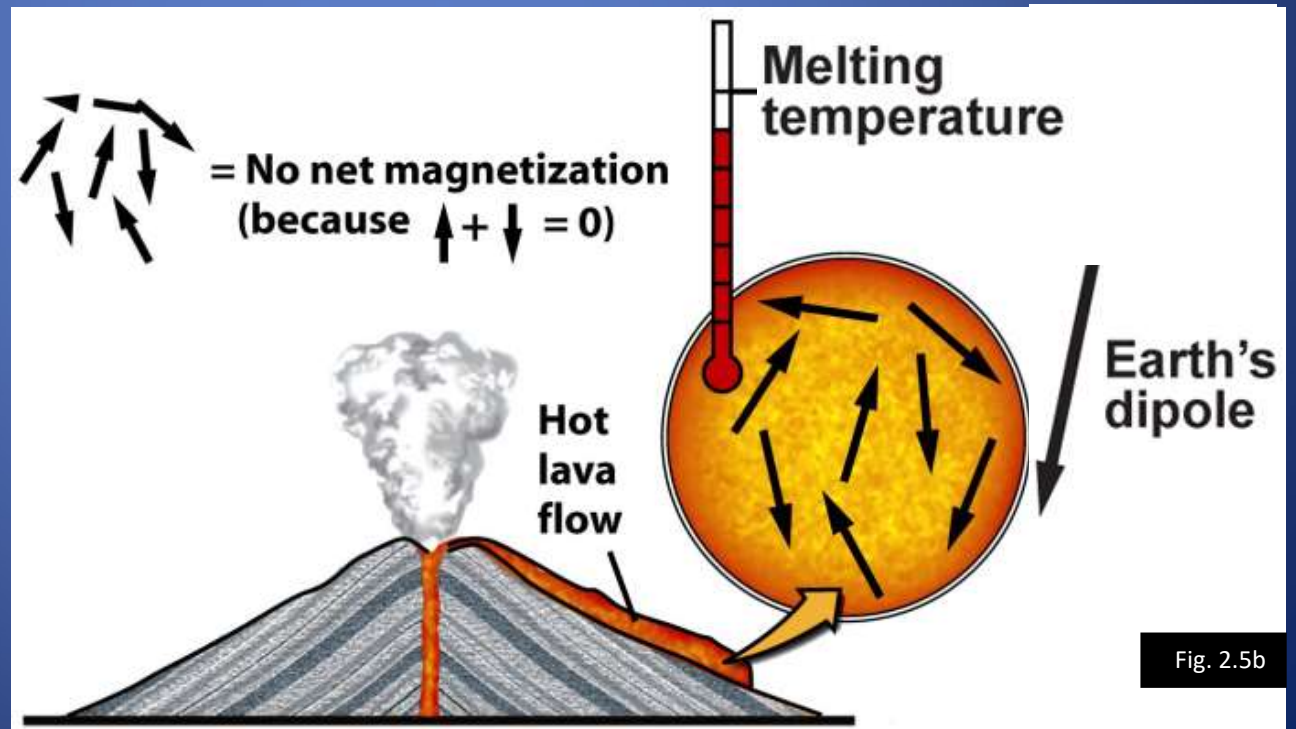
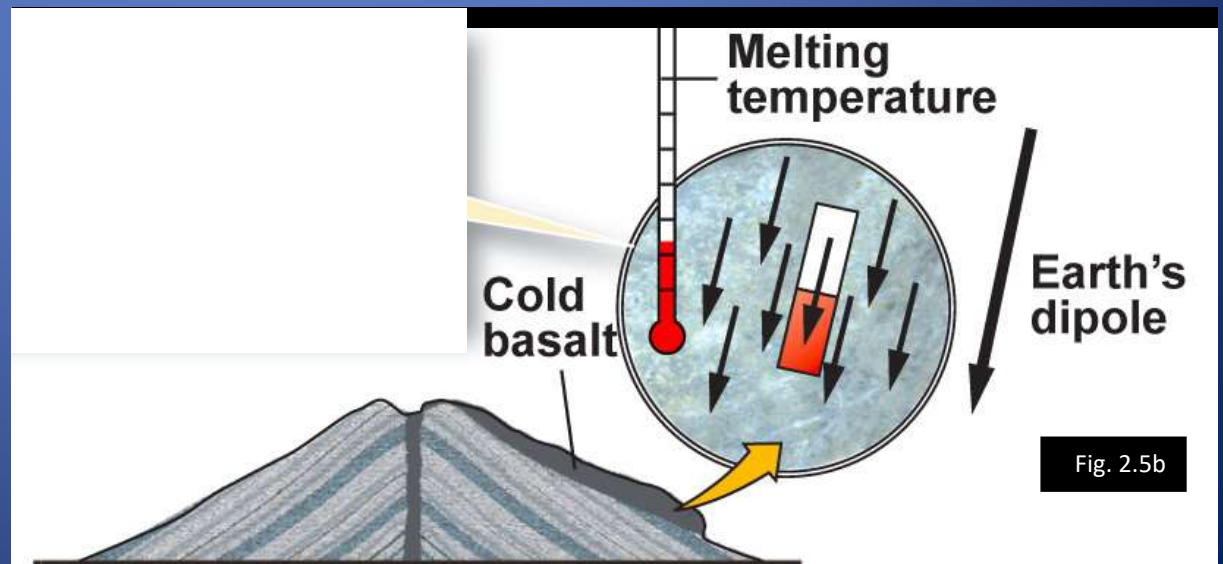


Fig. 2.5b

Paleomagnetism

- Iron minerals archive the magnetic signal at formation.
- Cooled magma
 - Low Temp—permanent magnetization
 - ▶ Thermal energy of atoms slows.
 - ▶ Dipoles align with Earth's magnetic field.
 - ▶ Magnetic dipoles become frozen in alignment with field.



Polar Wandering

- Layered basalts record magnetic changes over time.
- Inclination and declination indicate change in position.

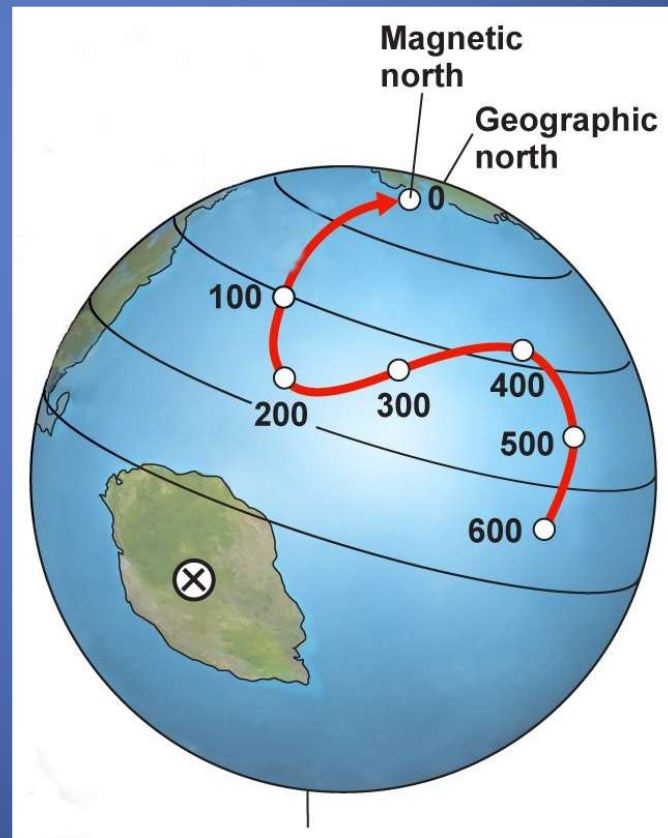
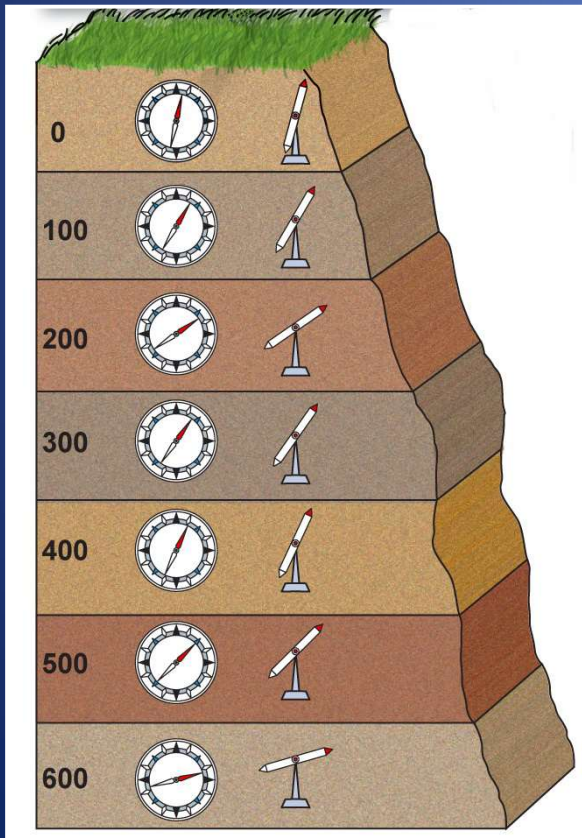


Fig. 2.6a

Apparent Polar Wandering

- Polar wandering paths were initially misinterpreted:
 - Not the signature of a wandering pole on a fixed continent
 - The signature of a fixed pole on a wandering continent

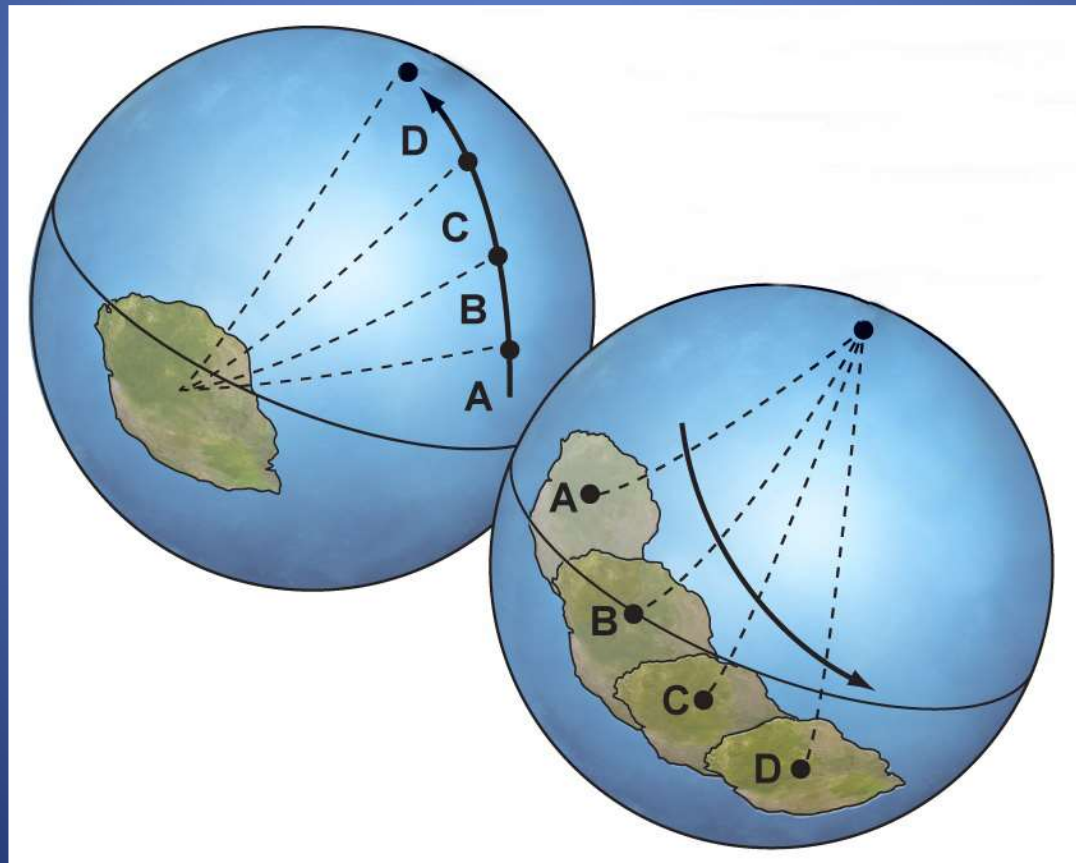
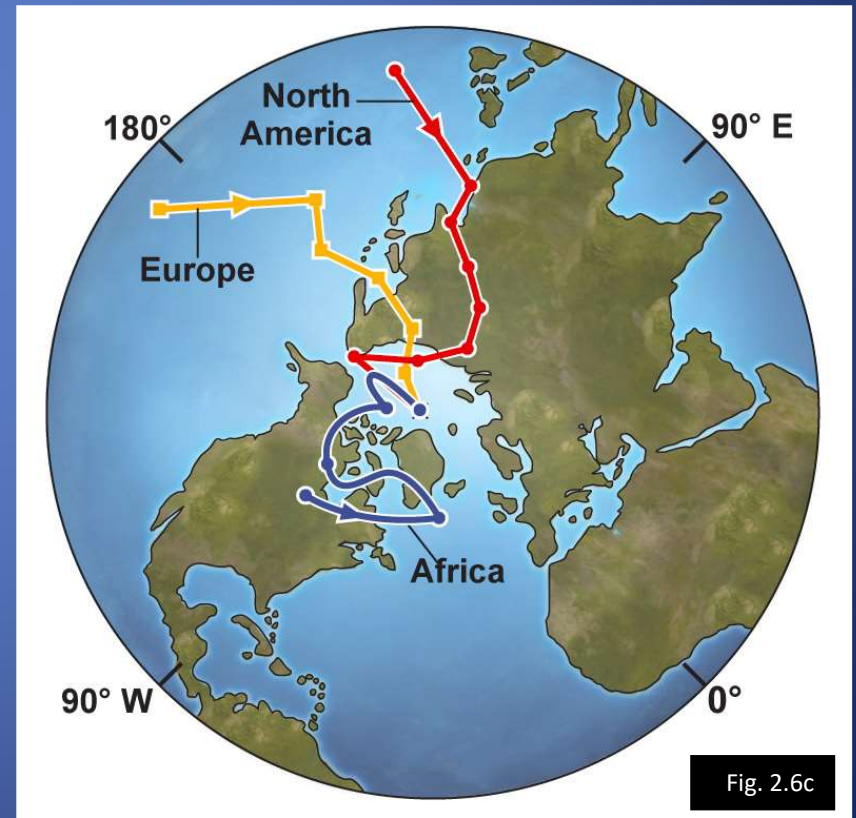


Fig. 2.6b

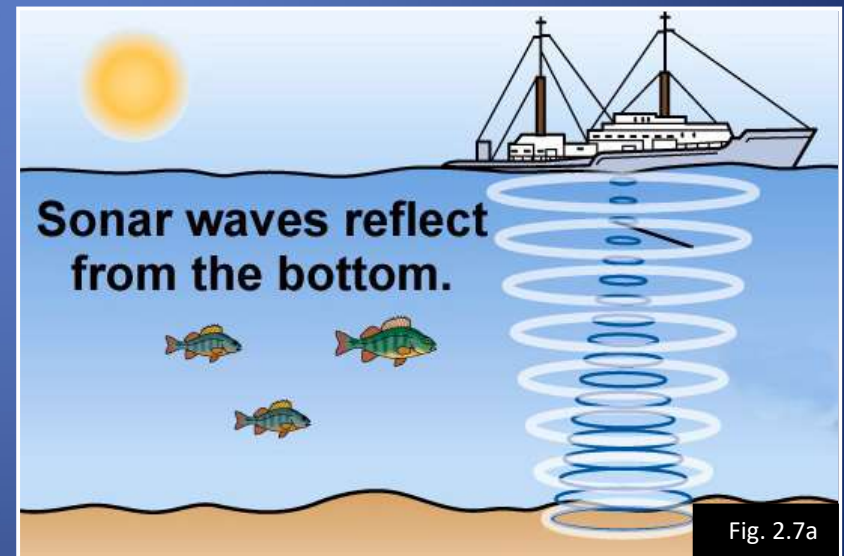
Polar Wandering

- Each continent had a separate polar wandering path. Now understood to represent that:
 - The location of the magnetic pole is fixed.
 - The continents themselves have moved.
- These curves align when continents are reassembled.



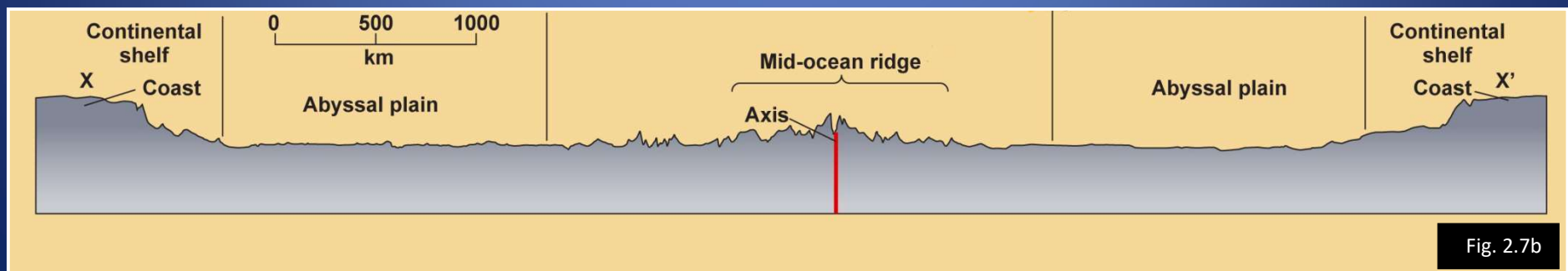
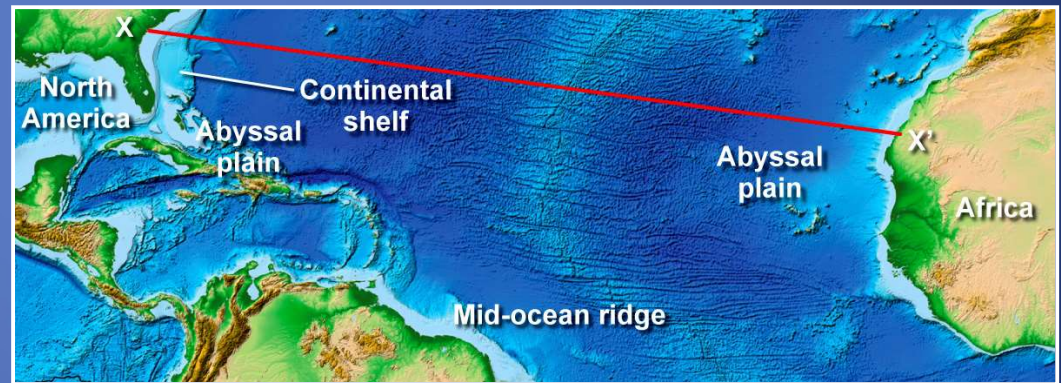
Sea-Floor Bathymetry

- Before World War II, we knew little about the sea floor.
- Echo-sounding (sonar) allowed rapid sea-floor mapping.
- Sea-floor maps created by ships crossing the oceans.
- Bathymetric maps are now produced using satellite data.



The Ocean Floor

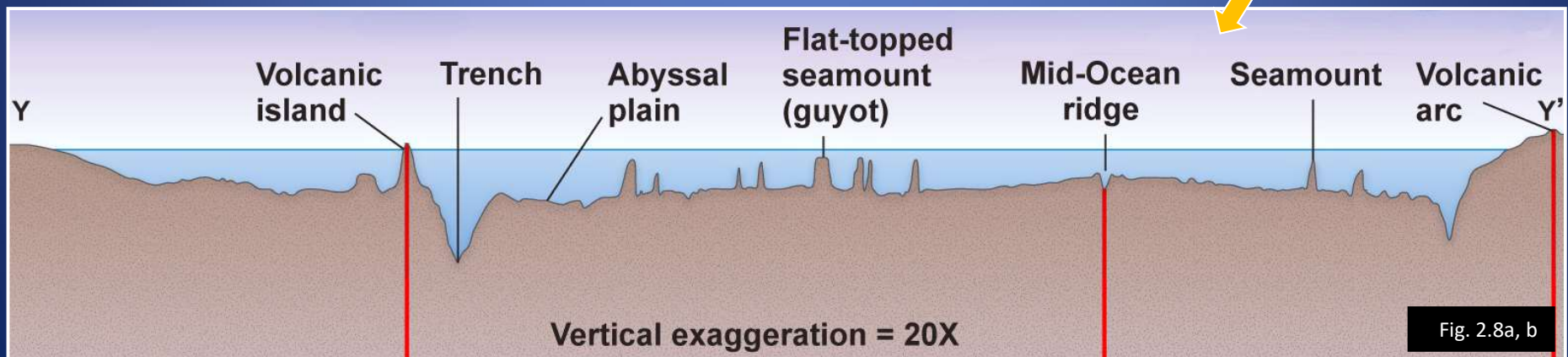
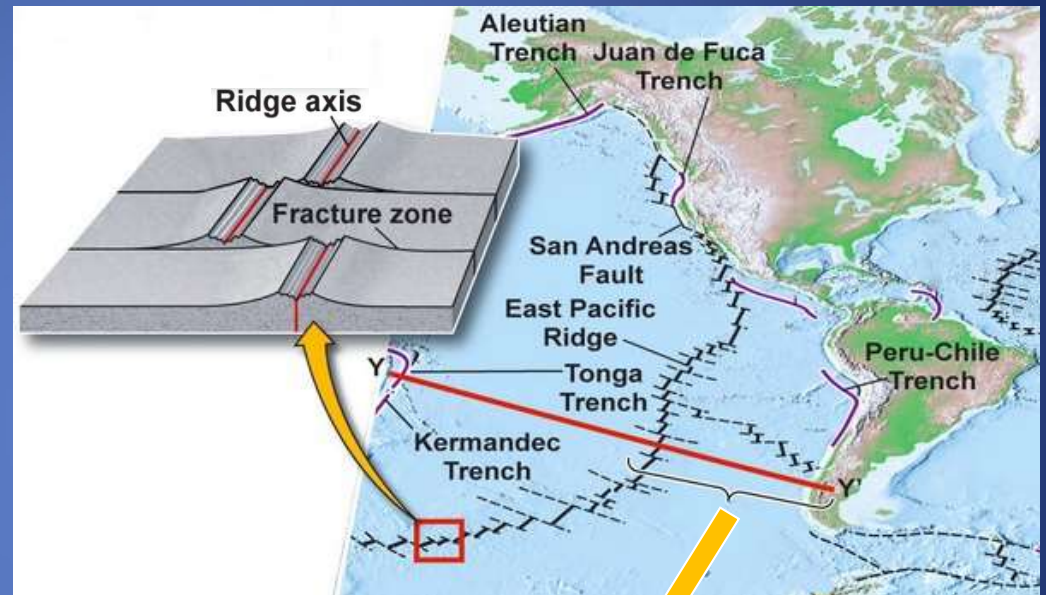
- Oceanographers were surprised to discover that:
 - A mid-ocean mountain range runs through every ocean.
 - Deep-ocean trenches occur near volcanic island chains.
 - Submarine volcanoes poke up from the ocean floor.
 - Huge fracture zones segment the mid-ocean ridge.
- These observations are all explained by plate tectonics.



The Ocean Floor

■ Sonar mapping delineated bathymetric features.

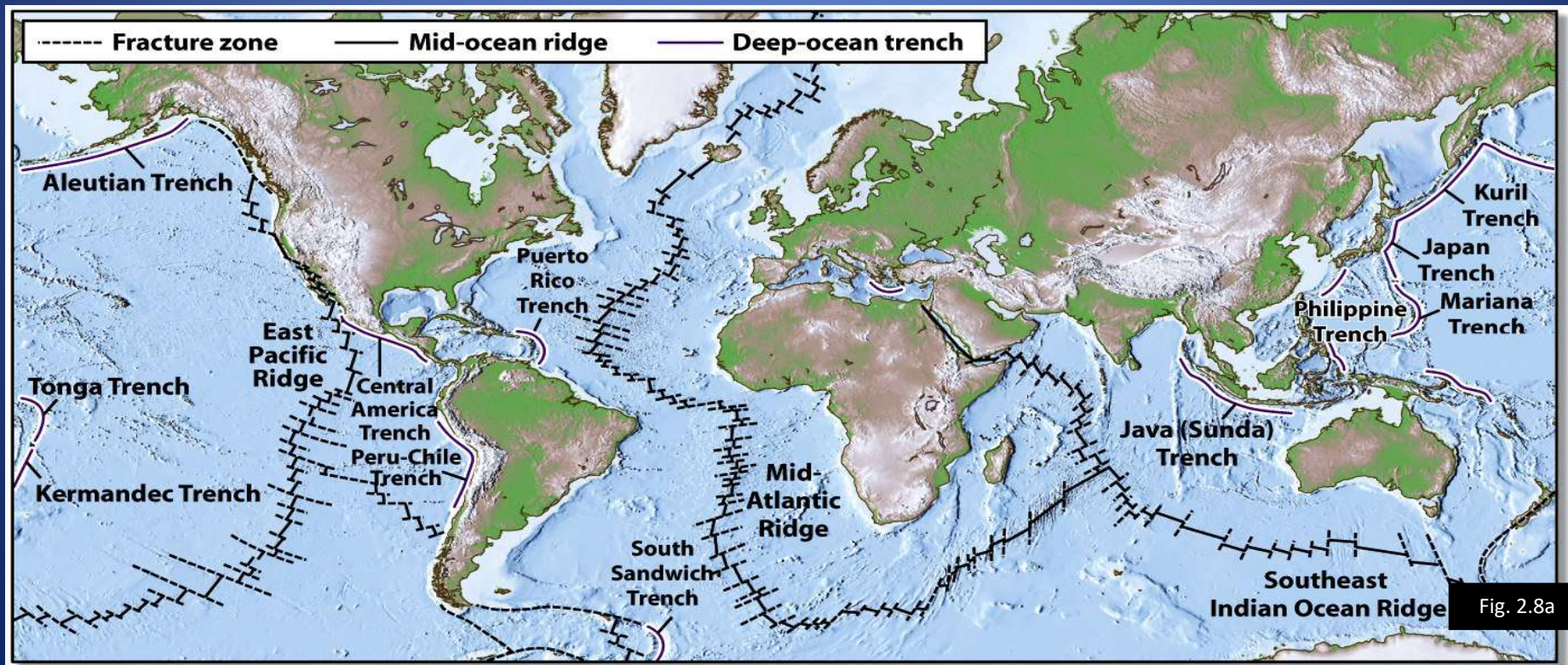
- Mid-ocean ridges
- Deep-ocean trenches
- Volcanic islands
- Seamounts
- Fracture zones



The Ocean Floor

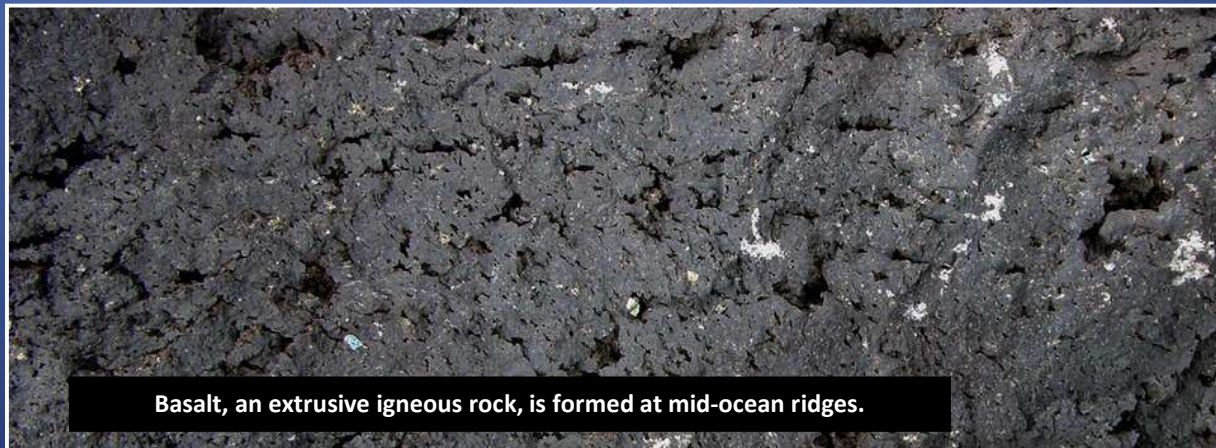
■ Today's view of the ocean floor reveals the location of:

- Mid-ocean ridges
- Deep-ocean trenches
- Oceanic fracture zones



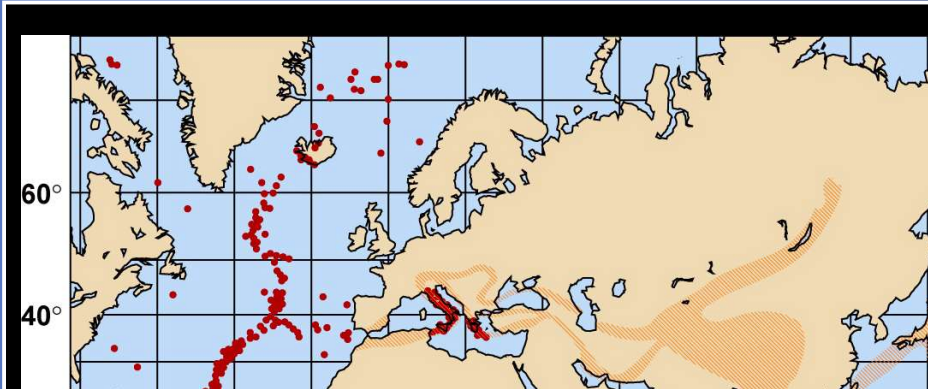
The Oceanic Crust

- By 1950, we had learned much about oceanic crust.
- Oceanic crust is covered by sediment.
 - Thickest near the continents
 - Thinnest (or absent) at the mid-ocean ridge
- Oceanic crust consists primarily of basalt.
 - Lacks variety of continental rock types
 - No metamorphic rocks
- Heat flow is much greater at the mid-ocean ridges.



Basalt, an extrusive igneous rock, is formed at mid-ocean ridges.

The Oceanic Crust

- Earthquakes occur in distinct belts in oceanic regions.
 - The earthquakes were surprising. They were limited to:
 - Parts of oceanic fracture zones
 - Mid-ocean ridge axes
 - Deep ocean trenches
 - Geologists realized that earthquakes defined zones of movement.
- 
- A map of the North Atlantic and surrounding regions, including parts of North America, Europe, and Africa. The map shows the distribution of earthquakes, indicated by red dots. The dots are concentrated along the mid-ocean ridge axes and fracture zones, forming distinct belts. The map includes latitude markers at 40° and 60° and a grid of latitude and longitude lines.

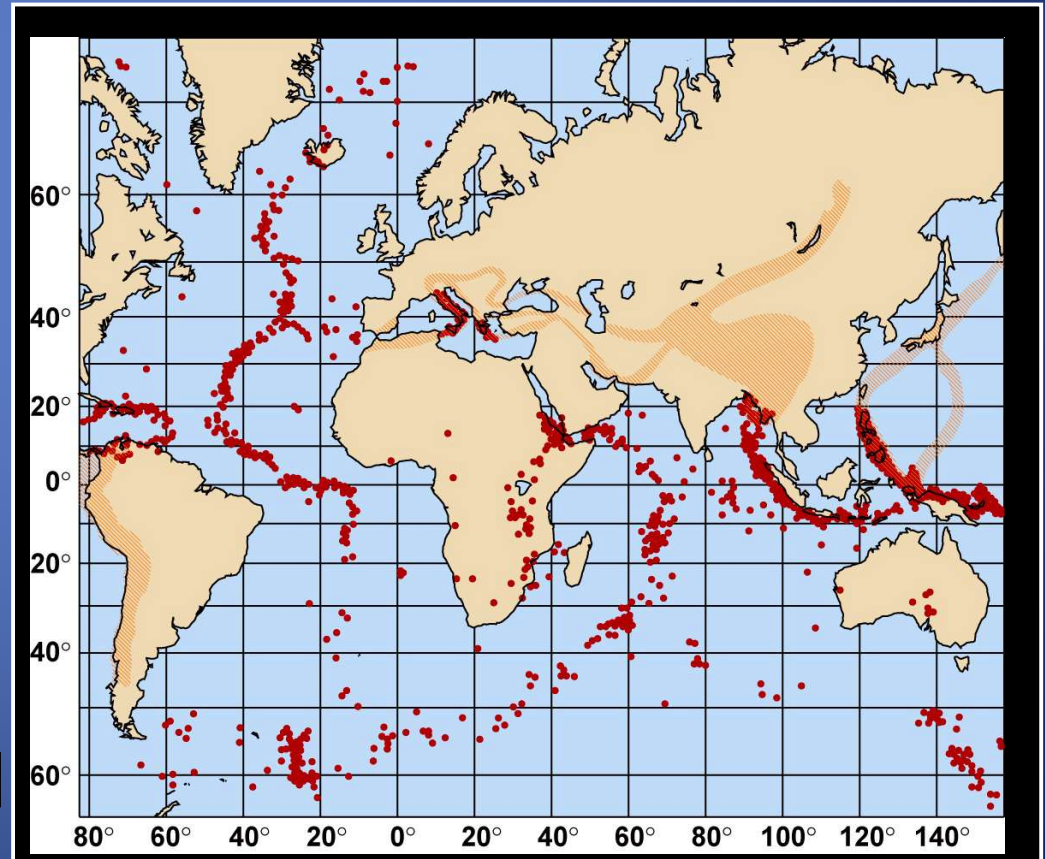
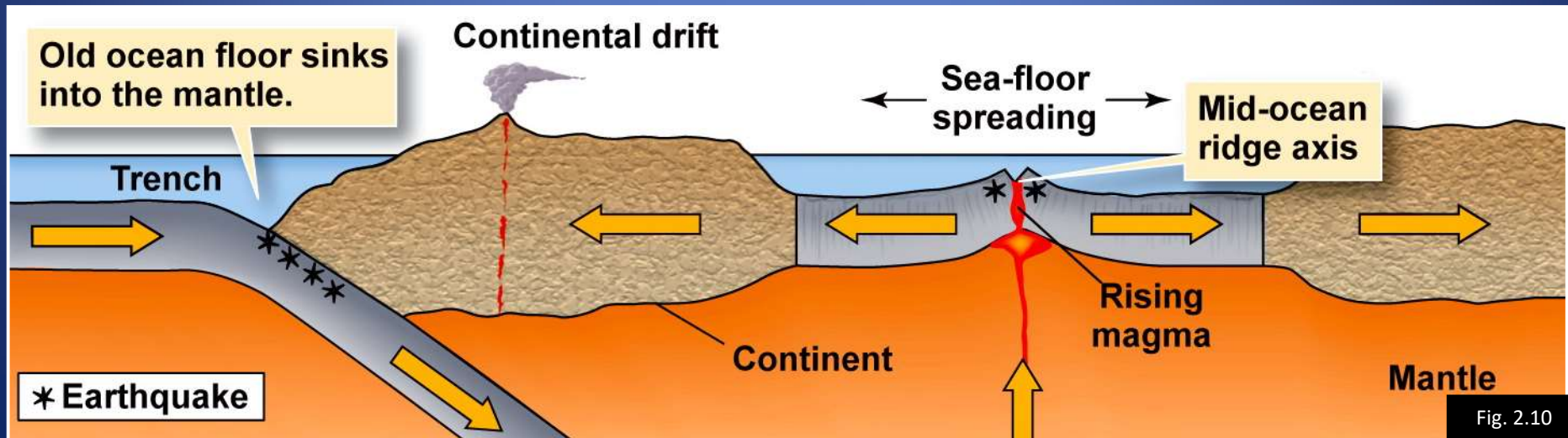


Fig. 2.9

Sea-Floor Spreading

- In 1960, Harry Hess published his “Essay in Geopoetry.”
 - Sediment thickens away from ridges.
 - Earthquakes at mid-ocean ridges indicate cracking.
 - ▶ Cracked crust splits apart.
 - ▶ High heat flow from molten rock rises into the cracked crust.
 - New ocean floor forming at mid-ocean ridges.



Sea-Floor Spreading

- Hess called his theory “sea-floor spreading.”
 - Upwelling magma erupts at the mid-ocean ridges.
 - New crust moves away from ridges, gathering sediment.
 - At trenches, the sea-floor sinks back into the mantle.
- Instantly provided a mechanism for continental drift.
 - Continents move apart as sea-floor spreading occurs.
 - Continents move together as sea-floor sinks into mantle.

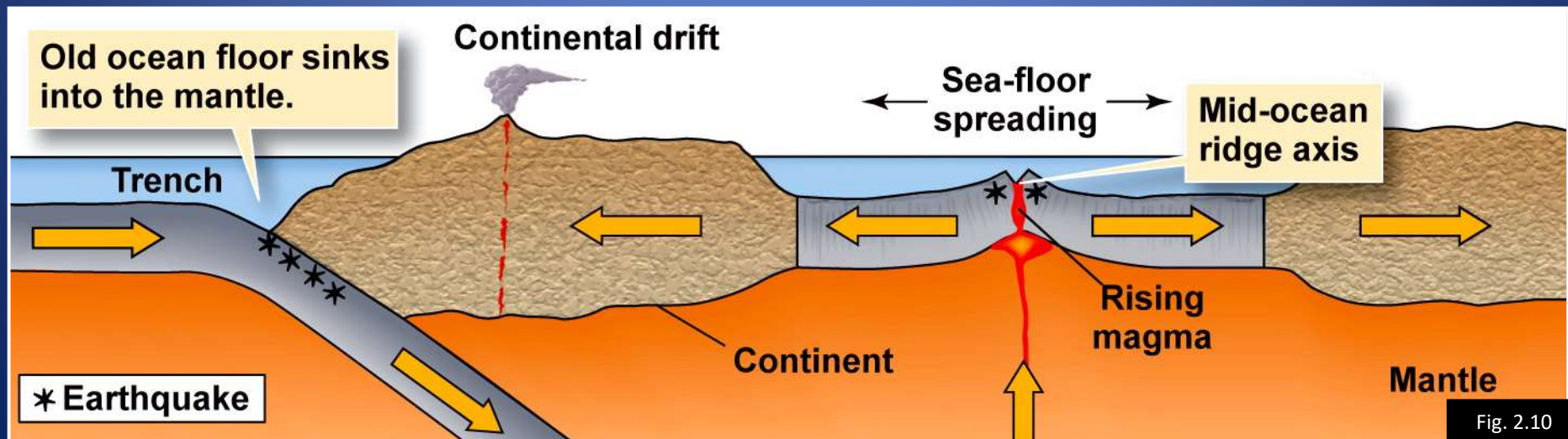


Fig. 2.10

Evidence of Sea-Floor Spreading

- Magnetism in sea-floor rocks varies farther from MOR.
 - Stripes of positive (stronger) and negative (weaker) magnetic intensity
 - Recorded in sea-floor basalts

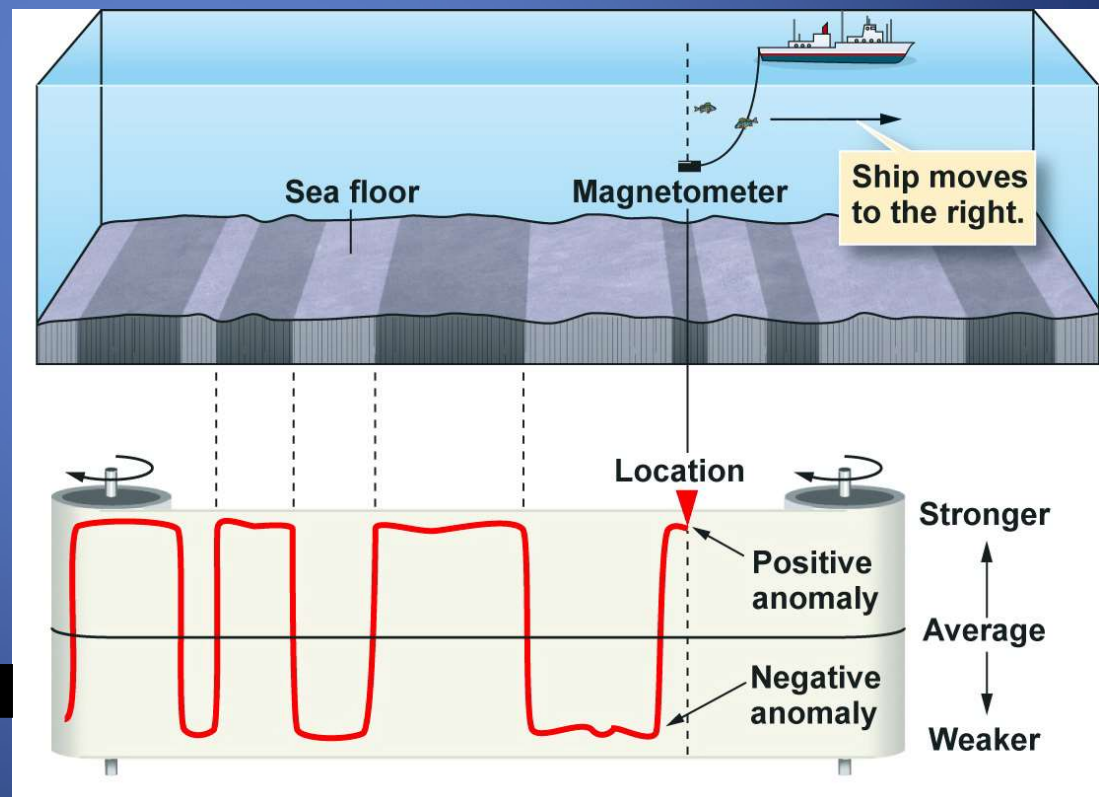
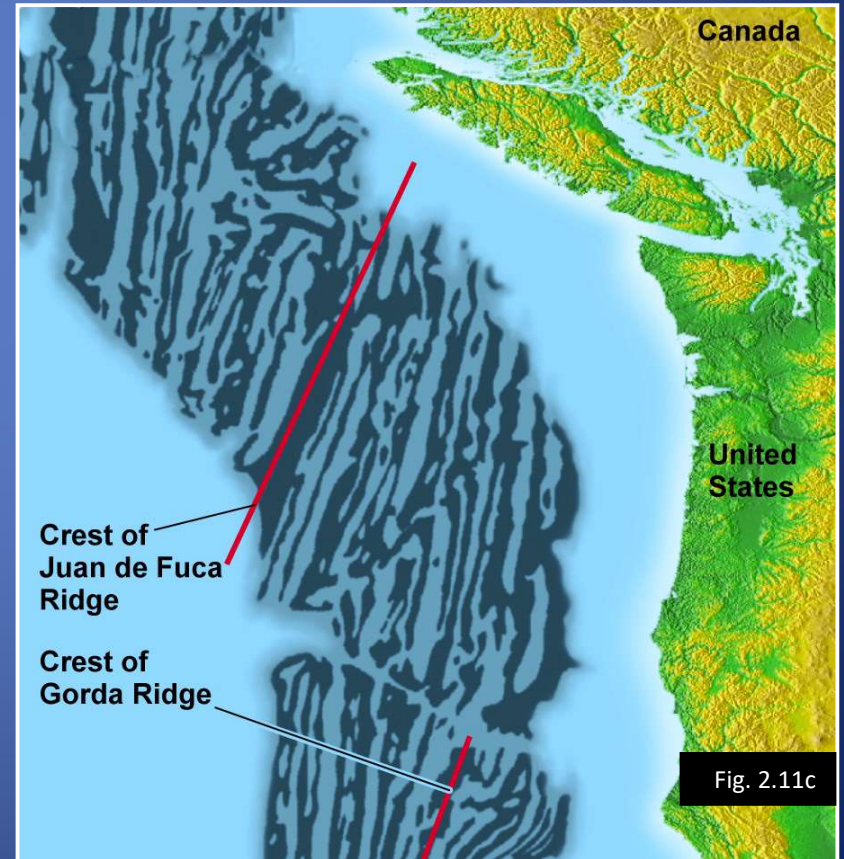


Fig. 2.11a, b

Evidence of Sea-Floor Spreading

- Magnetic anomalies map as stripes of positive and negative intensity.
- Magnetic stripes form a pattern.
- The pattern is symmetric on either side of the MOR.



Magnetic Reversals

- Layered lava flows reveal reversals in magnetic polarity.
 - The magnetic field sometimes “flips”; we don’t know why.
 - A reversed N magnetic pole is near the S geographic pole.
- Reversals are geologically rapid, expressed worldwide.
- Can be used as time markers.

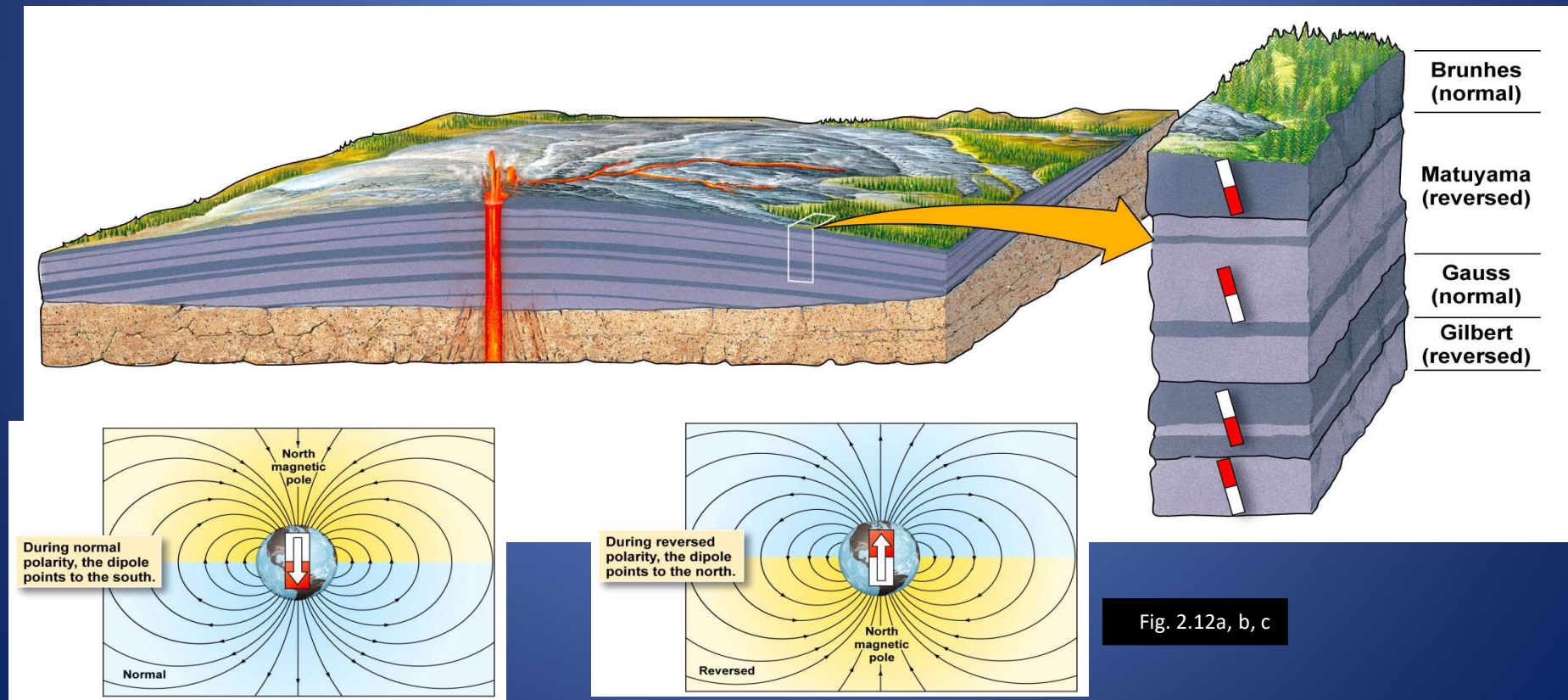
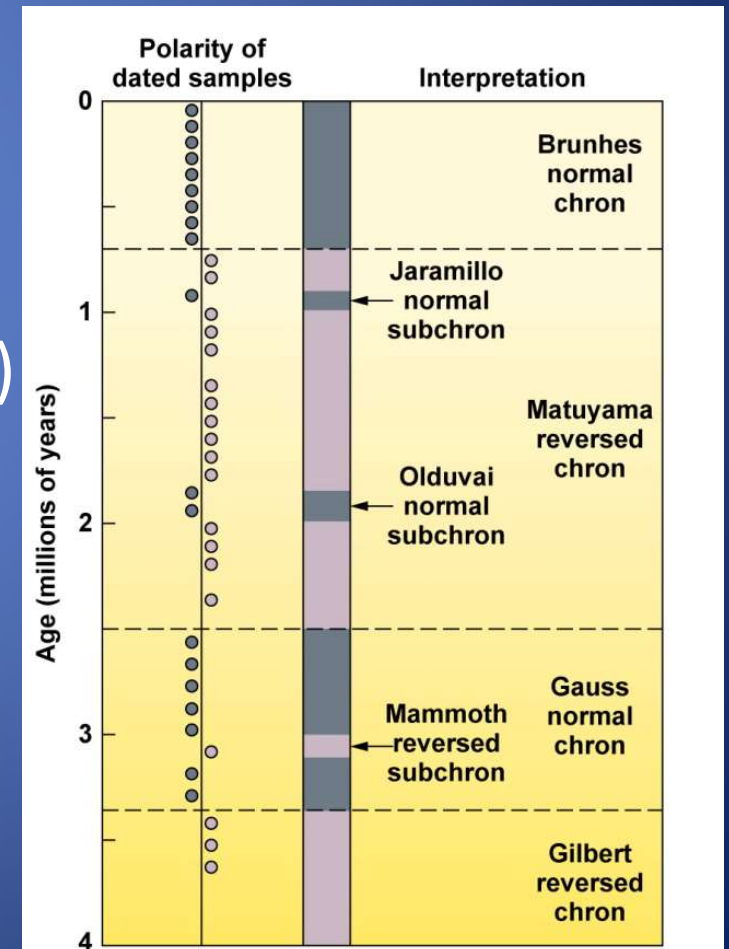


Fig. 2.12a, b, c

Magnetic Reversals

- Isotopic dating gives the timing of polarity reversals.
- A magnetic reversal time scale has been assembled.
- Reversals occur at uneven intervals.
 - Longer intervals (500 to 700+ Ka) are called chrons.
 - Shorter intervals (~200 Ka) are subchrons.
- Chrons for the last 4.5 Ma are named for scientists.

Fig. 2.12d



Sea-Floor Spreading

- Polarity reversals explain magnetic anomaly stripes.
- Positive anomaly—sea-floor rock normal polarity.
- Negative anomaly—sea-floor rock reversed polarity.
- Magnetic anomalies are symmetric across the MOR.

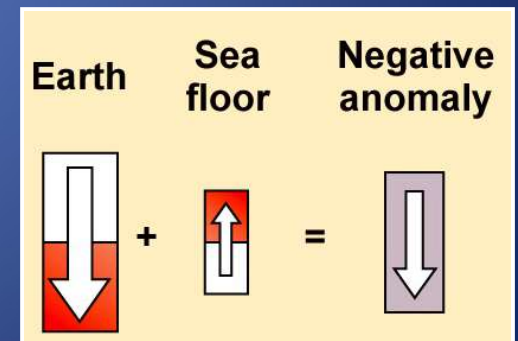
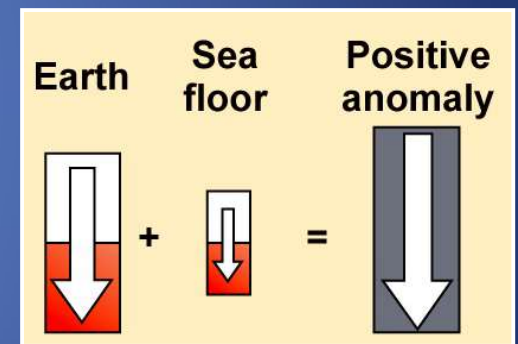
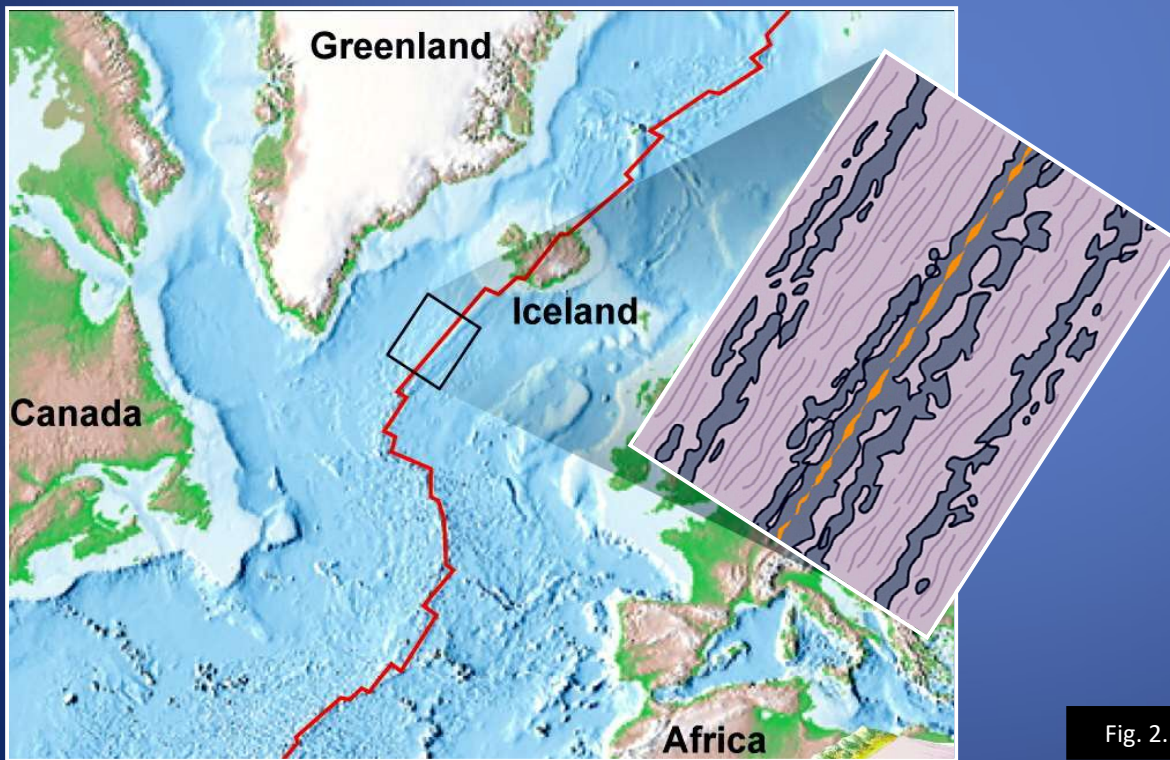


Fig. 2.13a, b

Sea-Floor Spreading

- Sea-floor spreading explains the stripes.
 - Magnetic polarity reversals are imprinted in sea-floor rock as the sea floor continues to spread.
- The width of the magnetic anomaly stripes:
 - Is related to the spreading rate
 - ▶ Faster spreading = wide stripes
 - ▶ Slower spreading = narrow stripes

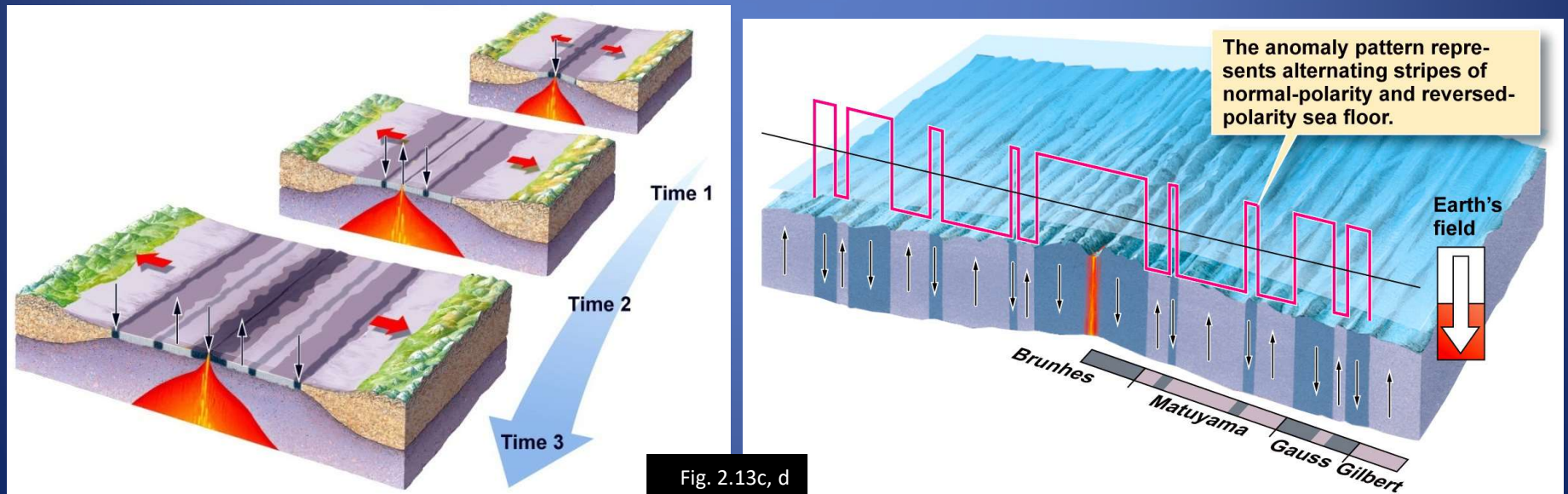
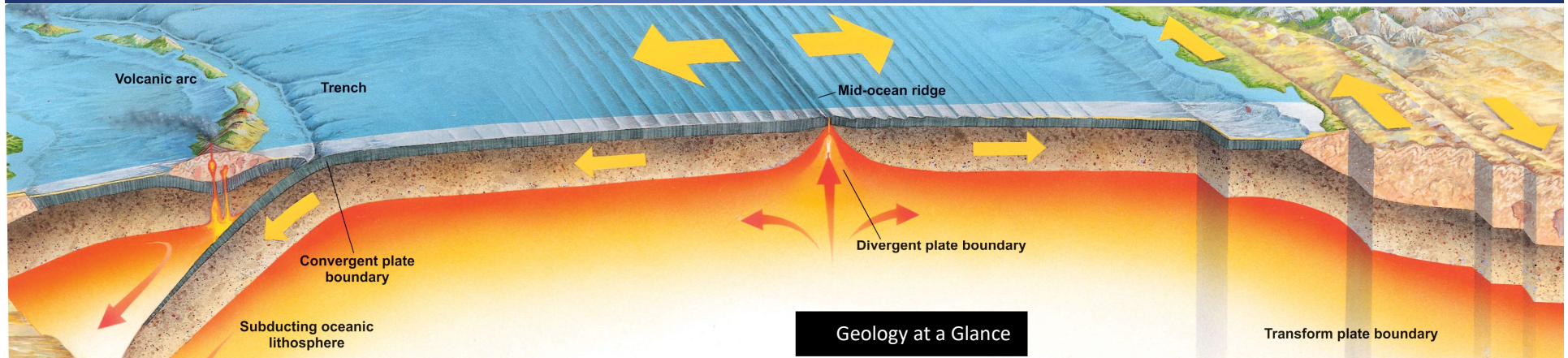


Plate Tectonics

- Plate tectonics: the explanation of “how Earth works.”
 - Earth’s outer shell is broken into rigid plates that move.
 - Plate motion defines three types of plate boundaries
- It provides a unified mechanism explaining:
 - The distribution of earthquakes and volcanoes.
 - Changes in past positions of continents and ocean basins.
 - The origins of mountain belts and seamount chains.
 - The origin and ages of ocean basins



Lithosphere

- Tectonic plates are fragments of lithosphere.
 - Lithosphere is made of both crust and the upper mantle.
 - The lithosphere is in motion over the asthenosphere.
- Lithosphere bends elastically when loaded.
- Asthenosphere flows plastically when loaded.

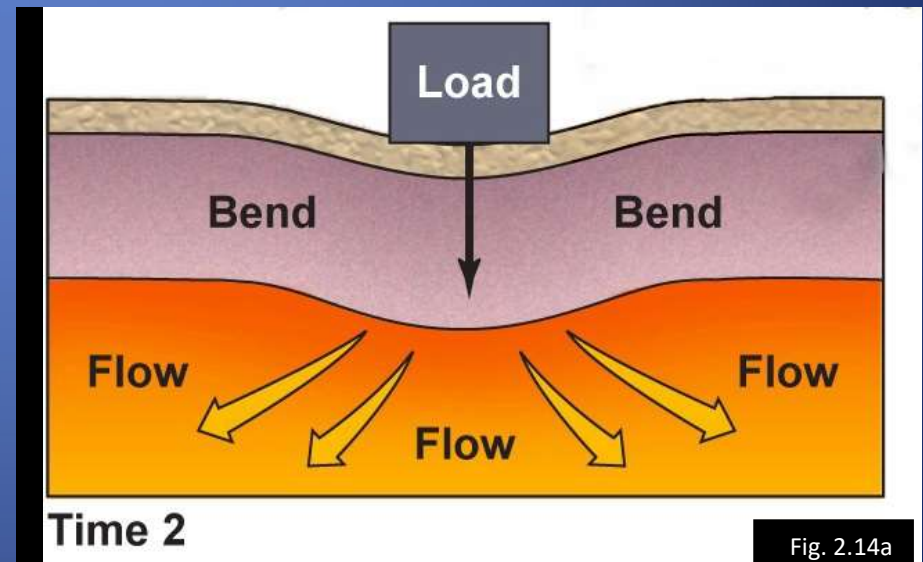
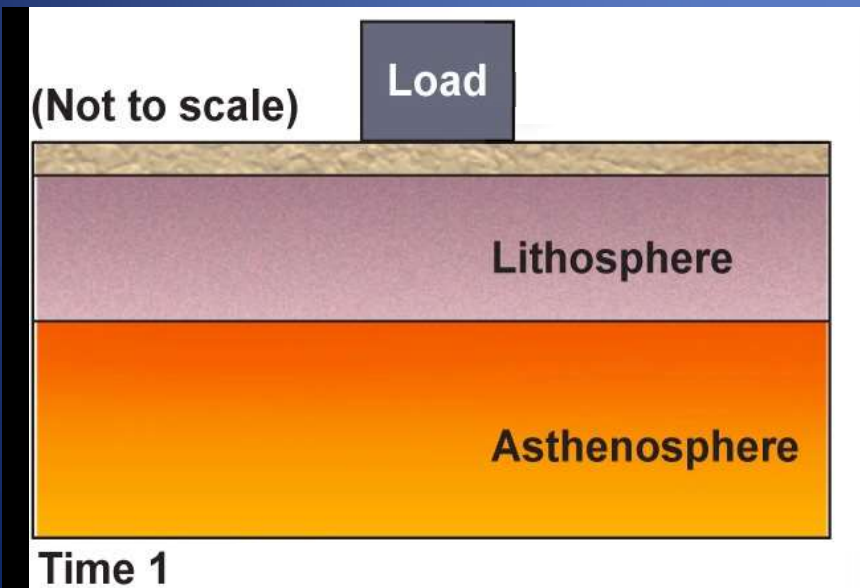


Fig. 2.14a

Two Types of Lithosphere

■ Continental: ~150 km thick.

- Felsic to intermediate crustal rocks
 - ▶ 25–70 km thick.
 - ▶ Lighter (less dense).
 - ▶ More buoyant—floats higher.

■ Oceanic: ~100 km thick.

- Mafic crust: basalt & gabbro
 - ▶ 7–10 km thick.
 - ▶ Heavier (more dense).
 - ▶ Less buoyant—sinks lower.

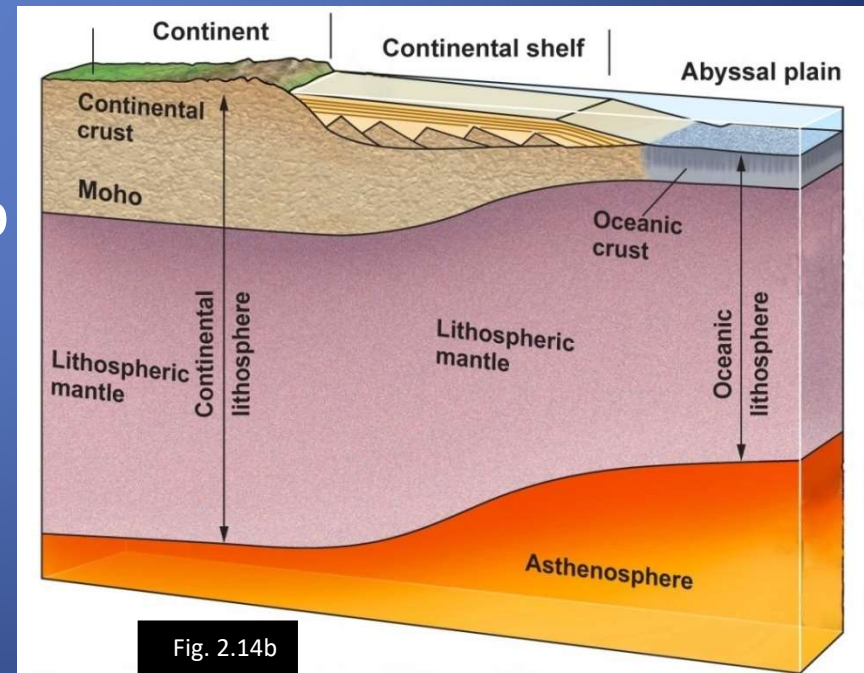


Plate Boundaries

- Lithosphere is fragmented into ~12 major tectonic plates.
- Plates move continuously at a rate of 1–15 cm/year.
 - Slow on a human time scale; extremely rapid geologically.
- Plates interact along their boundaries.

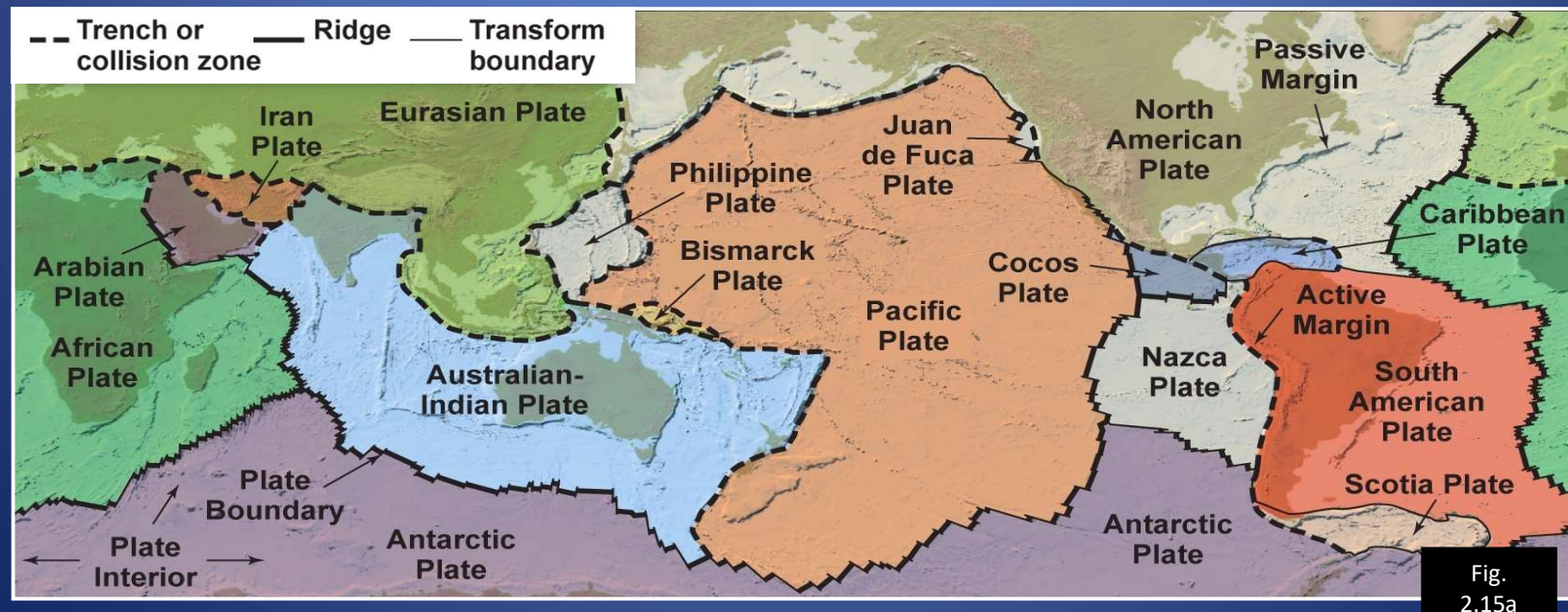


Plate Boundaries

- Locations on Earth where tectonic plates meet.
 - Identified by concentrations of earthquakes.
 - Associated with many other dynamic phenomena.
- Plate interiors are almost earthquake-free.

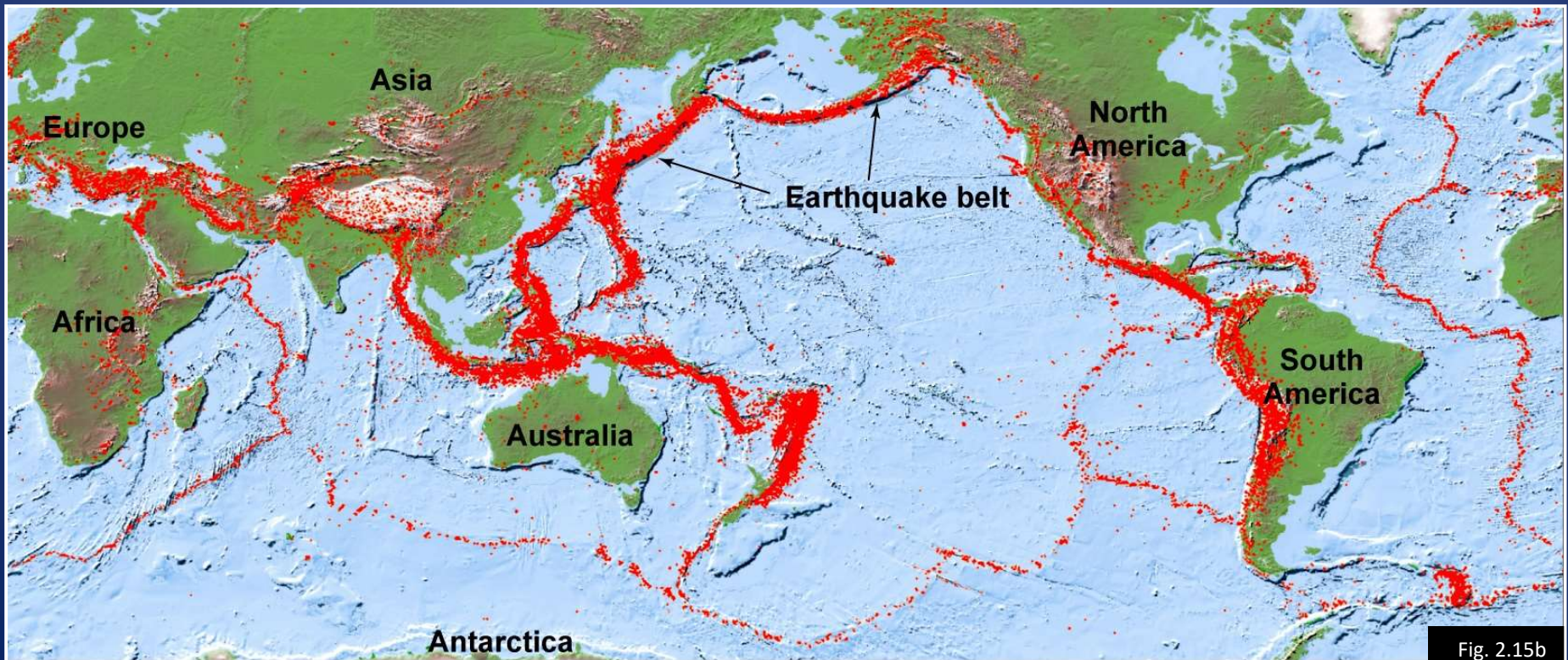


Fig. 2.15b

Plate Boundaries

■ Tectonic plates:

- Display a variety of sizes and shapes.
- Change size and shape throughout their history.

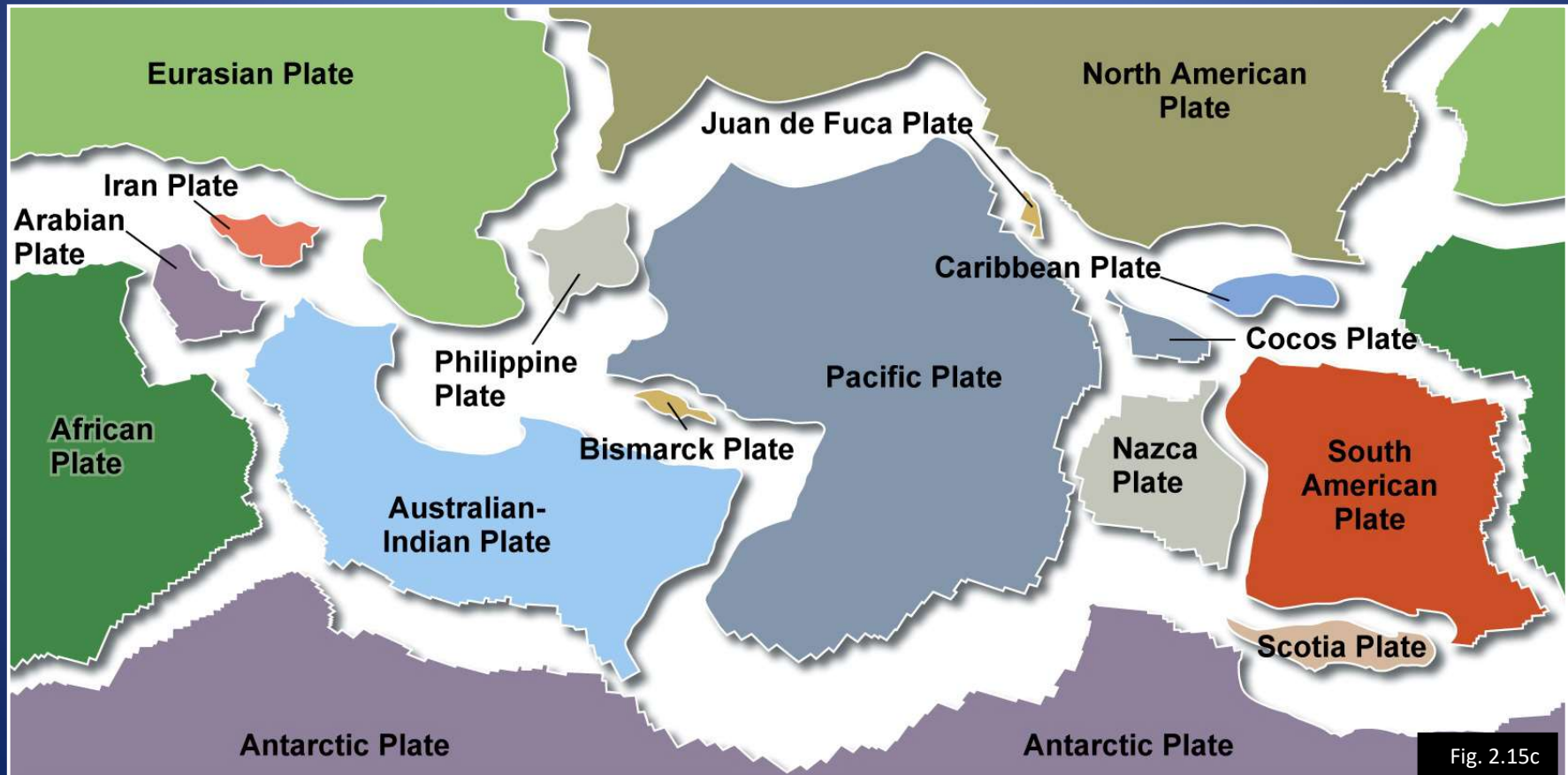


Fig. 2.15c

Continental Margins

- Where land meets the ocean.
 - Margins near plate boundaries are “active.”
 - Margins far from plate boundaries are “passive.”
 - Earthquakes common along active margins.
- Passive-margin continental crust thins seaward.
 - Traps eroded sediment.
 - Develops into the continental shelf.

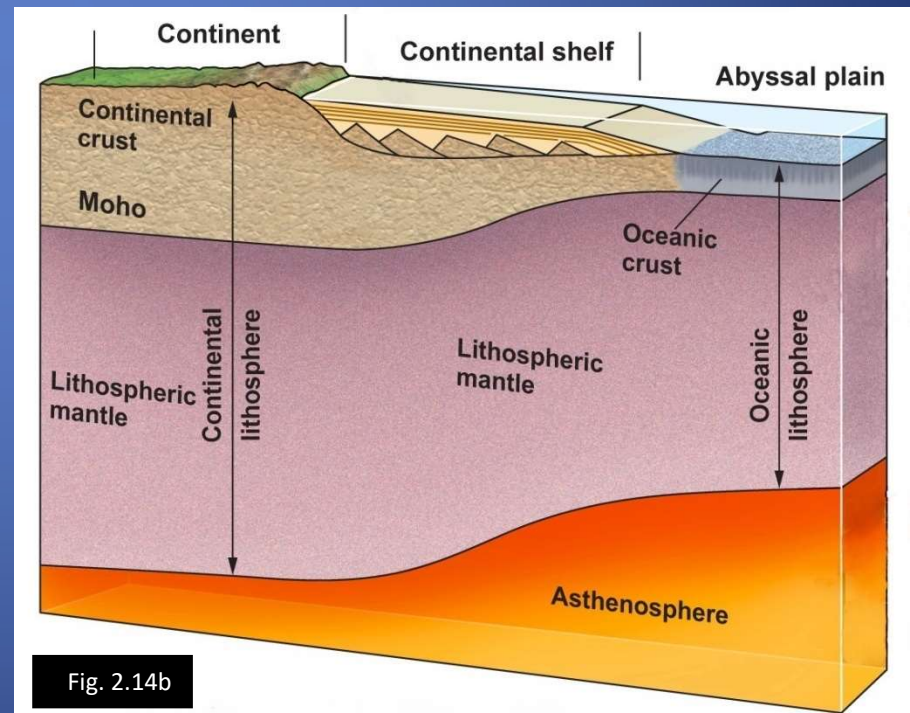


Fig. 2.14b

Plate Boundaries: Three Types

- Divergent boundary—tectonic plates move apart.
 - Lithosphere thickens away from the ridge axis.
 - New lithosphere created at divergent boundary
 - Also called: mid-ocean ridge.

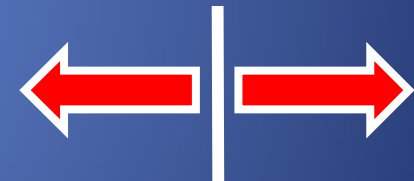
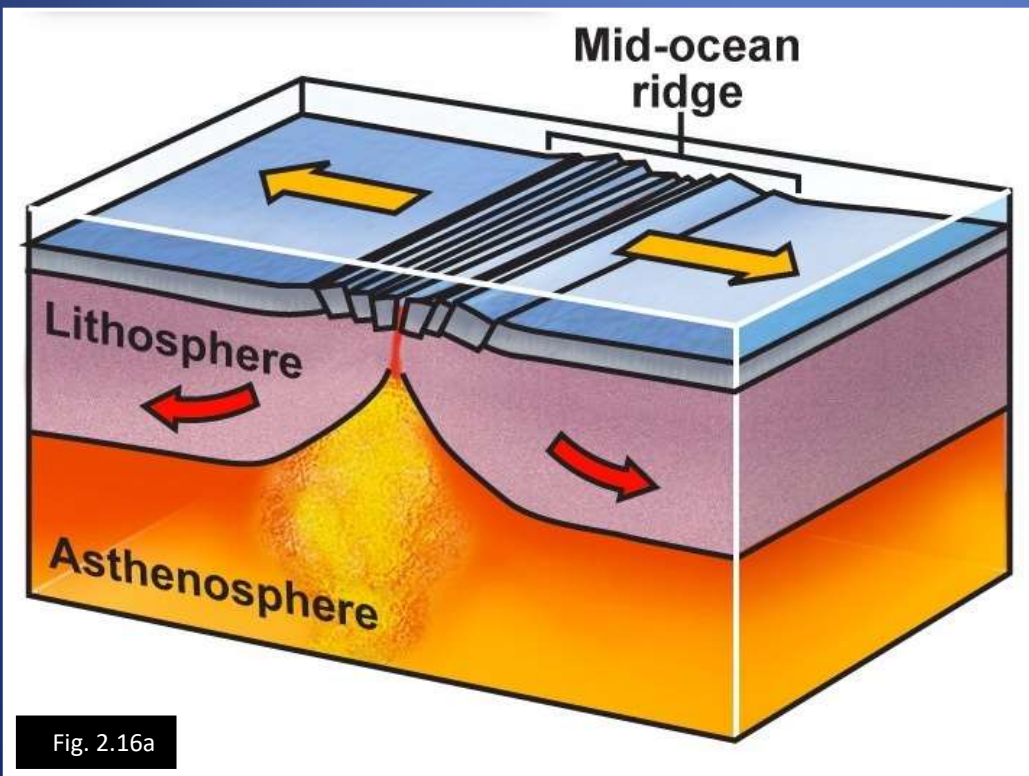


Plate Boundaries: Three Types

- Convergent boundary—tectonic plates move together.
 - The process of plate consumption is called subduction.
 - Also called: convergent margin, subduction zone, trench.

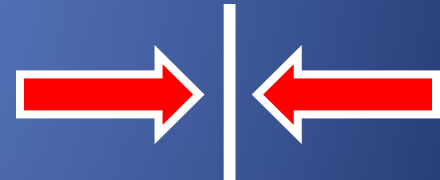
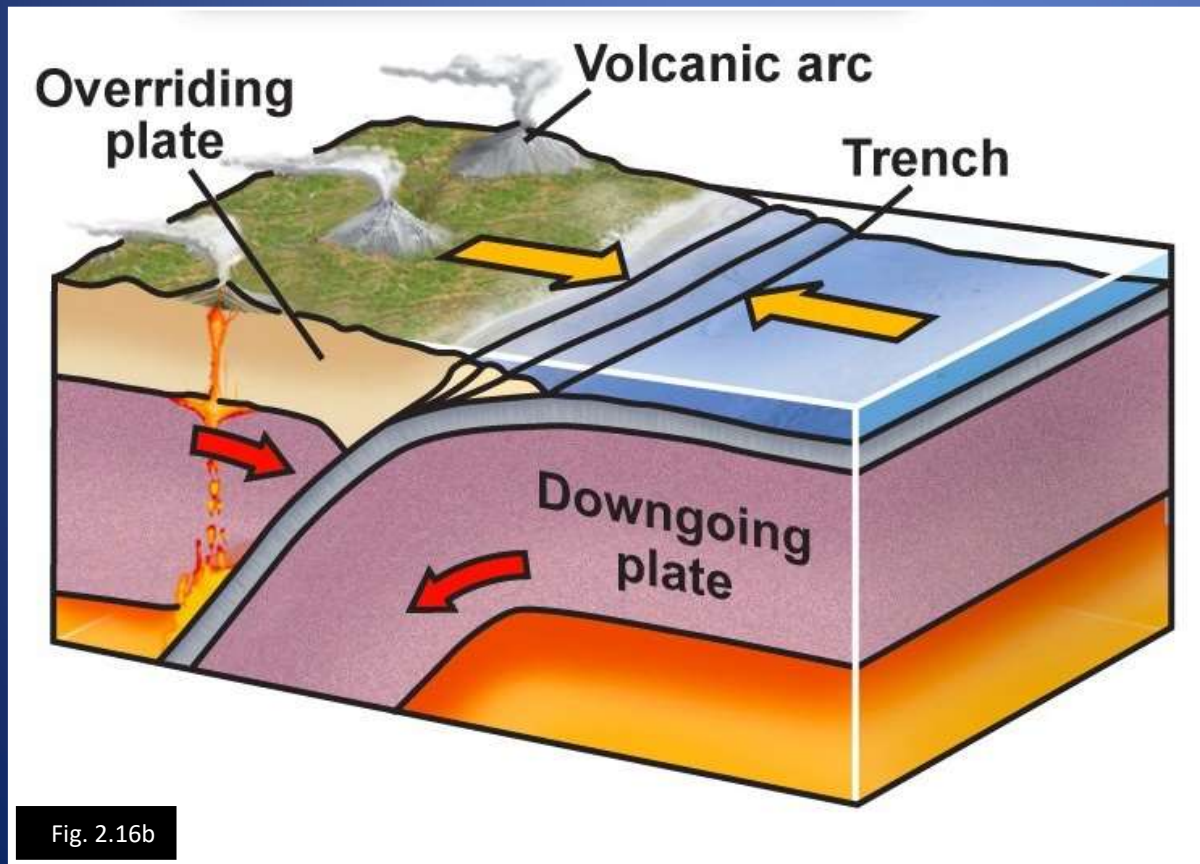
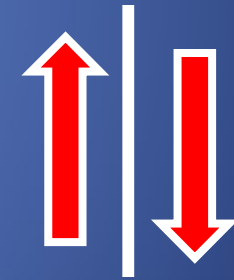
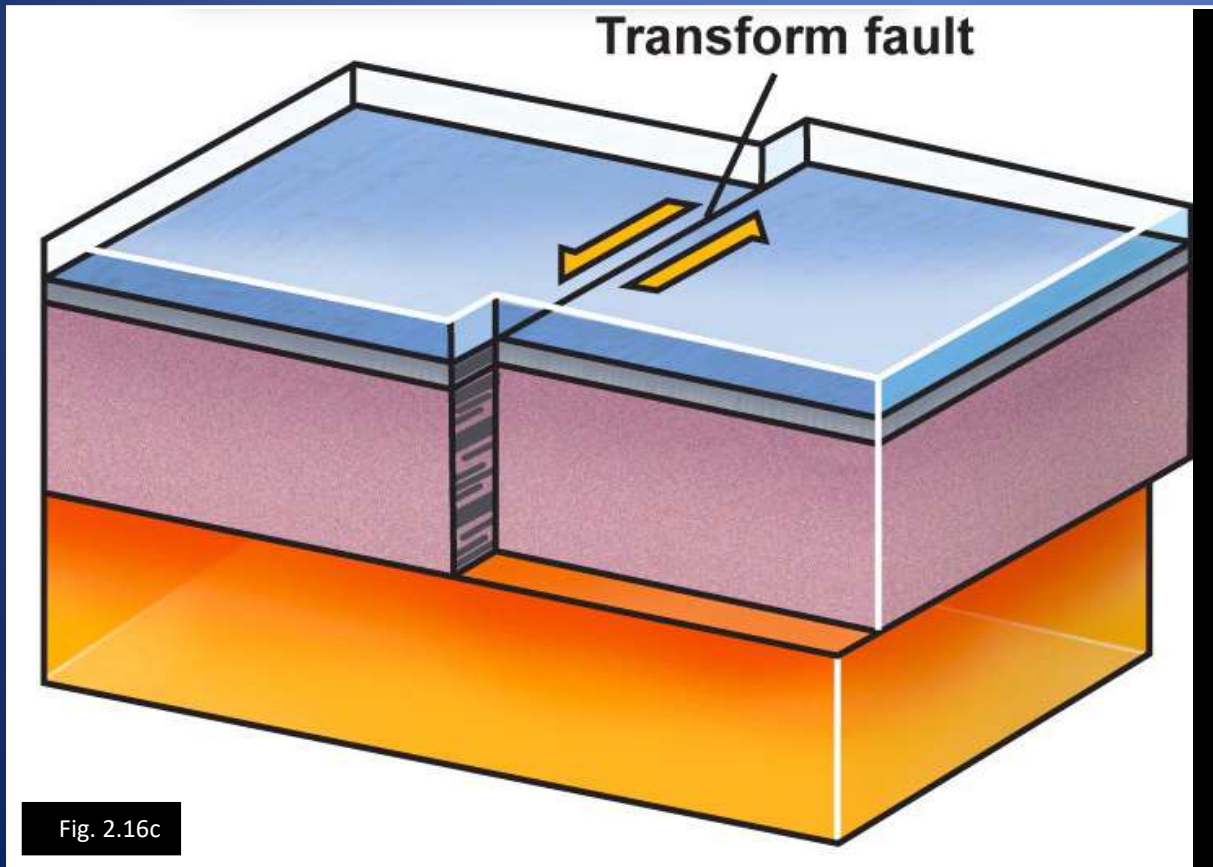


Plate Boundaries: Three Types

- Transform boundary—tectonic plates slide sideways.
 - Plate material is neither created nor destroyed.
 - Also called: transform fault, transform.



Divergent Boundaries

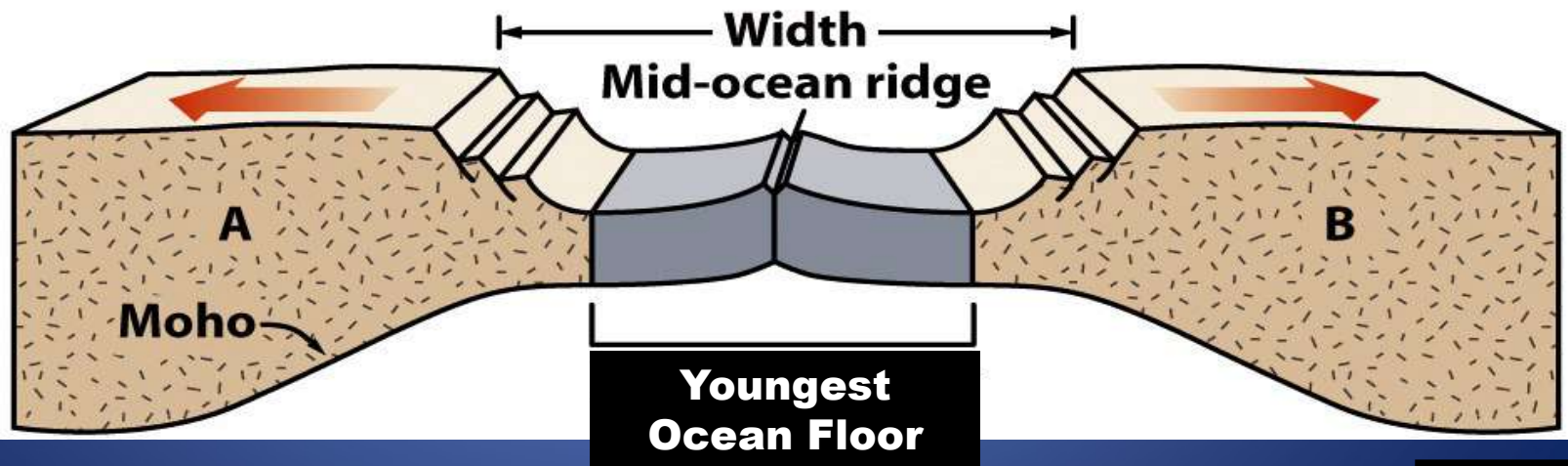
■ Sea-floor spreading progression.

● Early stage

- ▶ Rifting has progressed to mid-ocean ridge formation.
- ▶ Before substantial widening of the ocean.
- ▶ Forms a long, thin ocean basin with young oceanic crust.

● Example: The Red Sea

Time 1



Note: This diagram depicts only the crust, not the entire lithosphere.

Fig. 2.17a

Divergent Boundaries

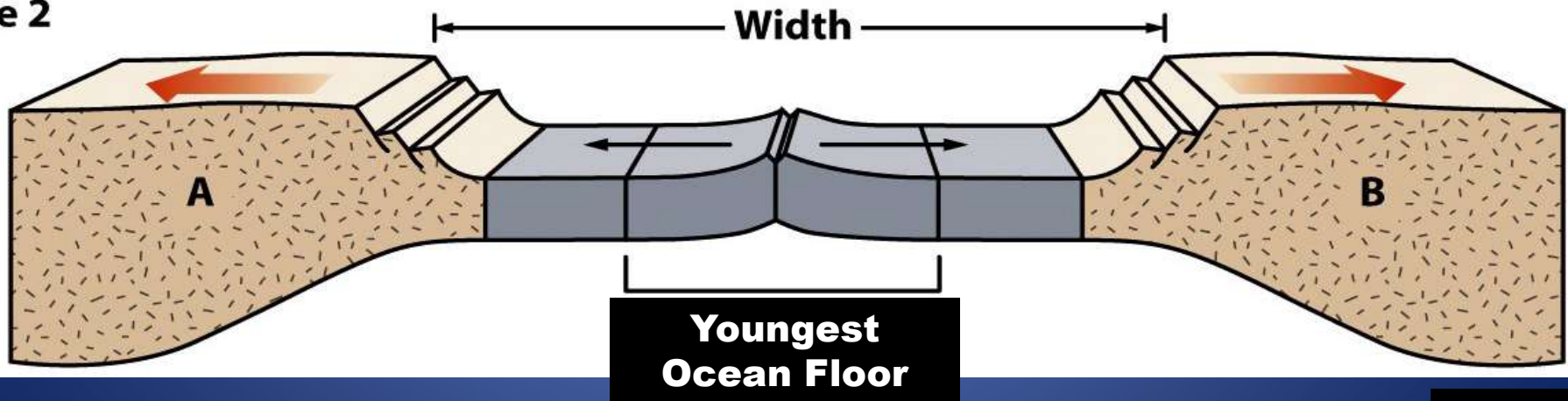
■ Sea-floor spreading progression.

● Mid-stage

- ▶ Ocean begins to widen.
- ▶ New sea-floor is added at the mid-ocean ridge.
- ▶ Continents move farther apart.

● Example: Greenland and the North Atlantic

Time 2



Note: This diagram only depicts the crust, not the entire lithosphere.

Fig. 2.17a

Divergent Boundaries

■ Sea-floor spreading progression.

● Late stage

- ▶ Mature, wide ocean basin.
- ▶ Linear increase in age with distance from central ridge.
- ▶ Edge of ocean basin—oldest; ridge proximal—youngest.

● Example: The Atlantic Ocean

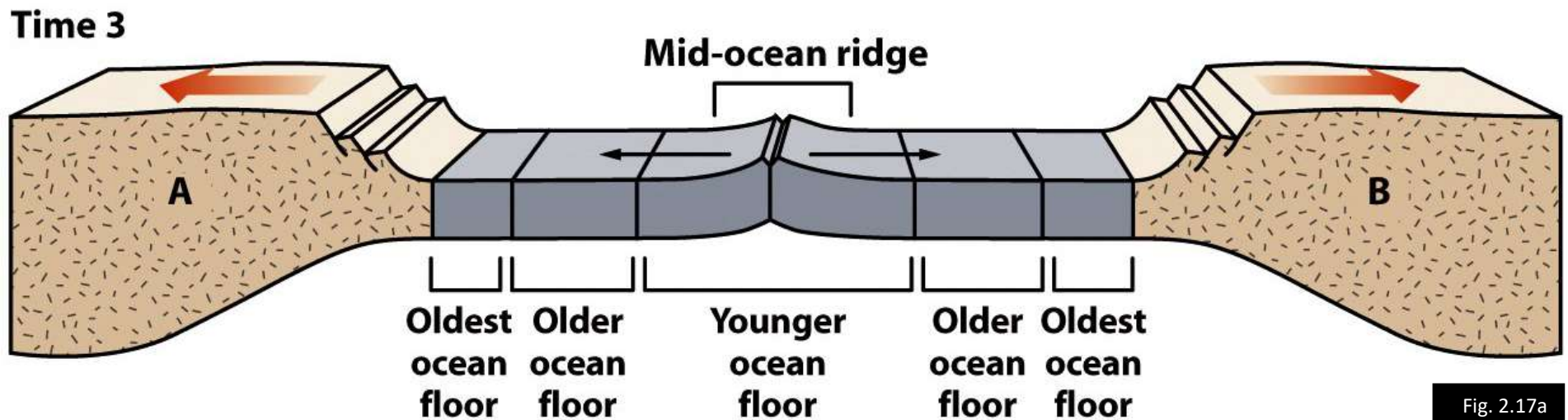


Fig. 2.17a

Mid-Ocean Ridges

- Linear mountain ranges in Earth's ocean basins.
- Example: The Mid-Atlantic Ridge
 - Stretches N–S through the entire Atlantic Ocean.
 - Elevated ridge (1,500 km wide) 2 km above abyssal plains.
 - New sea floor created only along axis of the ridge
 - Symmetrical

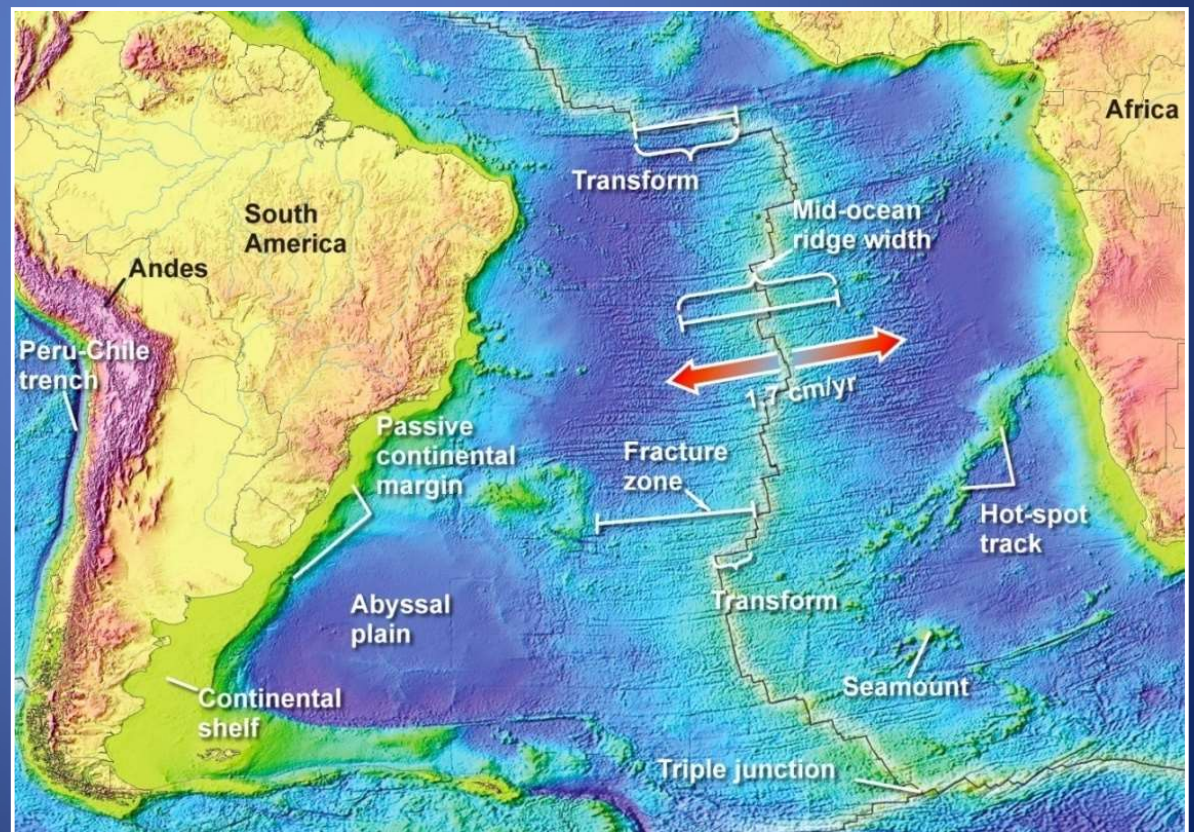
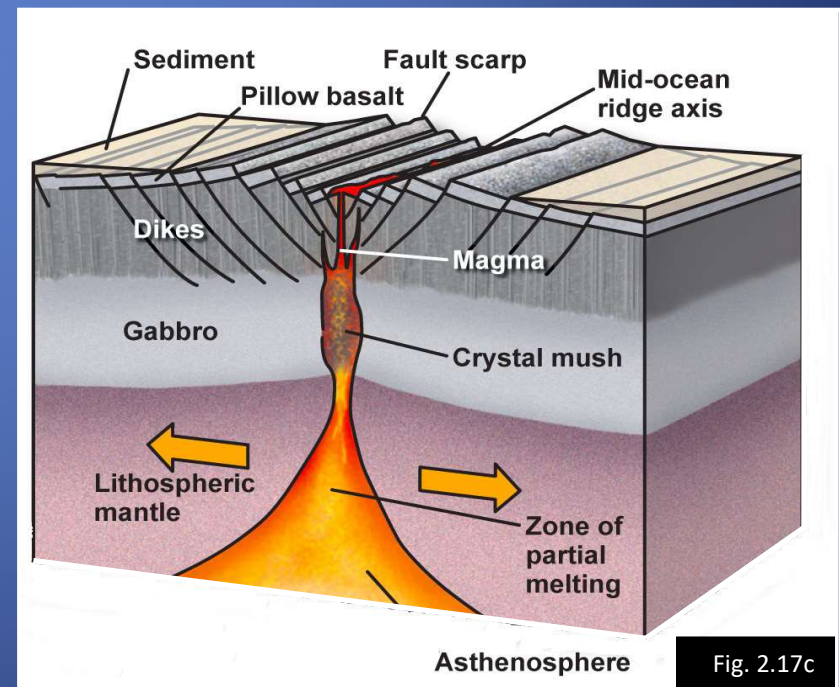


Fig. 2.17b

Mid-Ocean Ridges

- Sea-floor spreading opens the axial rift valley.
- Rising asthenosphere melts, forming mafic magma.
- Pooled magma solidifies into oceanic crustal rock.
 - Pillow basalt—magma quenched at the sea-floor.
 - Dikes—preserved magma conduits.
 - Gabbro—deeper magma.



Mid-Ocean Ridges

- “Black smokers” are found at some MORs.
 - Water entering fractured rock is heated by magma.
 - Hot water dissolves minerals and cycles back out of rock.
 - When water reaches the sea, minerals precipitate quickly.

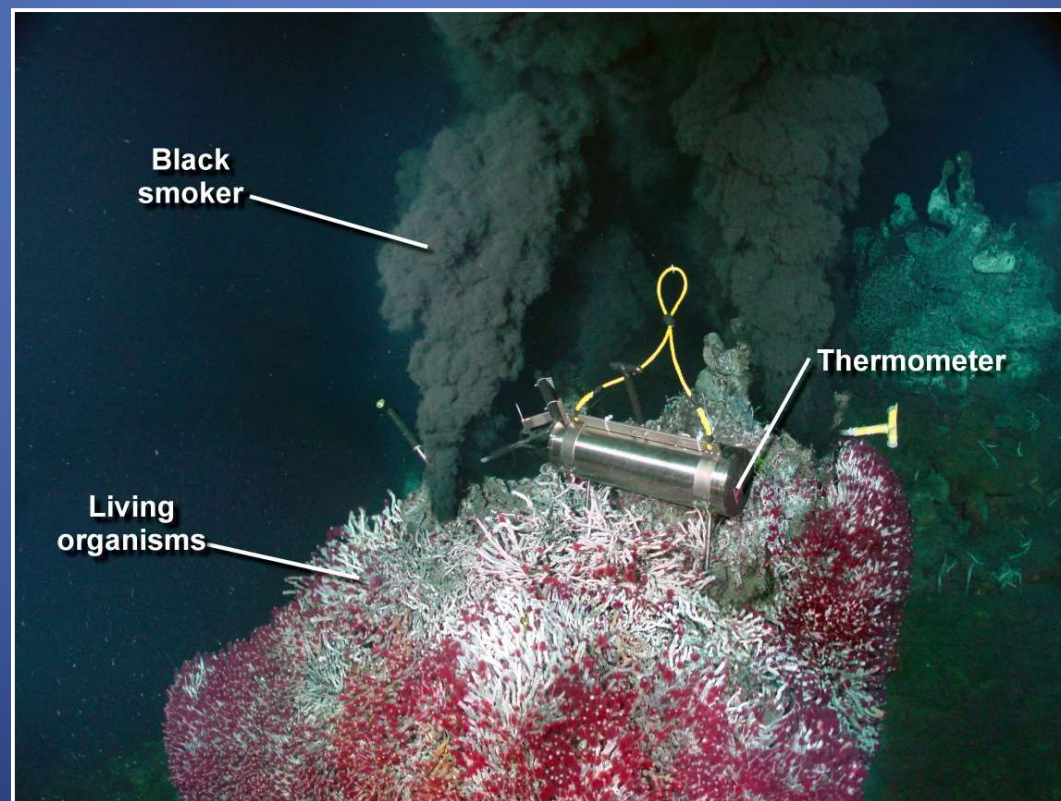


Fig. 2.18

Ocean Crustal Age

- Oceanic crust spreads away from the ridge axis.
 - New crust is closer to the ridge; older crust farther away.
 - Oldest oceanic crust is found at the far edge of the basin.

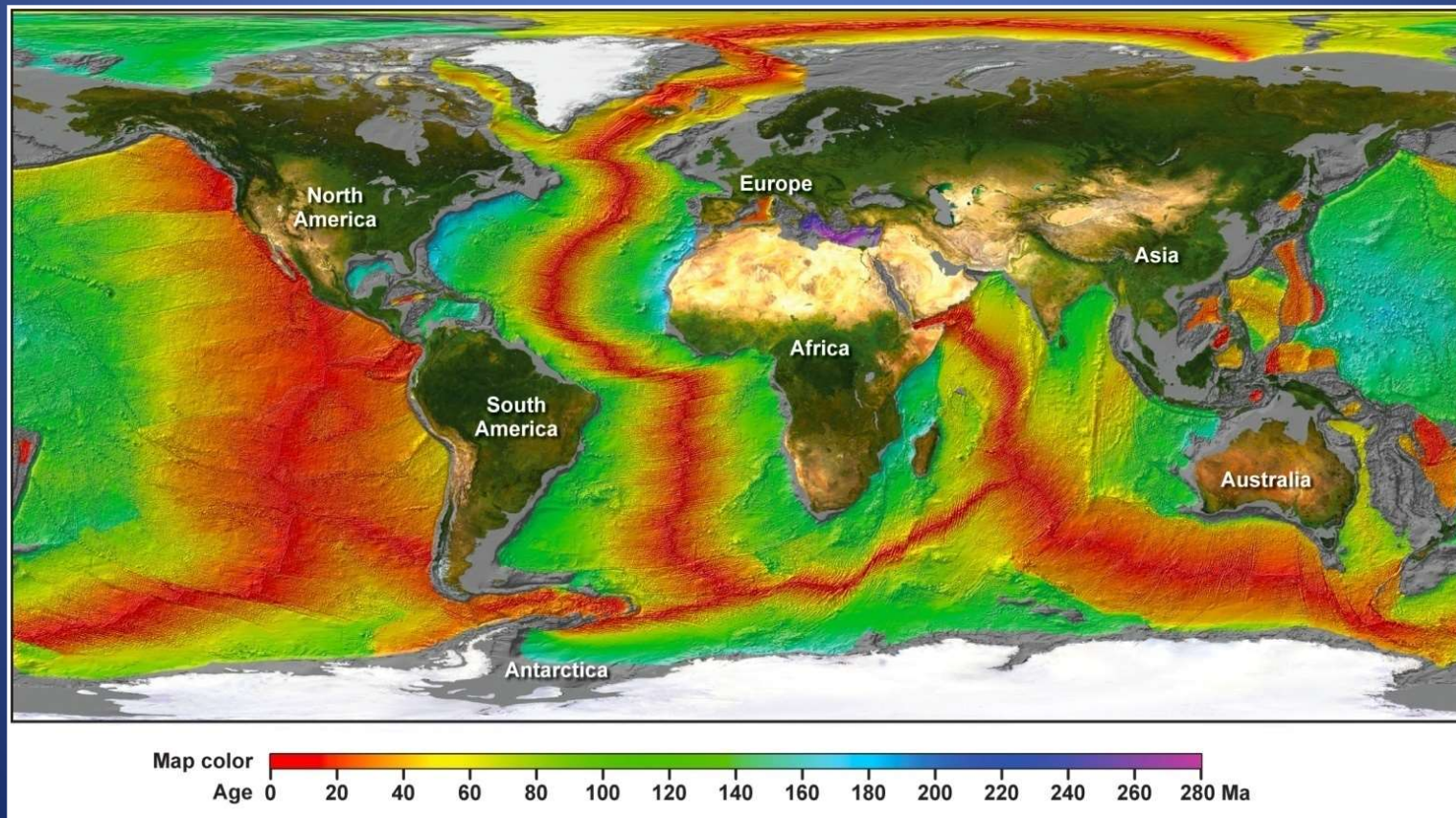
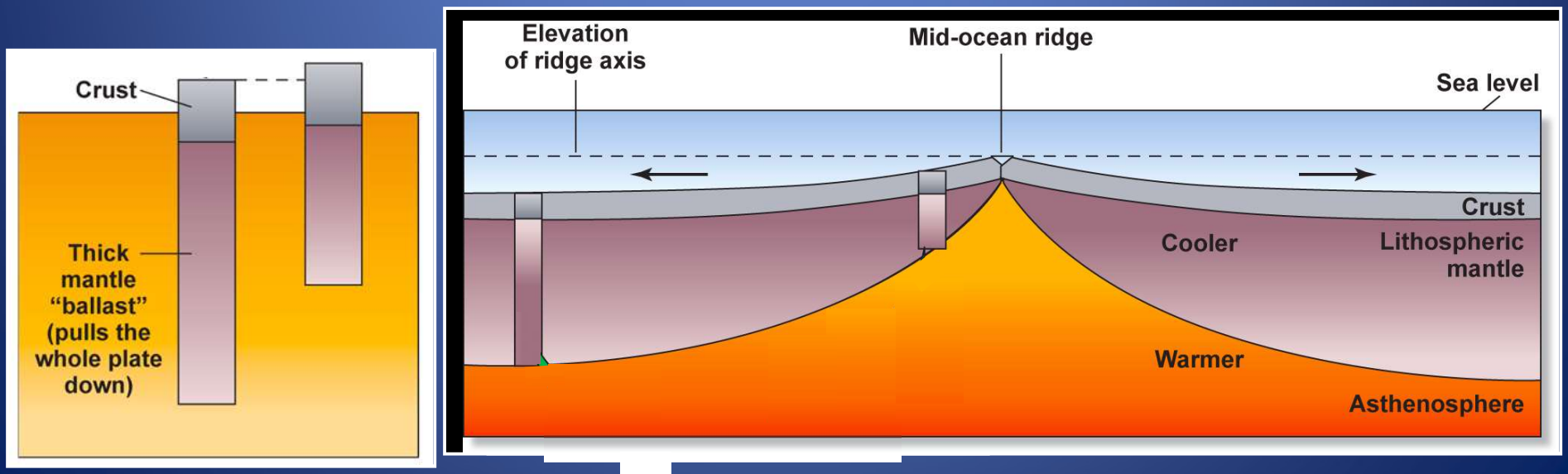


Fig. 2.19

Oceanic Lithosphere

- The hot asthenosphere is at the base of the MOR.
- Aging ocean crust moves away from this heat:
 - Cooling, increasing in density and sinking.
 - Older, thicker lithosphere sinks deeper into mantle.

Fig. 2.20a, b



Convergent Boundaries

- Lithospheric plates move toward one another.
- One plate sinks back into the mantle (subduction).
- The subducting plate is always oceanic lithosphere.
- Continental crust cannot be subducted—too buoyant.
- Subduction recycles oceanic lithosphere.
 - Subduction is balanced by sea-floor spreading.
 - Earth maintains a constant circumference.
- Convergent boundaries also called *Subduction Zones*.

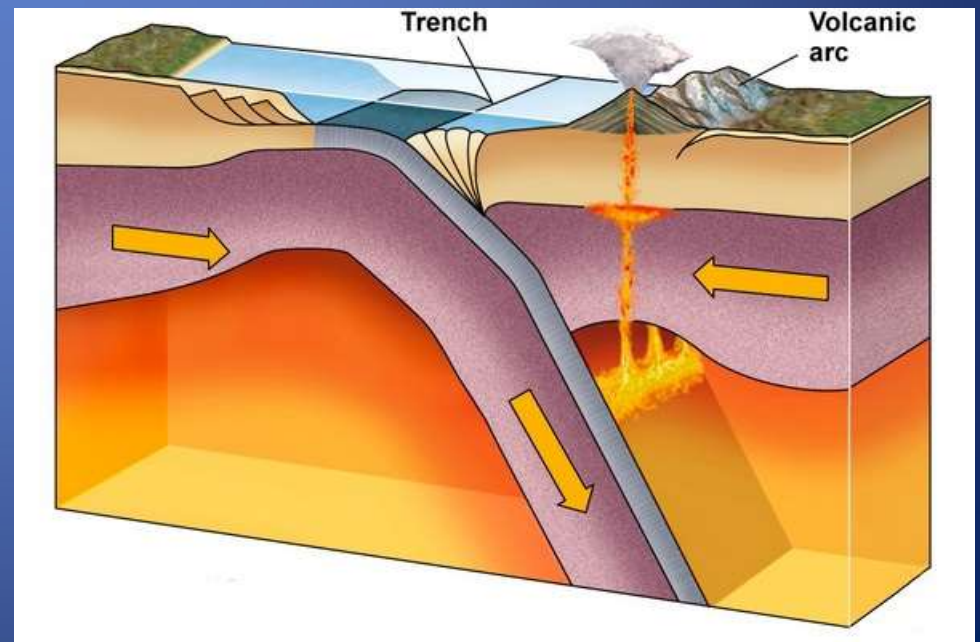
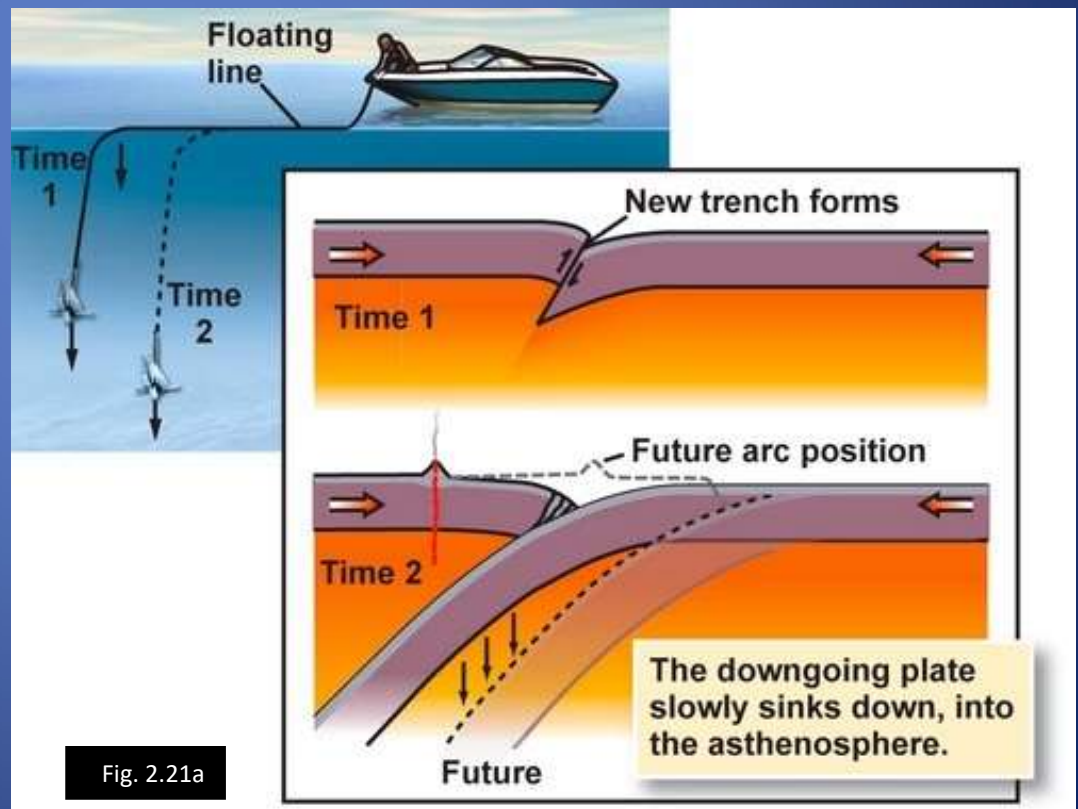


Fig. 2.16b

Subduction

- Old oceanic lithosphere is more dense than mantle.
- A flat-lying oceanic plate doesn't subduct easily.
- Plate edge bends down and slips into mantle, then the leading edge sinks downward like an anchor rope.



Convergent Boundaries

- The subducting plate descends at an average of 45° .
 - Plate descent is revealed by Wadati-Benioff earthquakes.
 - ▶ Earthquakes deepen away from trench.
- Quakes cease below 660 km.
- Plate descent may continue past the earthquake limit.
- The lower mantle may be a “plate graveyard.”

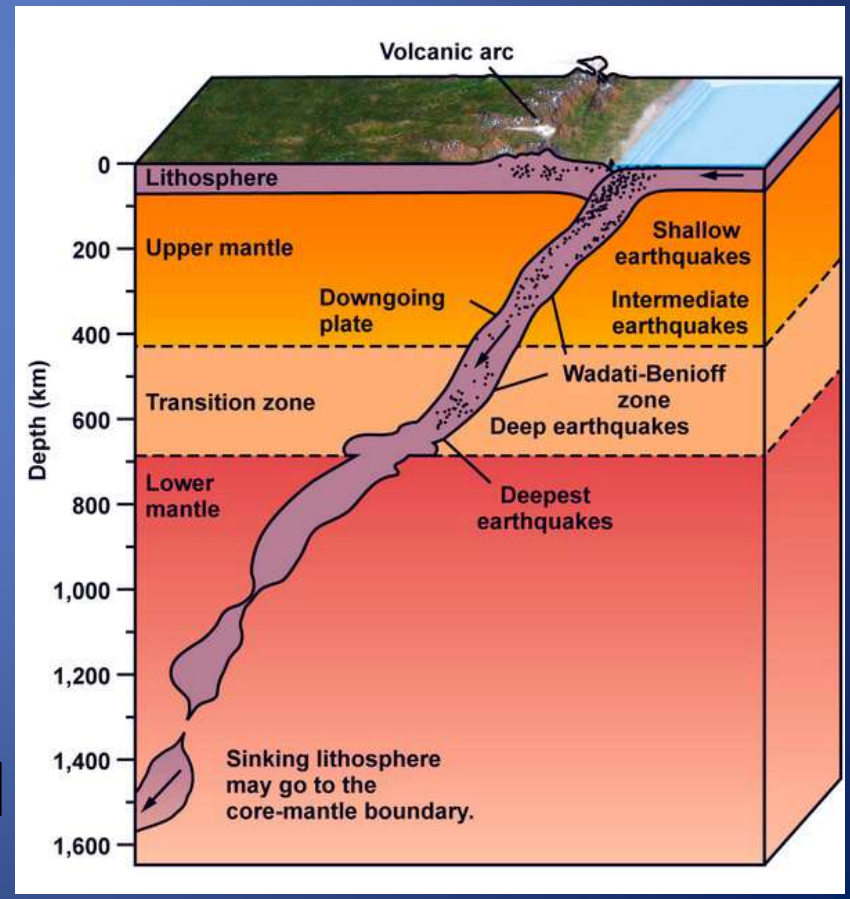
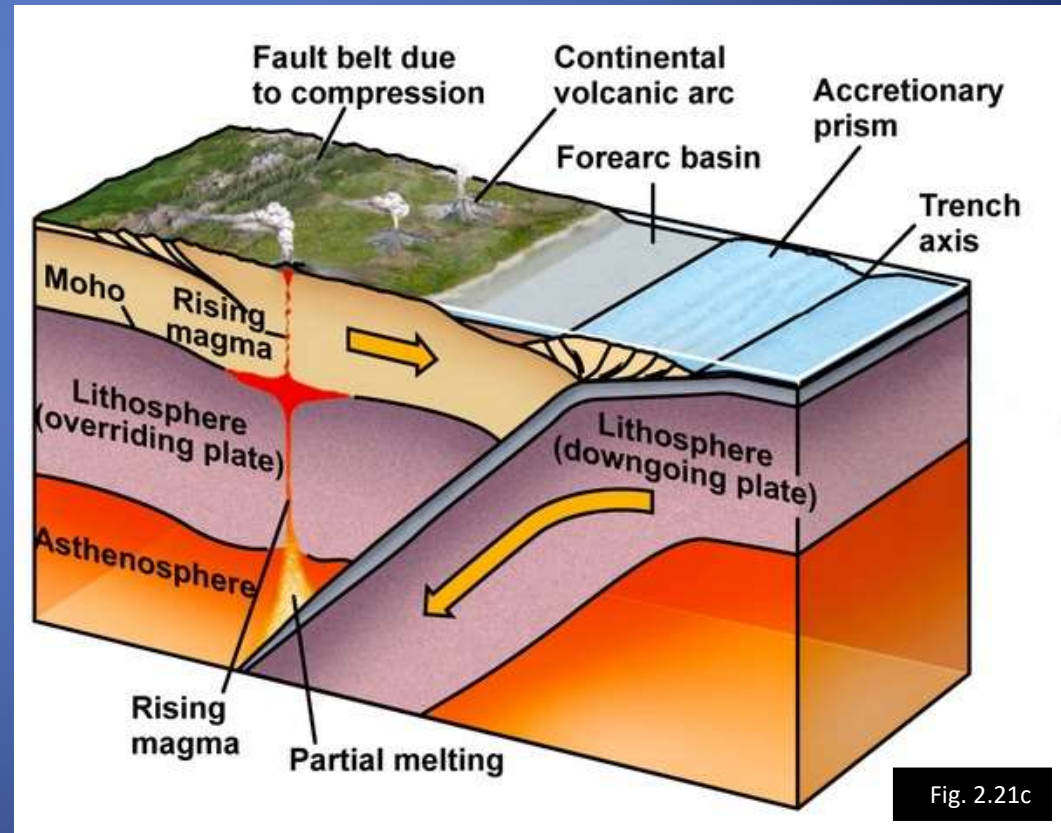


Fig. 2.21b

Subduction Features

- Subduction is associated with unique features:
 - Deep-ocean trenches.
 - Accretionary prisms.
 - Volcanic arcs.
 - Back-arc basins.



Convergent Boundaries

- Volcanic Arc—a chain of volcanoes on overriding plate.
 - The descending plate partially melts at ~150 km depth.
 - Magmas rise and melt through overriding plate.
- Arc type depends upon the overriding plate.
 - Continental crust—continental arc.
 - Oceanic crust—**island arc**.

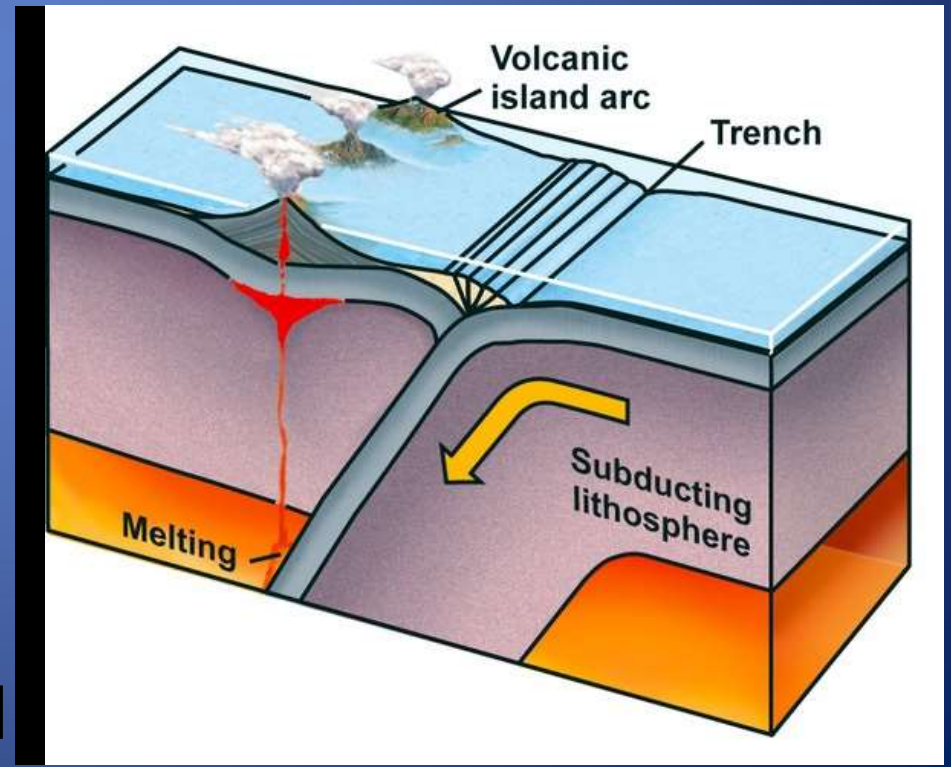


Fig. 2.21d

Convergent Boundaries

- Back-arc basins—a marginal sea behind an arc.
 - Forms between an island arc and a continent.
 - Offshore subduction traps a piece of oceanic crust, or
 - Stretching lithosphere creates a new spreading ridge.

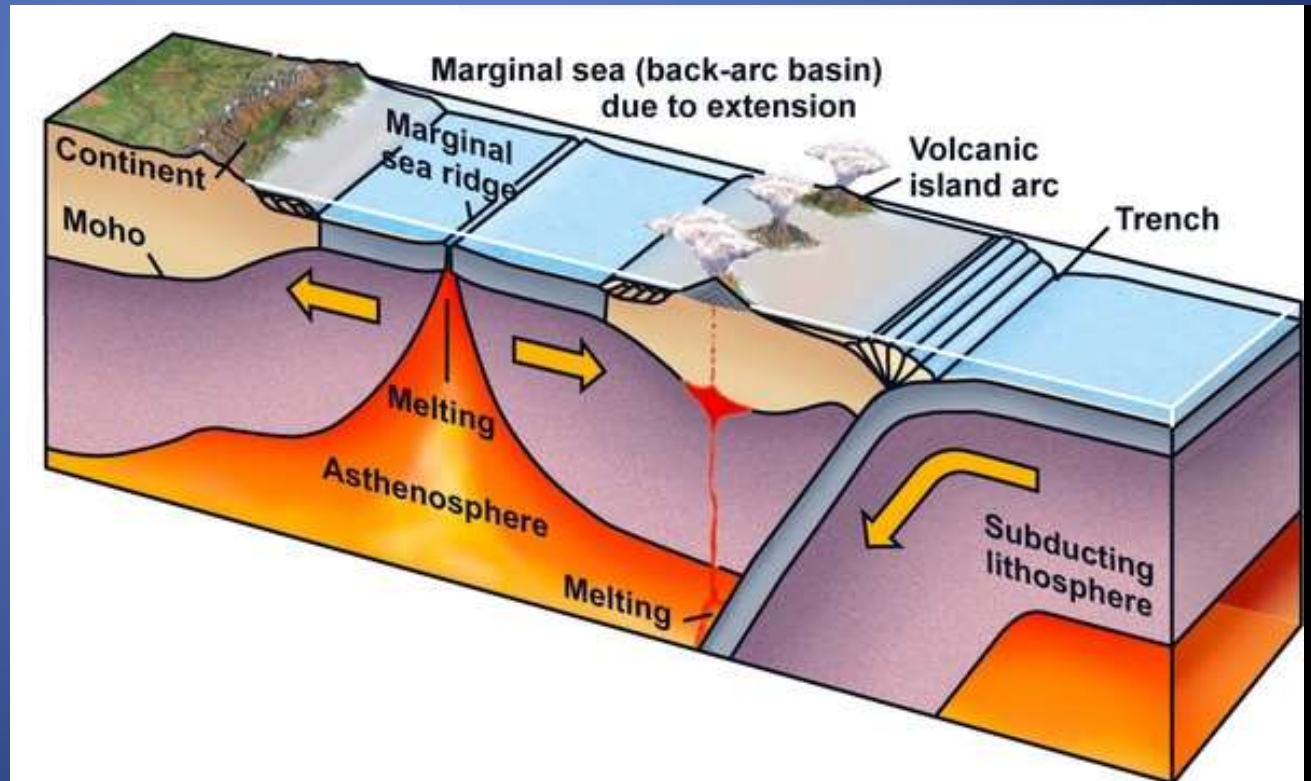


Fig. 2.21e

Transform Boundaries

- Lithosphere fractures and slides laterally
 - No new plate forms; none consumed.
 - Many transforms offset spreading ridge segments.
 - Some transforms cut through
- Characterized by:
 - Earthquakes
 - Absence of volcanism

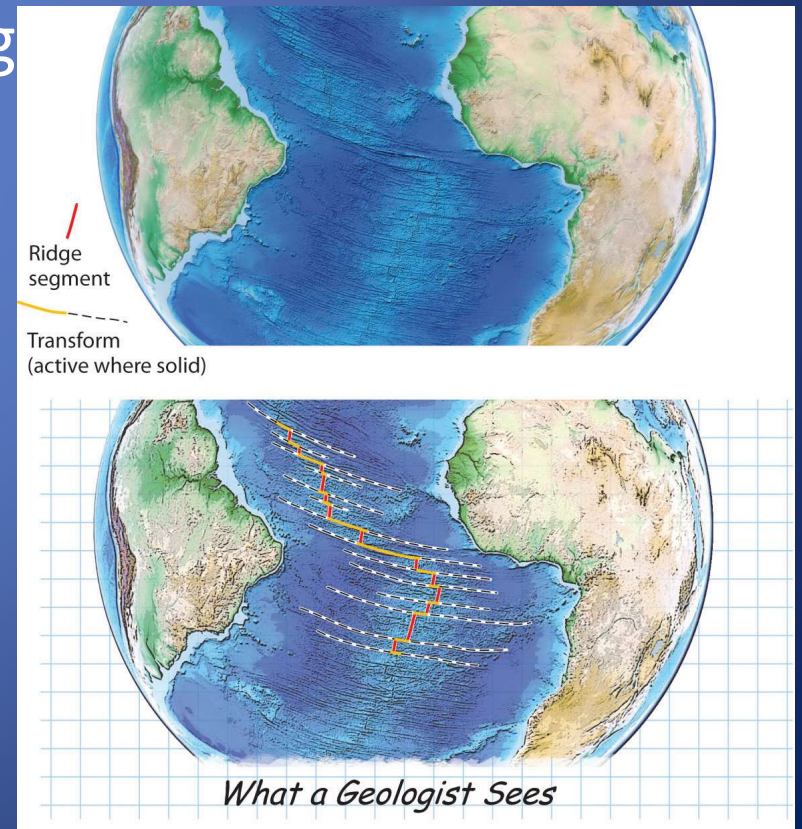


Fig. 2.22a

Oceanic Transforms

- The mid-ocean ridge axis is offset by transform faults.
 - Fracture zones lie at right angles to ridge segments.
 - Active slip (earthquakes) occurs between ridge segments.
 - Portions of fracture zones extending beyond ridges are not seismically active.

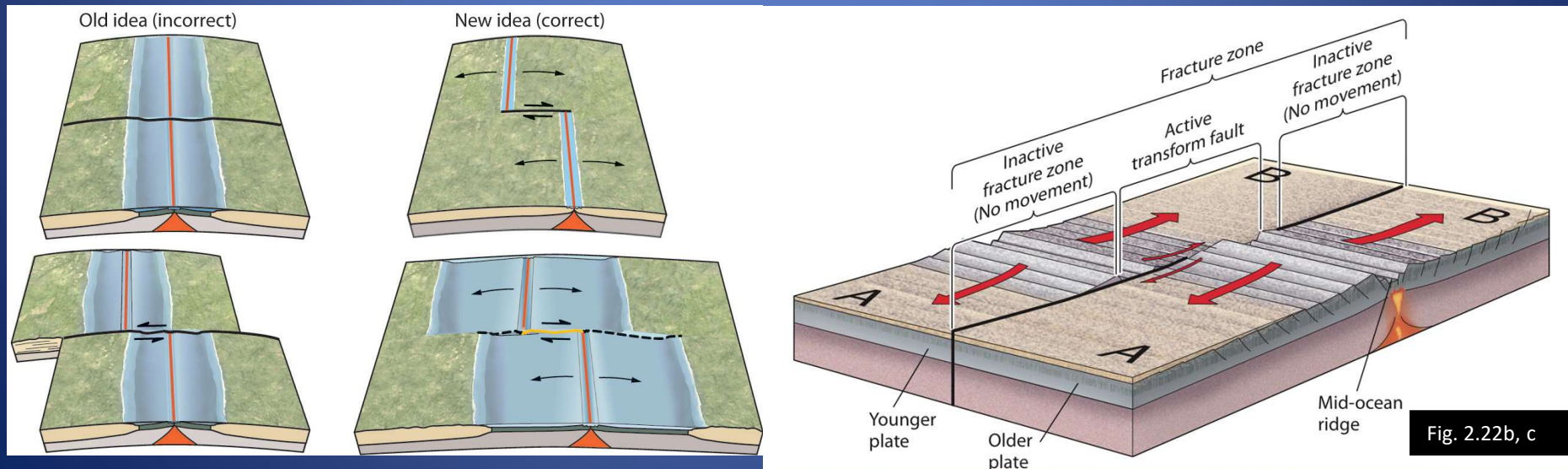


Fig. 2.22b, c

Transform Boundaries

- Continental transforms—cut across continental crust.
- Example: The San Andreas Fault, California

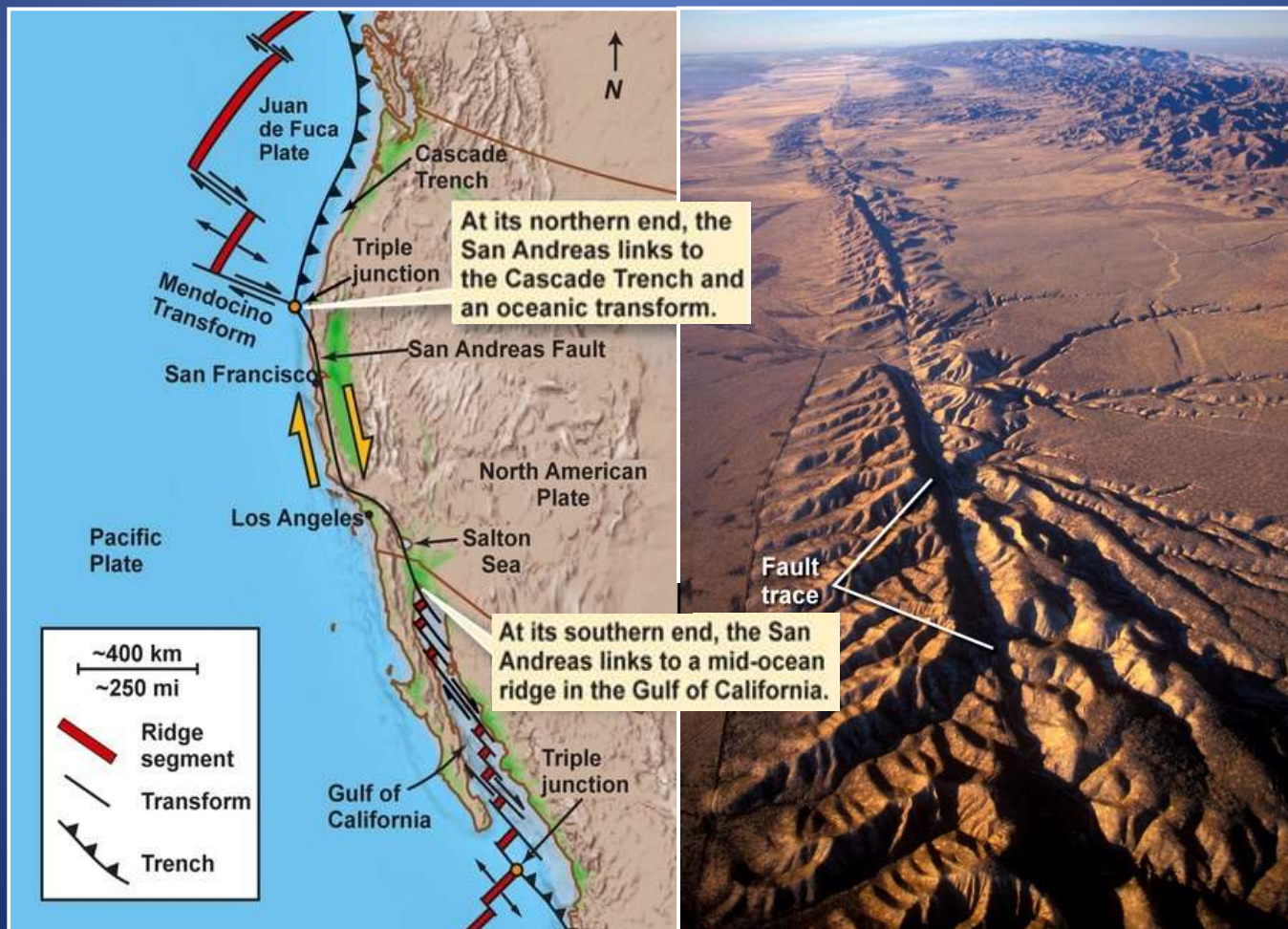


Fig. 2.22d, e

Triple Junctions

- Point where three plate boundaries intersect.
- Multiple boundary combinations occur.

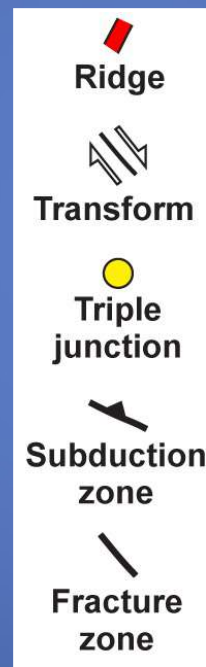
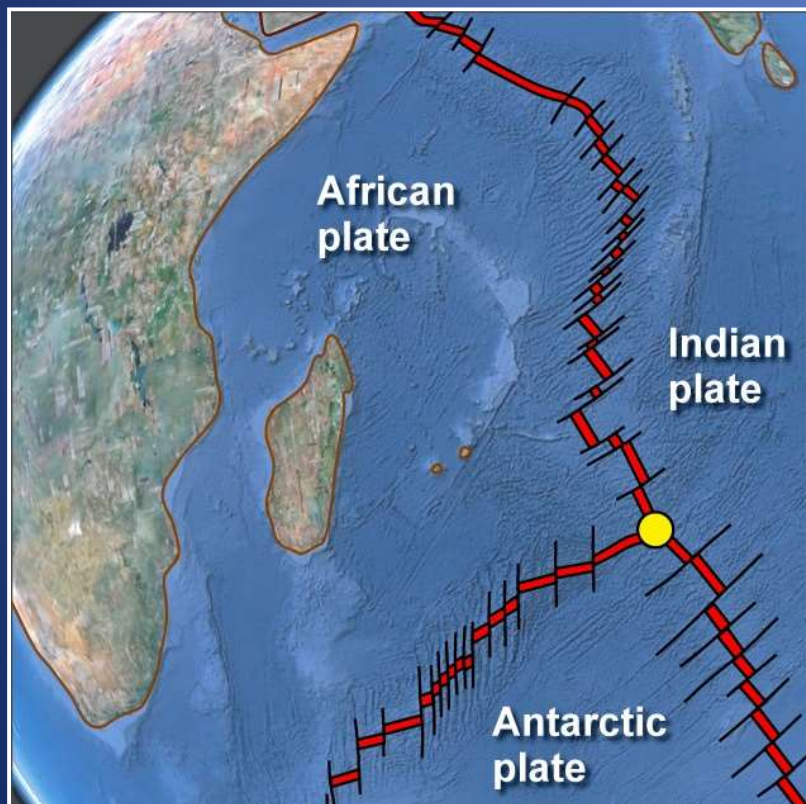
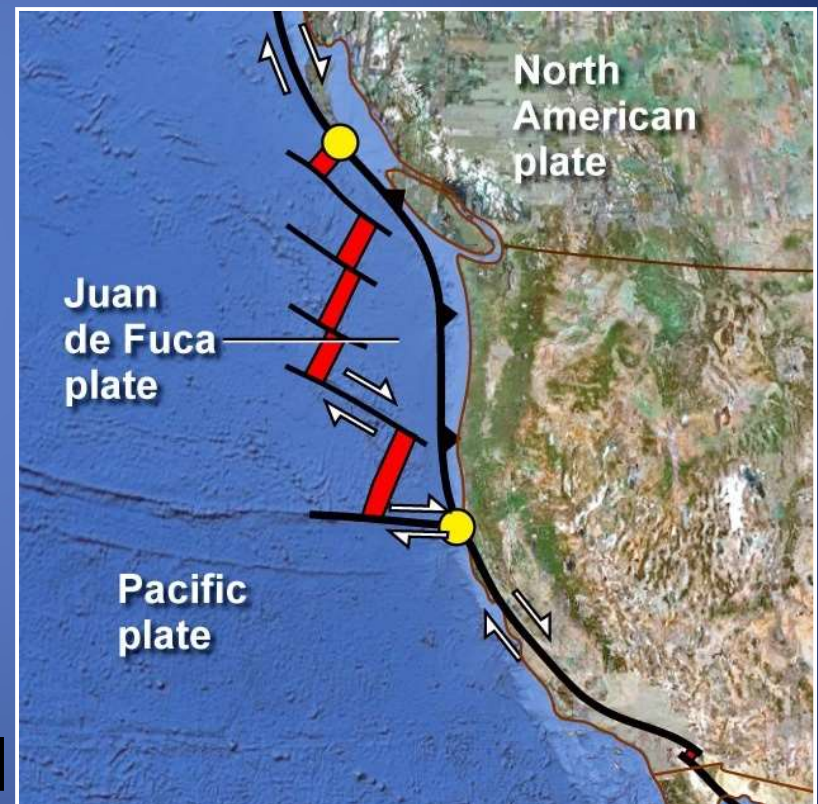
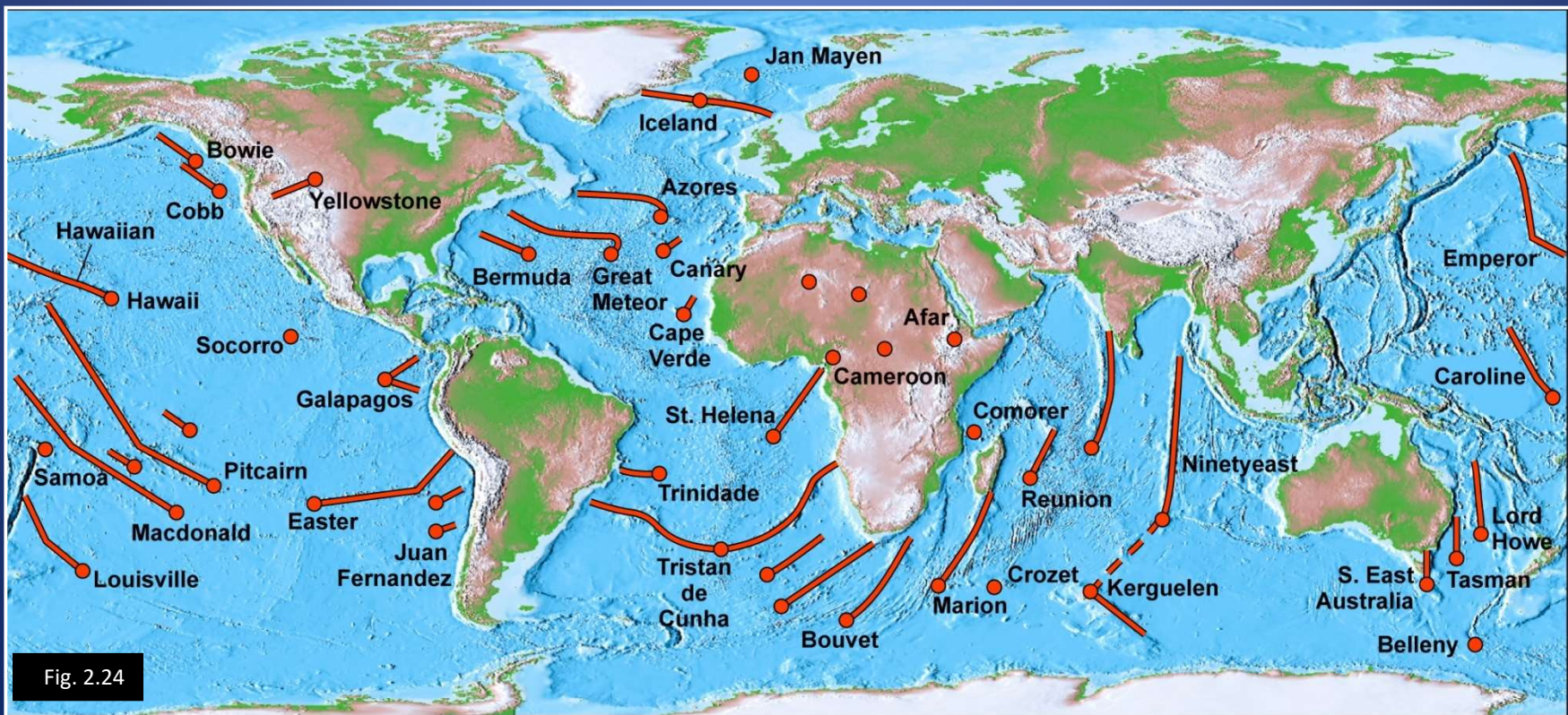


Fig. 2.23a, b



Hot Spots

- Plumes of deep mantle material independent of plates.
 - Not linked to plate boundaries
 - Originates as a deep *mantle plume*
 - Plume partially melts lithosphere; magma rises to surface.



Hot Spots

- Hot spots perforate overriding plates.
- Volcanoes build above sea level.
- Plate motion pulls volcano off plume.
 - Volcano goes extinct and erodes.
 - Chain of extinct volcanoes called a *hot-spot track*.
- Hot spots reinforce sea-floor spreading.

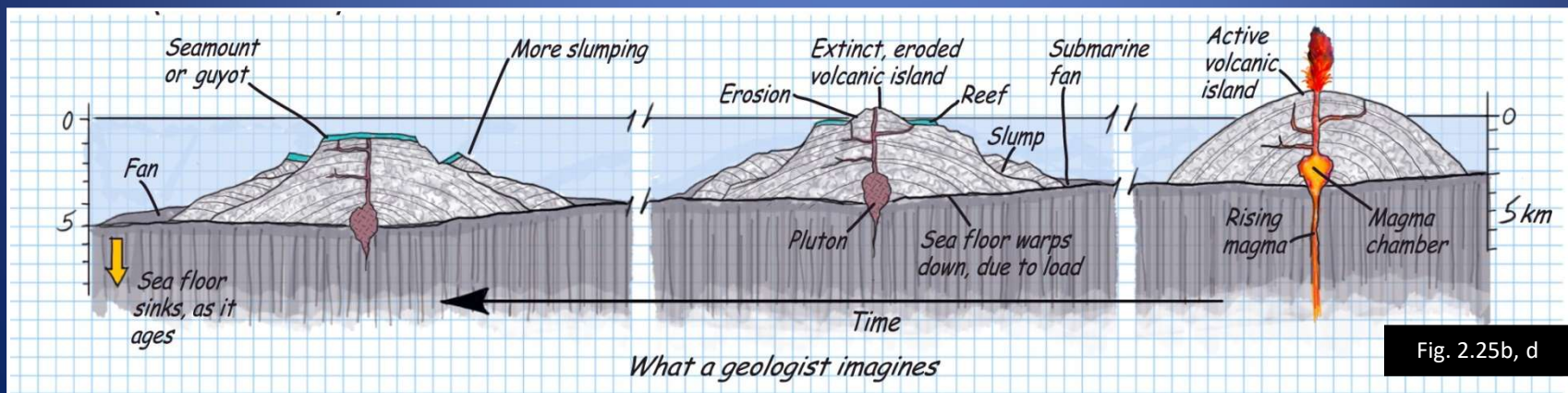
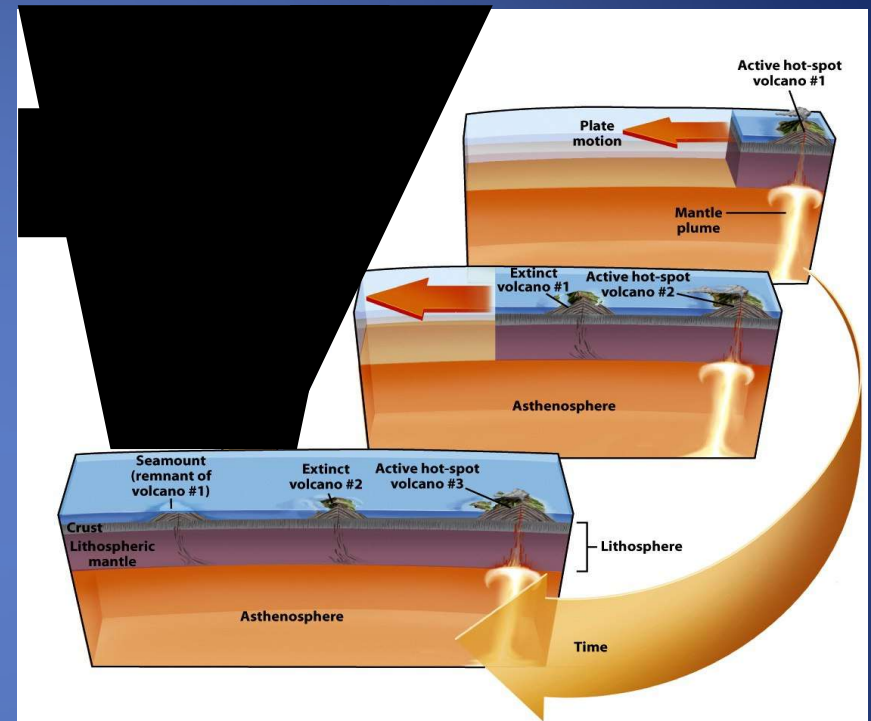


Fig. 2.25b, d

Hot Spots

- Hot-spot seamounts age away from originating hot spot.
- Age trend defines rate of plate motion.
- Line of seamounts indicates direction of plate motion.

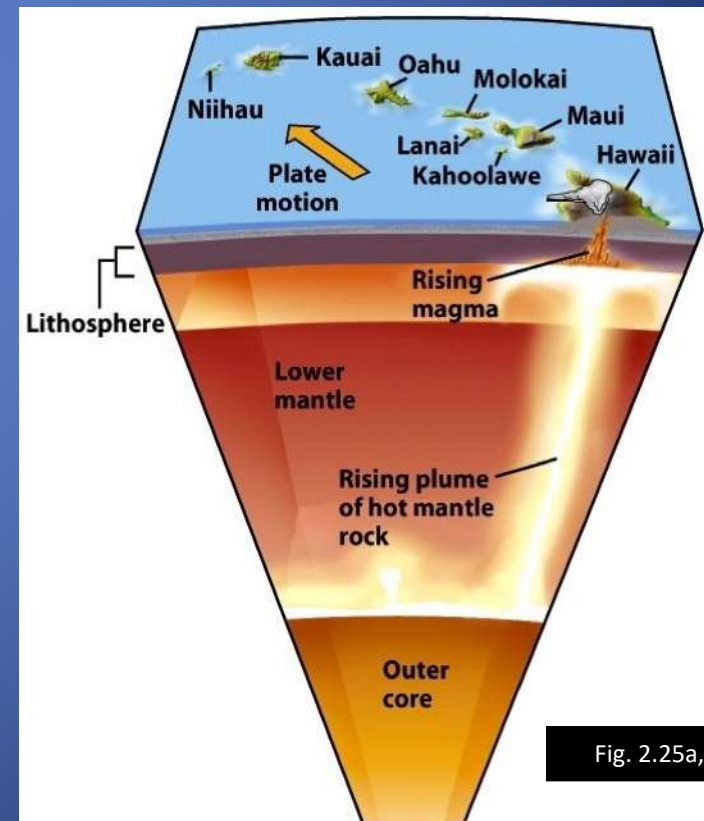
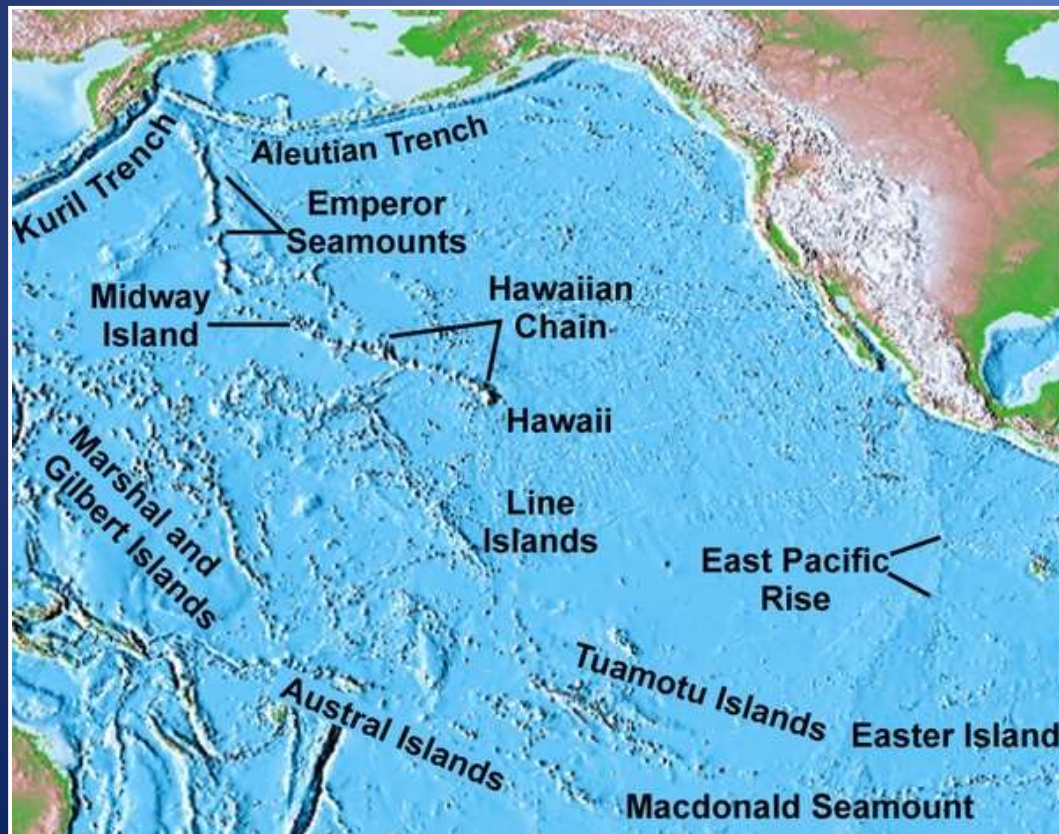


Fig. 2.25a, c

Continental Rifting

- Continental lithosphere can break apart.
 - Lithosphere stretches and thins.
 - Brittle upper crust faults.
 - Ductile lower crust flows.
 - Asthenosphere rises and melts.
 - Magma erupts.
- Continuation can create a new mid-ocean ridge.
- This process led to the breakup of Pangaea.

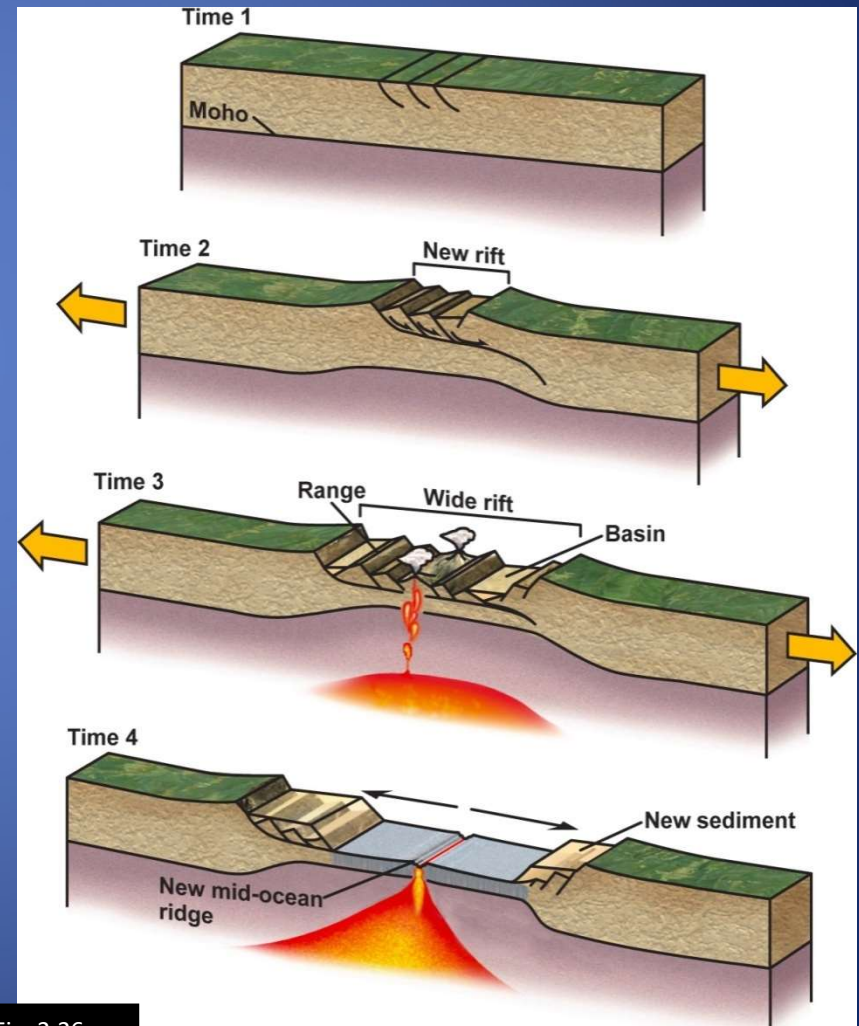


Fig. 2.26a

Continental Rifting

- Western U.S. Basin and Range Province is a rift.
 - Narrow north-south mountains separated by basins.
 - Rifting tilted blocks of crust to form mountains.
 - Sediment eroded from blocks, filling adjacent basins.



Fig. 2.26b

Continental Rifting

■ East African Rift:

- The Arabian plate is rifting from the African plate.
- Rifting has progressed to sea-floor spreading in:
 - ▶ The Red Sea.
 - ▶ The Gulf of Aden.
- Stretching continues along the East African Rift.
 - ▶ Elongate trough bordered by faulted high cliffs
 - ▶ Volcanoes – Mt. Kilimanjaro
- The rift and two spreading ridges comprise a triple junction.

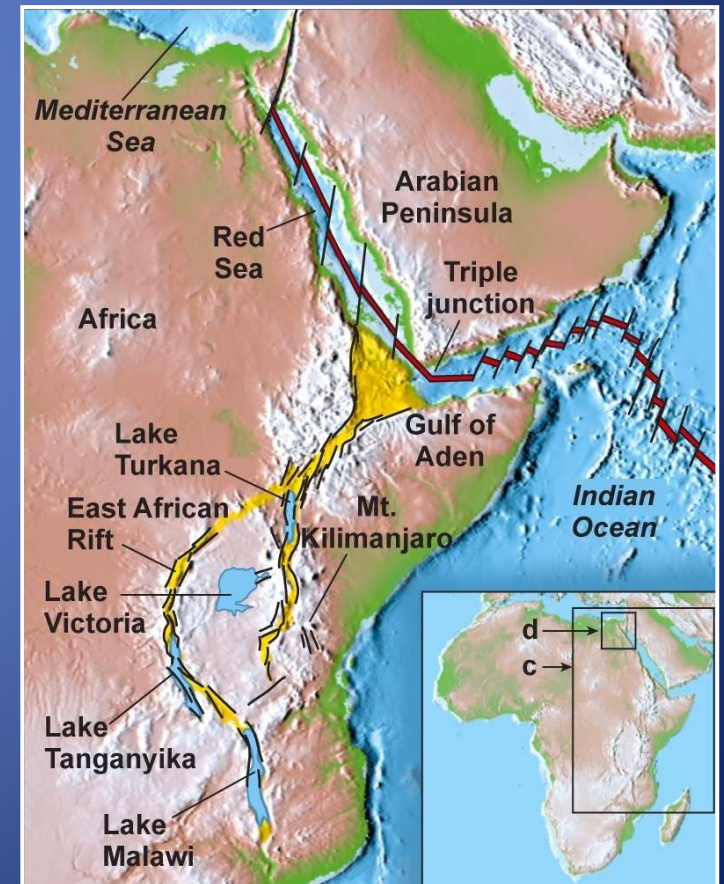


Fig. 2.26c

Plate Collision

- Subduction consumes ocean basins.
- Ocean closure ends in continental collision.
 - Subduction ceases, subducting plate detaches, sinks.
 - Continental crust is too buoyant to subduct.
 - Collision deforms crust, mountains are uplifted.

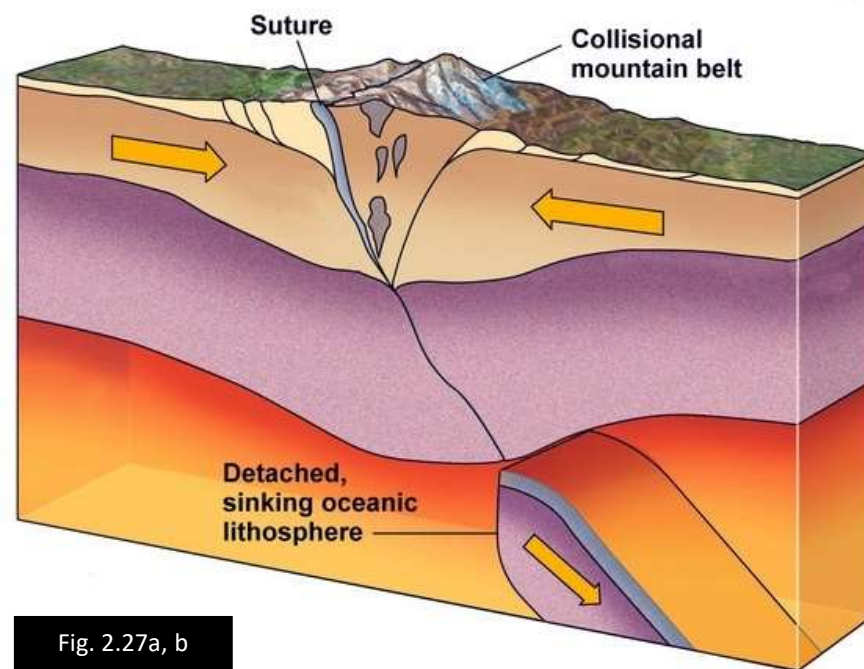
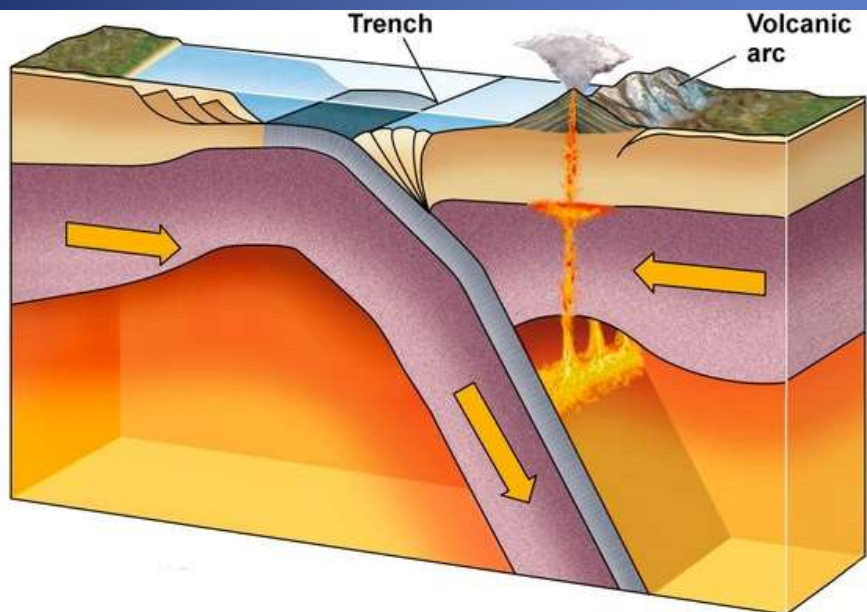


Fig. 2.27a, b

Driving Mechanisms

■ Two forces drive plate motions:

- Ridge-push—elevated MOR pushes lithosphere away.
- Slab-pull—denser subducting plate is pulled downward.
- Convection in the asthenosphere speeds or slows motion.

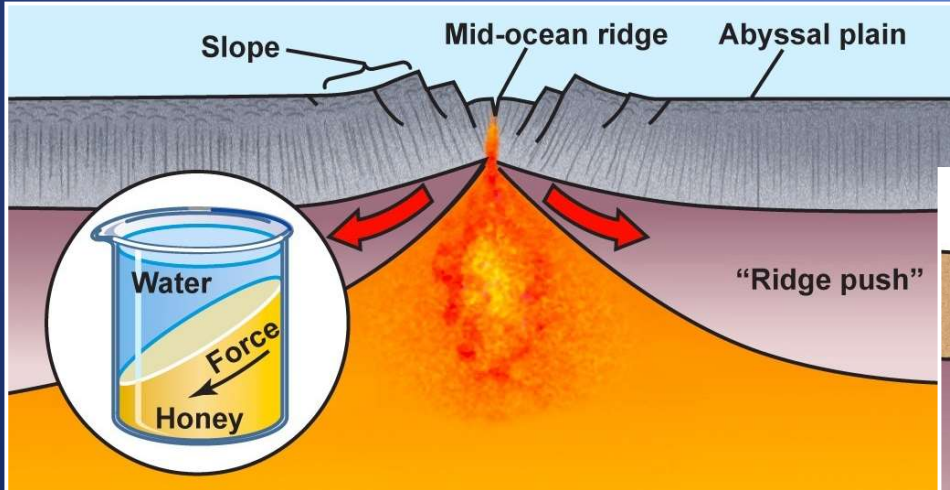


Fig. 2.28a, b

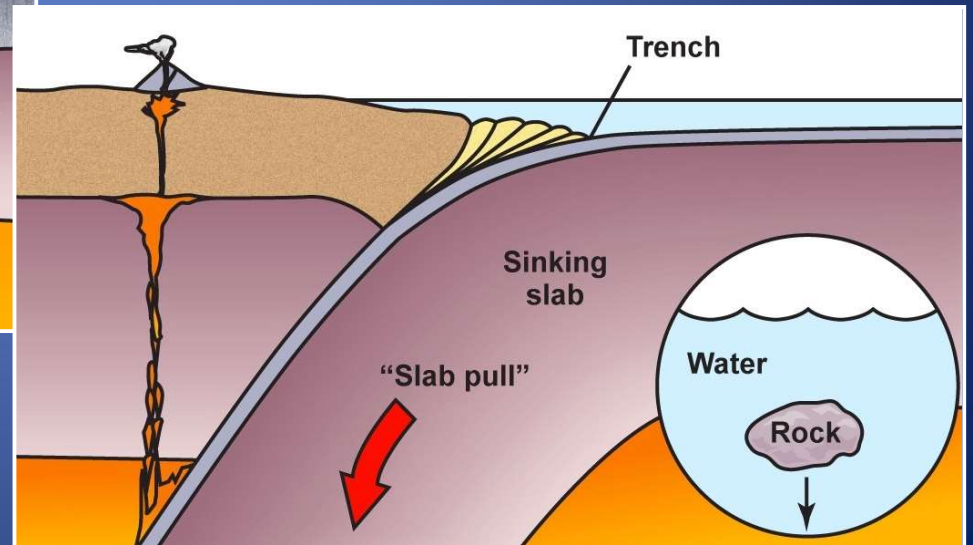


Plate Velocities

- Absolute plate velocities may be mapped by:
 - Plotting plate motion relative to a fixed spot in the mantle.
 - Measuring volcano ages/distance along a hot spot track.

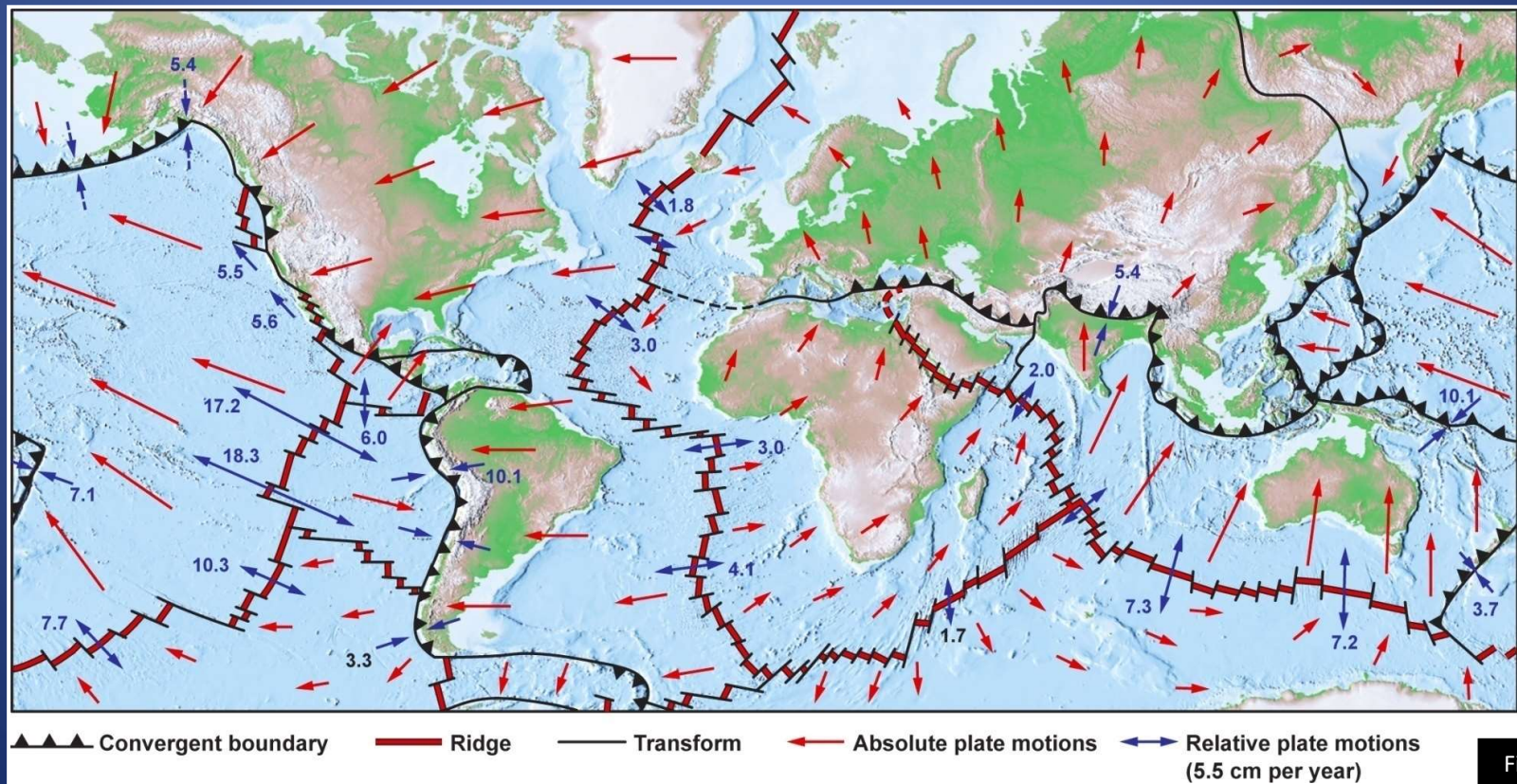


Fig. 2.29

Plate Velocities

- Plate motion is now determined by GPS measurements.
 - Global Positioning System (GPS) uses satellites.
 - Knowledge of plate motion is now accurate and precise.

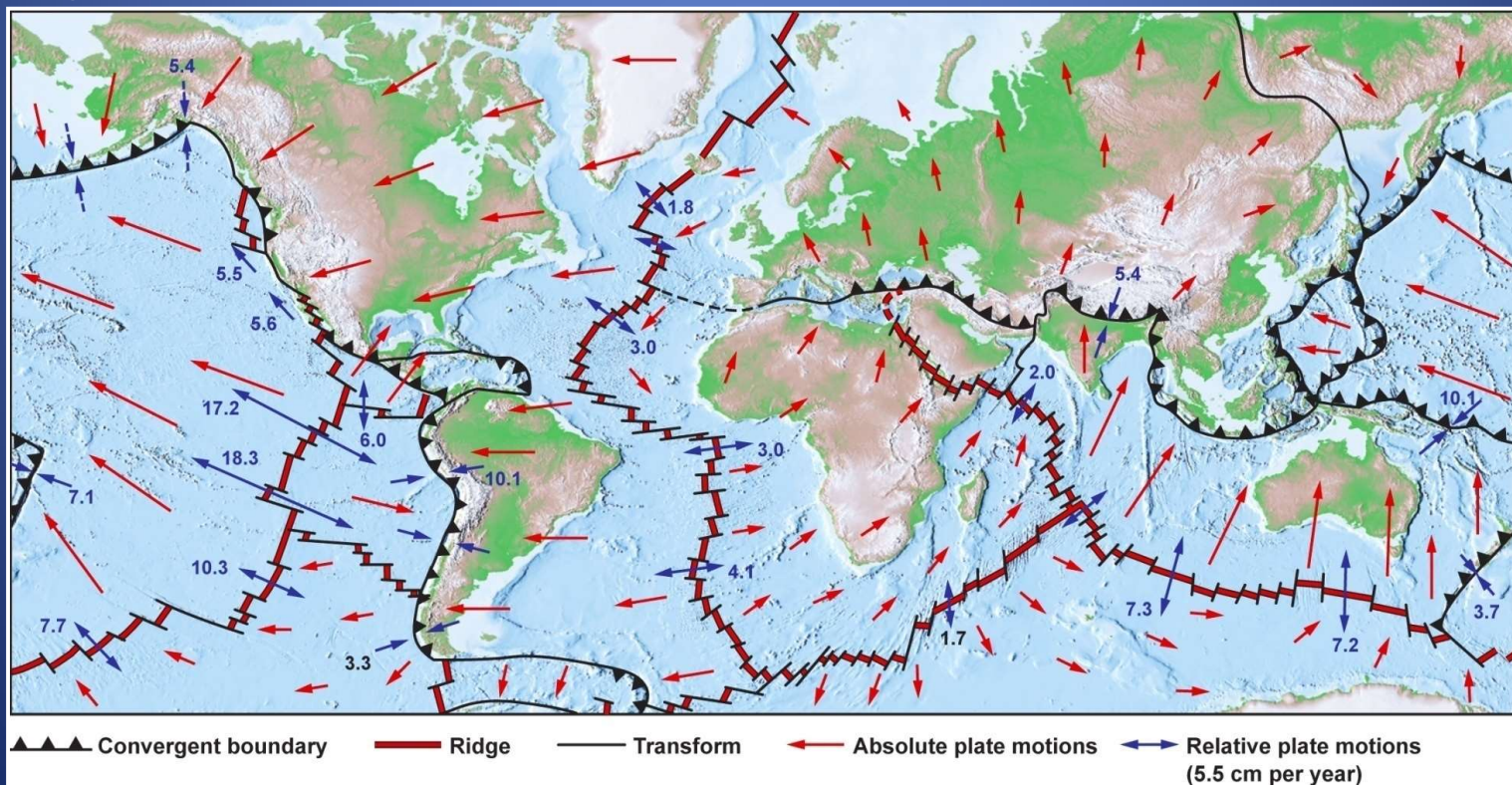
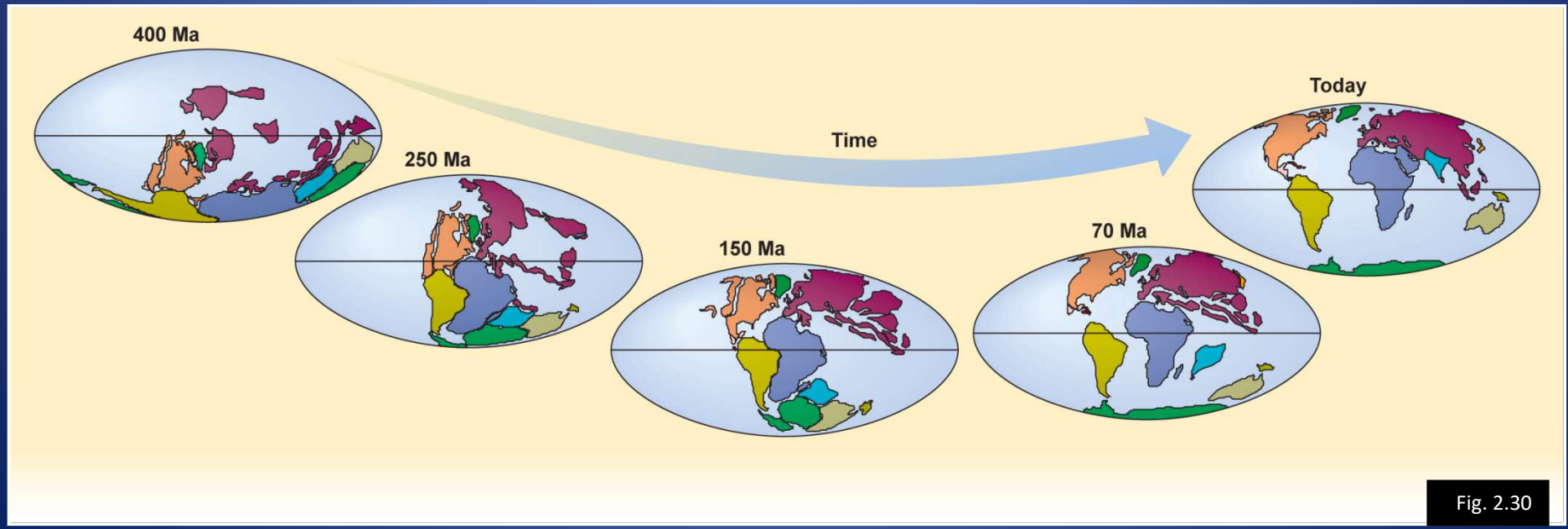


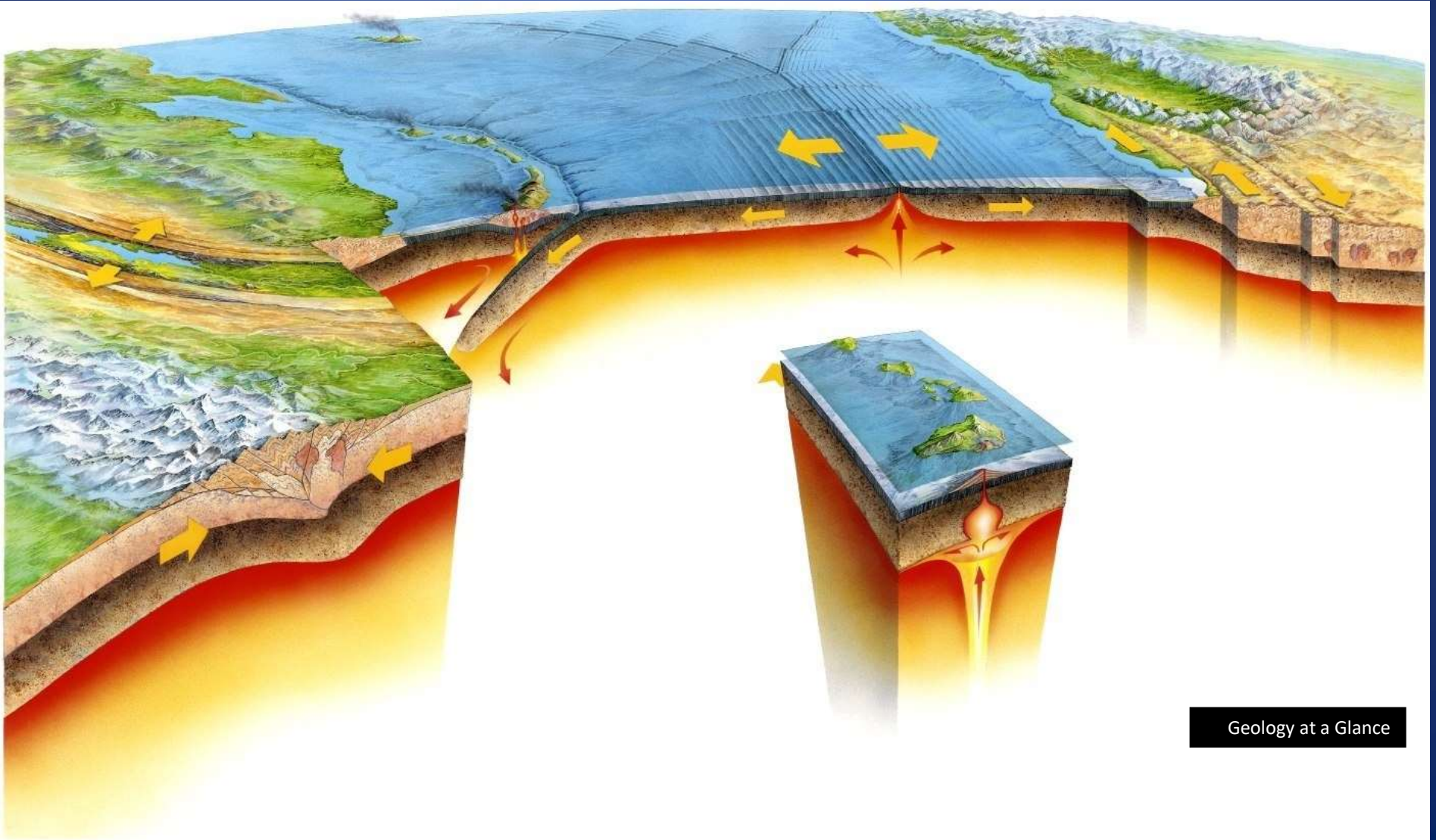
Fig. 2.29

The Dynamic Planet

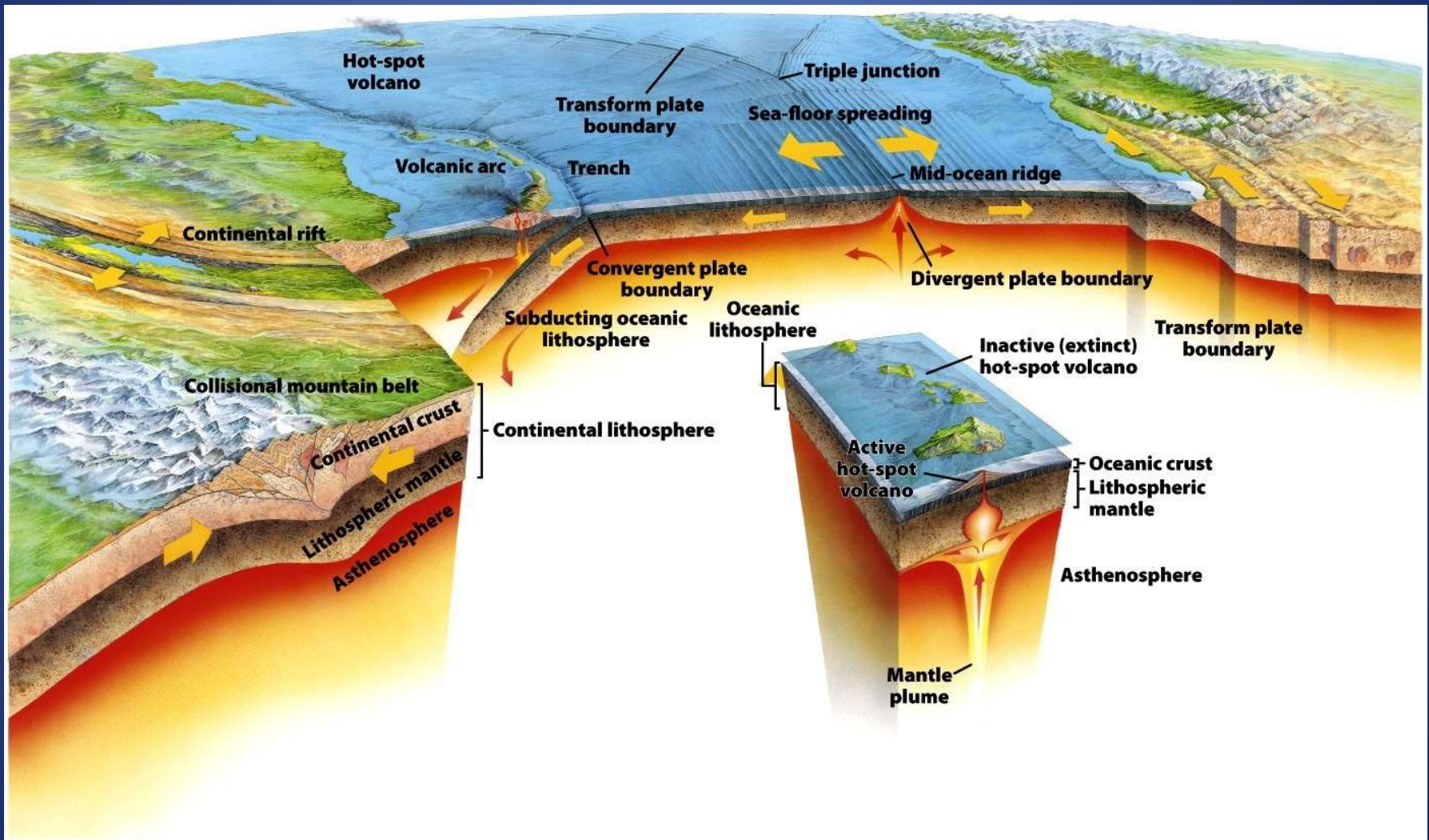
- Earth's surface changes continuously.
 - These changes appear slow to us.
 - Geologically, change is rapid.
- Earth looked very different in the past.
- Earth will look very different in the future.



The Dynamic Planet



The Dynamic Planet



- Plate Tectonics Summary: Ocean floor created at mid-ocean ridges is consumed at oceanic trenches.

Useful Web Resources

- Dr. Christopher Scotese's Paleogeographic Maps
 - www.scotese.com/
- Dr. Ronald Blakey's Paleogeographic Maps
 - <http://www2.nau.edu/rcb7/globaltext2.html>
- The Science Channel: 100 Greatest Discoveries: Sea-Floor Spreading
 - <http://science.discovery.com/videos/100-greatest-discoveries-shorts-sea-floor-spreading.html>
- The Science Discovery's 100 Greatest Discoveries: Continental Drift
 - <http://science.discovery.com/videos/100-greatest-discoveries-shorts-continental-drift.html>
- Earthguide Online Classroom Sea-floor Spreading Animation
 - http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_seafloorspreading.html
- Library of Congress Manuscript of the Heezen–Tharp “World Ocean Floor” Map
 - [http://memory.loc.gov/cgi-bin/query/h?ammem/gmd:@field\(NUMBER+@band\(g9096c+ct003148\)\)](http://memory.loc.gov/cgi-bin/query/h?ammem/gmd:@field(NUMBER+@band(g9096c+ct003148)))
- Discovering Plate Boundaries Interactive Exercise, Dale Sawyer, Rice University
 - <http://terra.rice.edu/plateboundary/downloads.html>
- Goddard Space Flight Center, Scientific Visualization Studio, Plate Tectonics
 - <http://svs.gsfc.nasa.gov/vis/a000000/a002900/a002953/index.html>
- Teachers' Domain PBS Video Clip on Alfred Wegener
 - www.teachersdomain.org/resource/ess05.sci.ess.earthsys.wegener1/