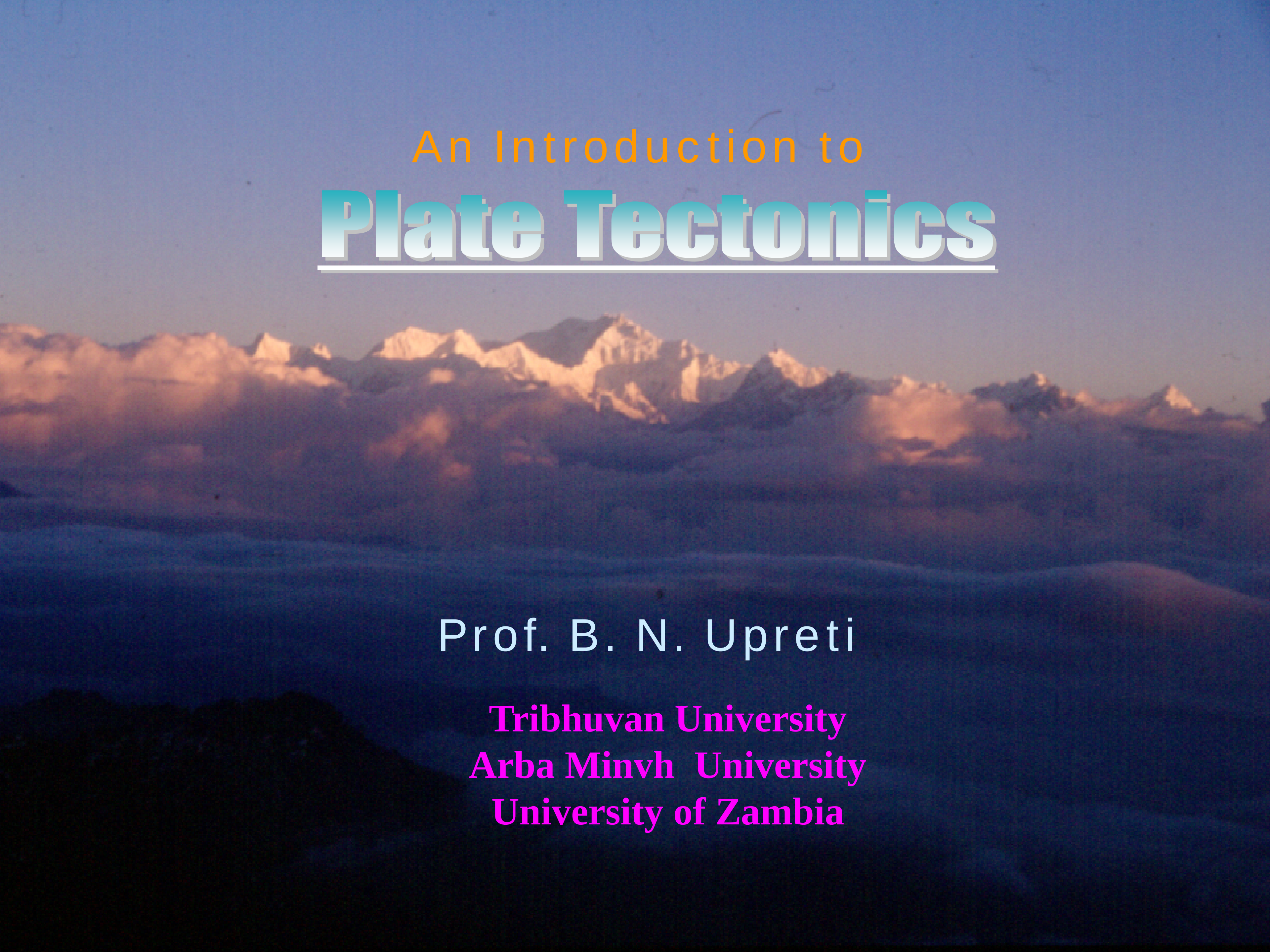


An Introduction to

Plate Tectonics

Prof. B. N. Upreti

Tribhuvan University
Arba Minvh University
University of Zambia

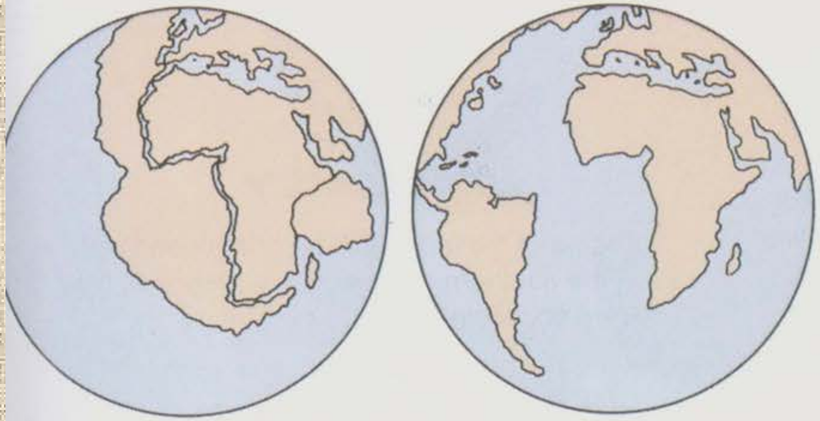
PLATE TECTONICS

CONTINENTAL DRIFT

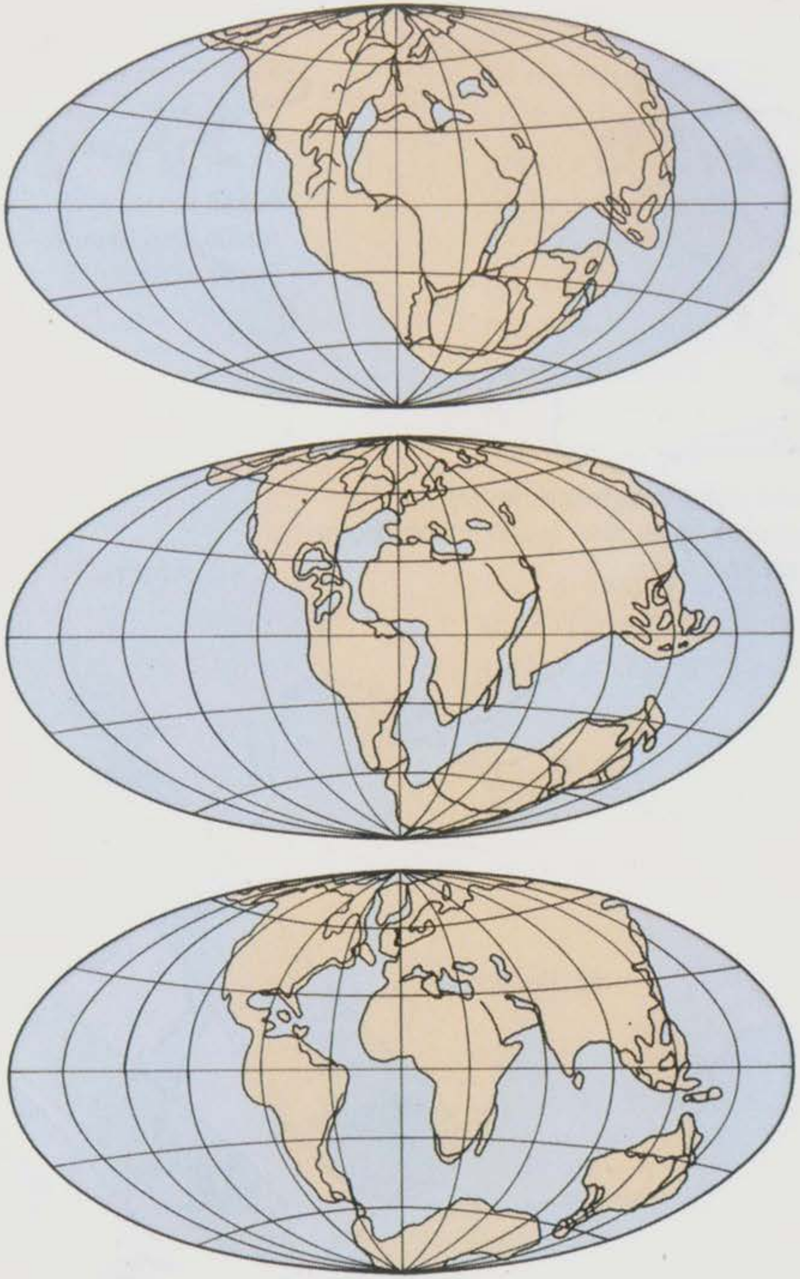
The suggestion that there might have been lateral displcements of the continental masses on a gigantic scale is generally ascribed to *F.B. Taylor* in America (1908) and to *Alfred Wegener* in Germany (1910). For several years they developed their ideas independently.

However, the germ of the idea can be traced back to 1620, when *Francis Bacon* pointed out the parallelism of the opposing shores of the atlantic.

Nearly two centuries later *Antanio Snider* united the continents in much the same way as Wegener did. He published a book in 1858 with two maps showing the reassembling of the continents.



(A) Maps made by Antonio Snider-Pelligrini in 1858.



(B) Maps made by Alfred Wegener in 1915.

FIGURE 17.1 **Continental drift** was illustrated as early as 1858 by Antonio Snider-Pelligrini when he published these maps (A) in his book *Creation and Its Mysteries Revealed*. The idea seemed too far-fetched to the public and the scientific communities of the time and was forgotten, not to be revived for 50 years. Wegener published his series of maps (B) in 1915. His evidence, most of which was quite valid, was drawn from all of the sciences. Wegener called the original land mass Pangaea ("all lands") and believed that the continents somehow plowed through the oceanic crust as they drifted.

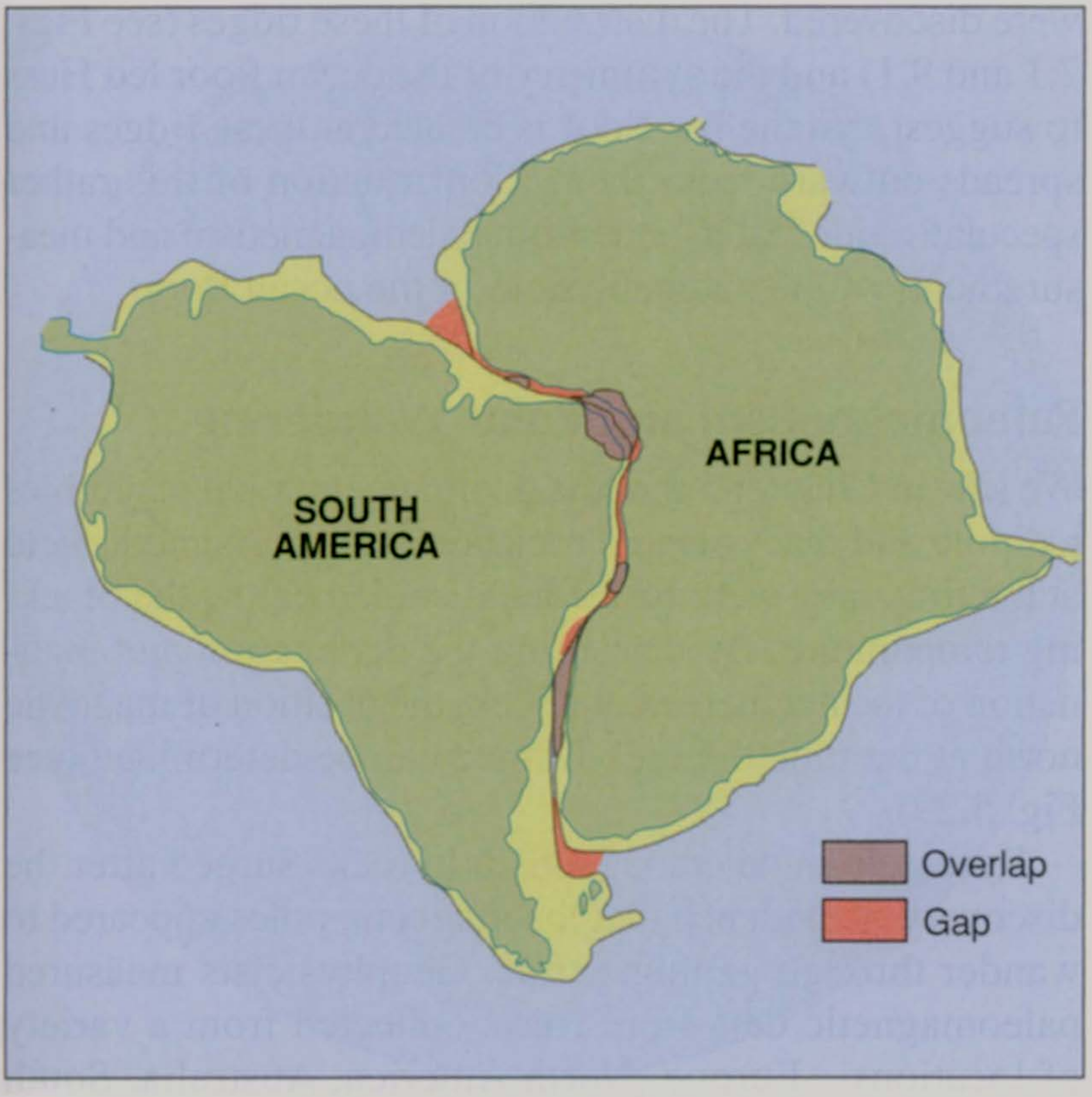
Taylor (1910): He pictured the original Laurasia as being a continuous sheet of sial and supposed it to have spread outwards towards the equator, more or less radially from the polar region, much as a continental ice sheet would do. Wherever the resistance was least, the crust flowed out in lobes, raising up mountainous loops and arcs in front.

Evidences for continental drift

Wegener (1915)

- **Paleontological evidence**
- **Evidence from structure and rock types**
- **Evidence from glaciation**
- **Evidence from other paleoclimatic records**

Photo by Upreti taken from the exhibit of Natural History Museum, London)



■ **FIGURE 7.4** Bullard's fit of South America and Africa. The outlines correspond to the 914-m bathymetric contour. Light red shaded areas represent gaps and gray shaded areas represent overlaps in the fit.

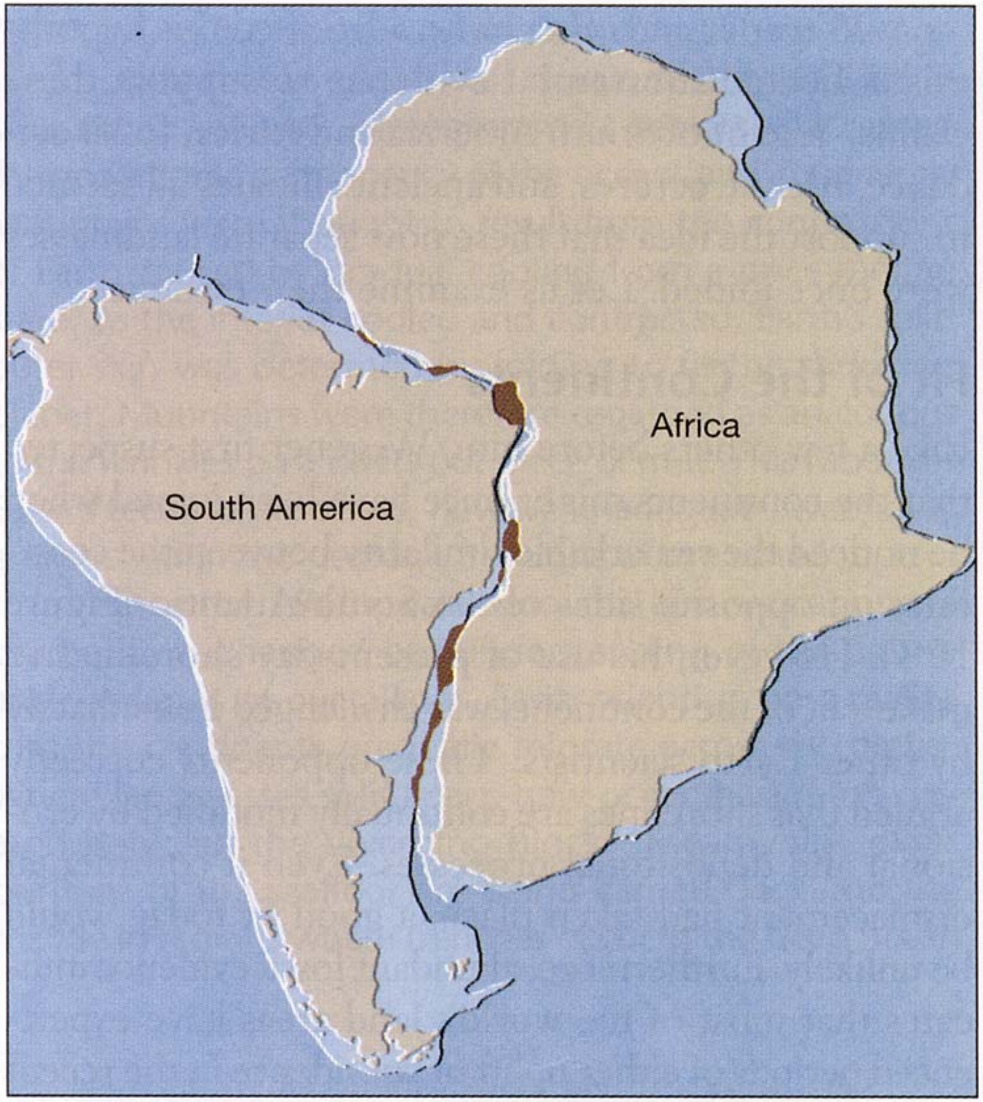


Figure 19.3 This shows the best fit of South America and Africa along the continental slope at a depth of 500 fathoms (about 900 meters). The areas where continental blocks overlap appear in brown. (After A. G. Smith, "Continental Drift." In *Understanding the Earth*, edited by I. G. Gass. Courtesy of Artemis Press)

Alfred Wagener

Died at the age of 50

FIGURE 3.1 Alfred Wegener, the German meteorologist who proposed a comprehensive model of continental drift and presented geologic evidence in support of the idea.

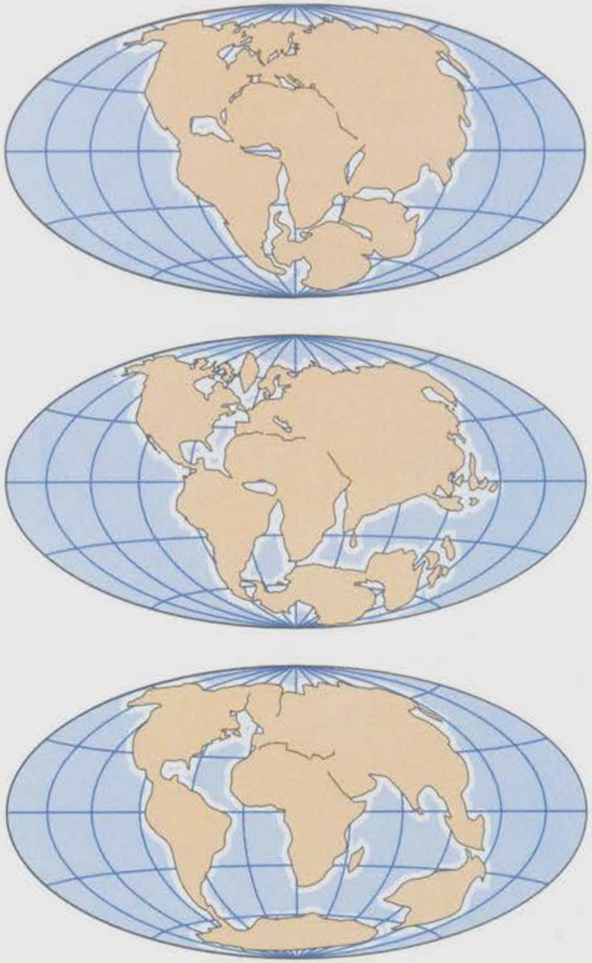
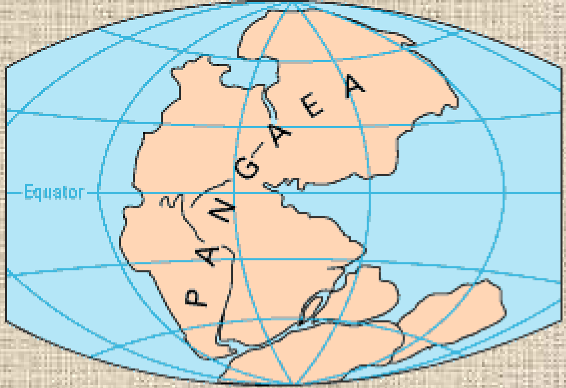
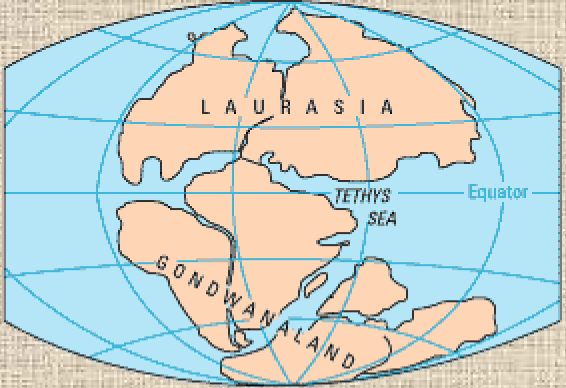


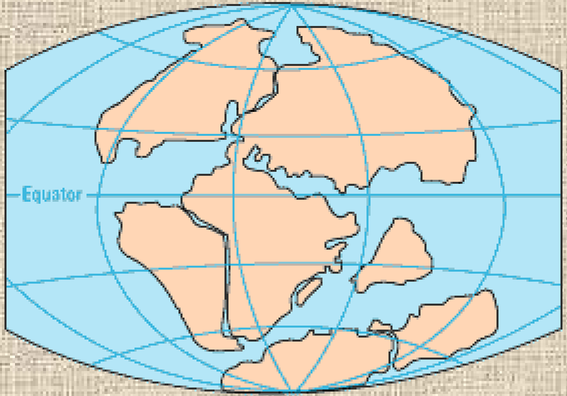
FIGURE 3.2 Wegener's image of Pangaea and its subsequent breakup and dispersal.



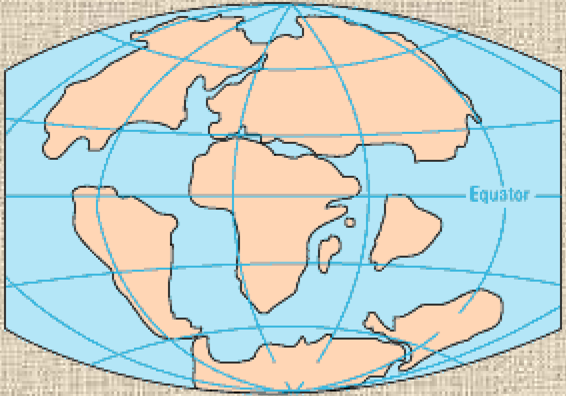
PERMIAN
225 million years ago



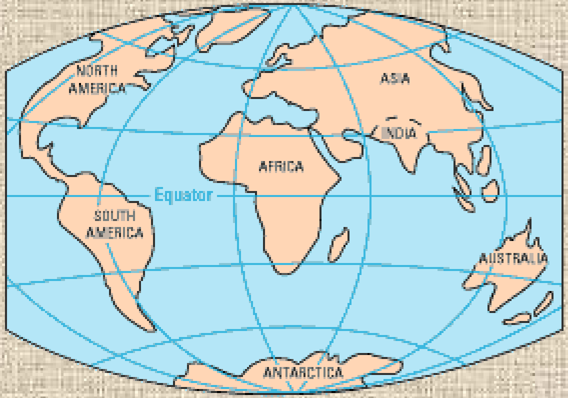
TRIASSIC
200 million years ago



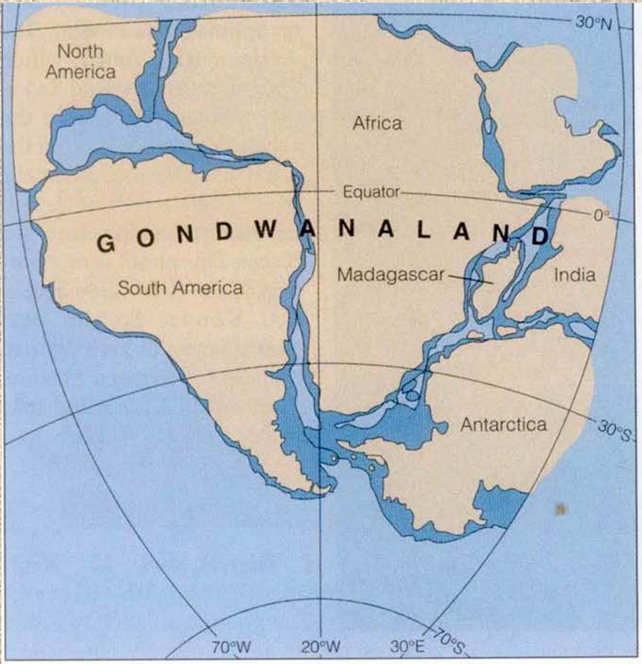
JURASSIC
135 million years ago



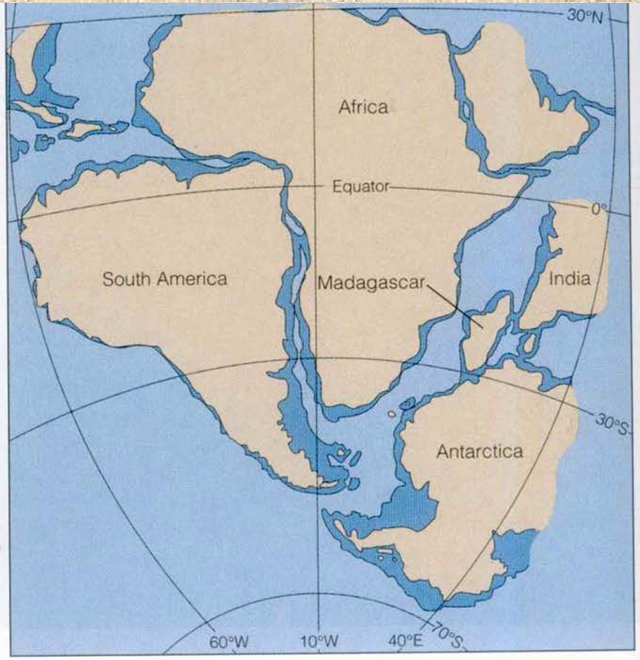
CRETACEOUS
65 million years ago



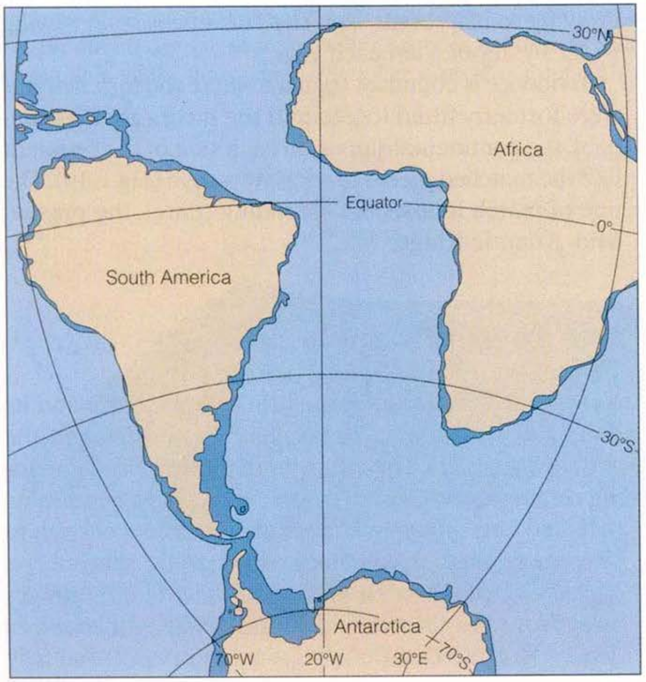
PRESENT DAY



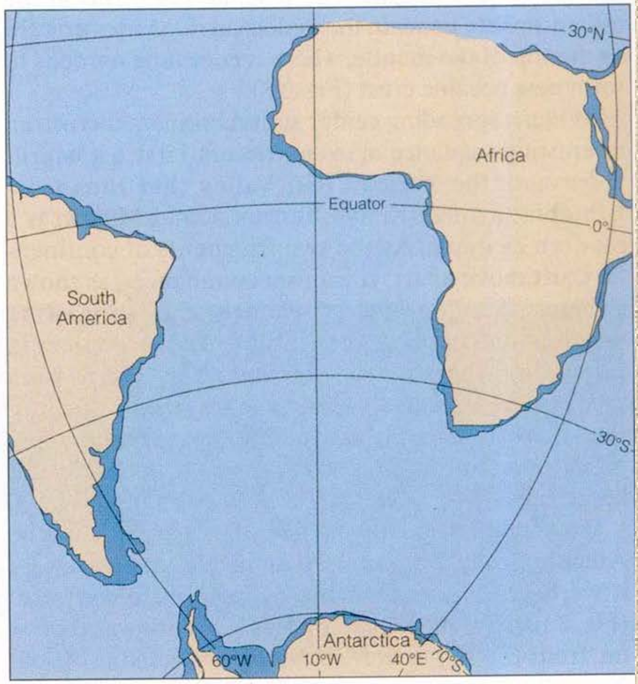
200 million years ago



120 million years ago



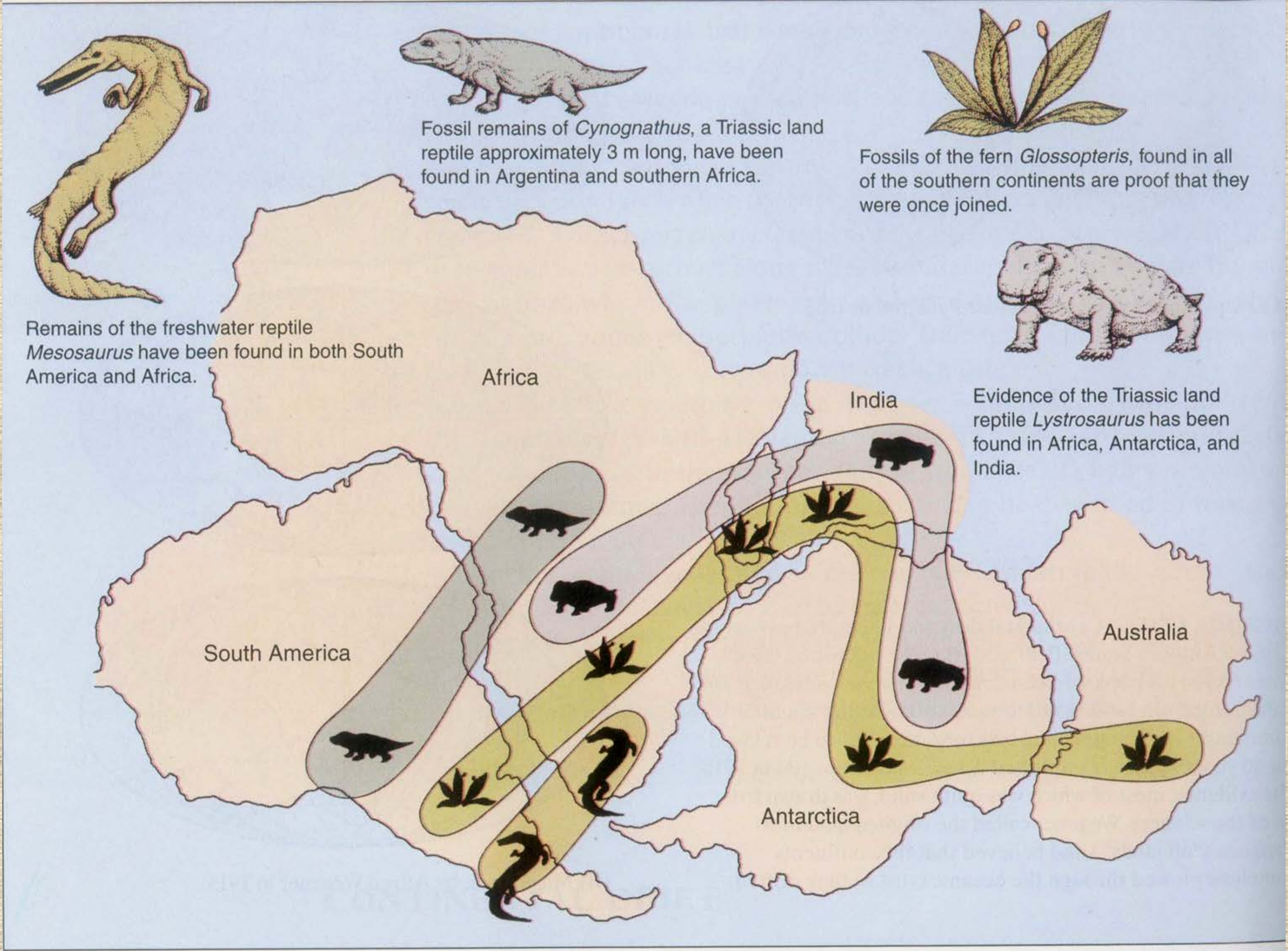
56 million years ago



Present

Paleontological evidence


ARCTIC OCEAN
ARCTIC OCEAN
ATLANTIC OCEAN
PACIFIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN
ATLANTIC OCEAN
Glacial limit
Cynognathus
Glossopteris
Lystrosaurus
Mesosauros



Fossil remains of *Cynognathus*, a Triassic land reptile approximately 3 m long, have been found in Argentina and southern Africa.

Fossils of the fern *Glossopteris*, found in all of the southern continents are proof that they were once joined.

Remains of the freshwater reptile *Mesosaurus* have been found in both South America and Africa.

Evidence of the Triassic land reptile *Lystrosaurus* has been found in Africa, Antarctica, and India.

FIGURE 17.2 **Paleontologic evidence of continental drift** can be appreciated by considering the distribution of some fossil plants and animals found in South America, Africa, Madagascar, India, Antarctica, and Australia. *Mesosaurus,* a Permian freshwater reptile, is found in both Brazil and South Africa. *Glossopteris,* a fossil fern, is found on all of the southern continents in the zone shown on the map. *Lystrosaurus,* a Triassic land reptile, is found in South Africa, South America, India, and Antarctica. *Cynognathus,* an older Triassic reptile, is found in Argentina and South Africa. *(Modified from L. Motz)*

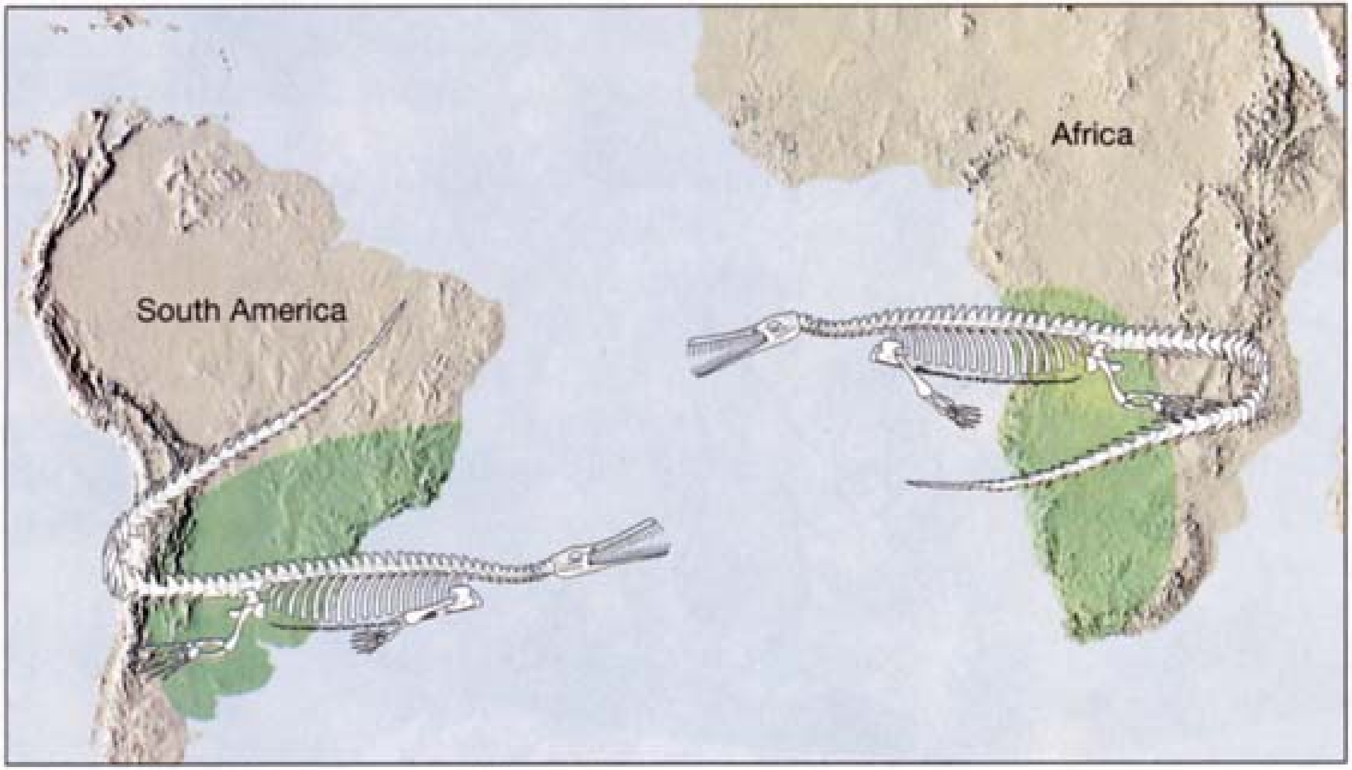


Figure 19.4 Fossils of *Mesosaurus* have been found on both sides of the South Atlantic and nowhere else in the world. Fossil remains of this and other organisms on the continents of Africa and South America appear to link these landmasses during the late Paleozoic and early Mesozoic eras.

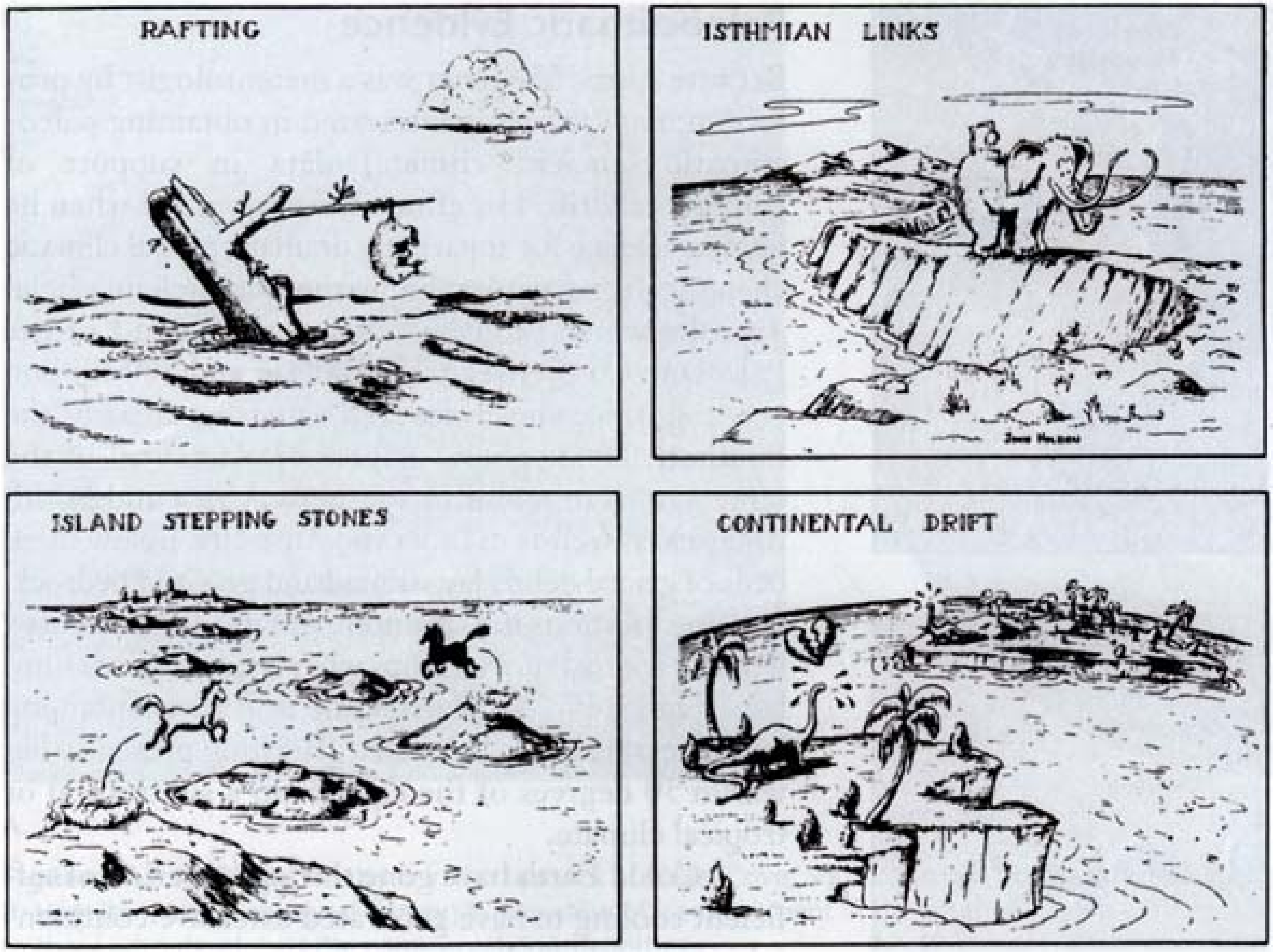
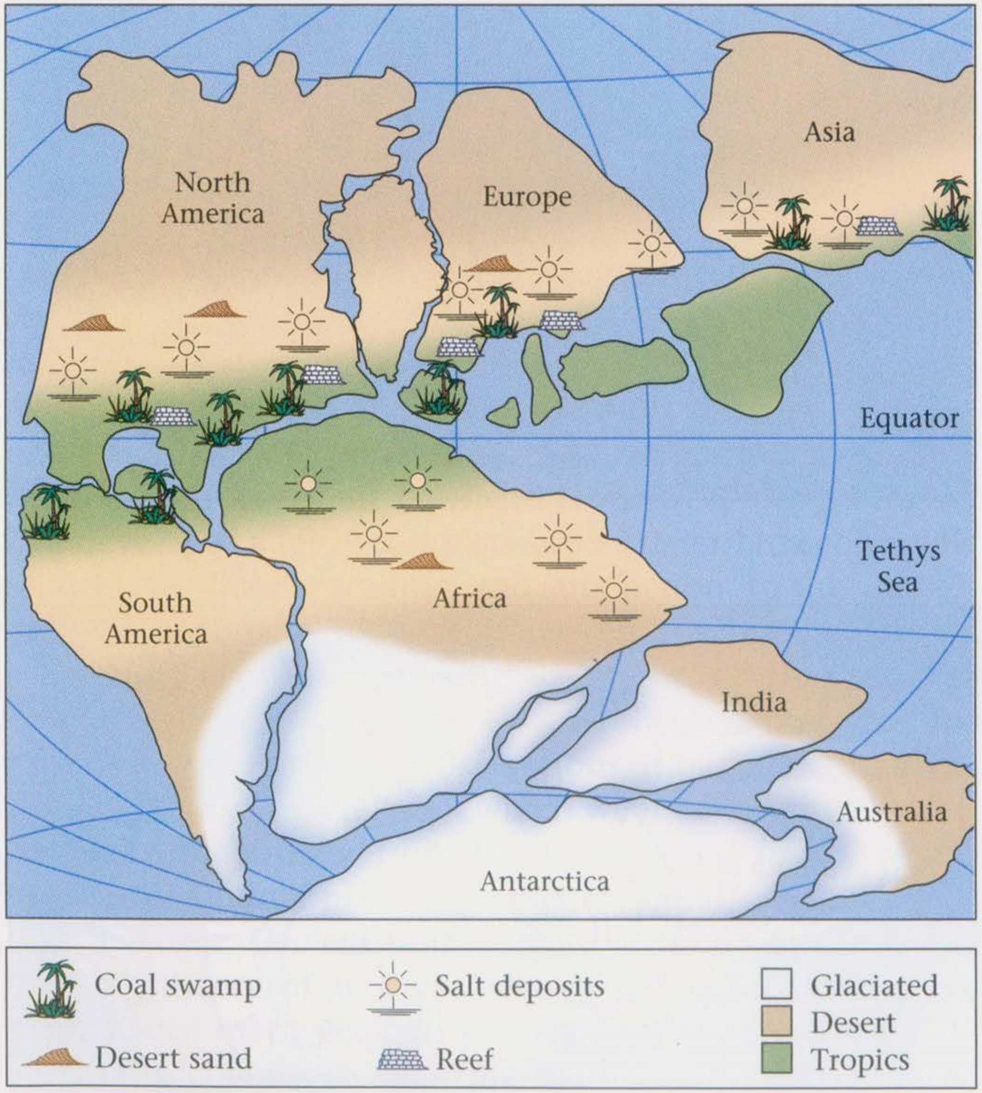


Figure 19.5 These sketches by John Holden illustrate various explanations for the occurrence of similar species on landmasses that are presently separated by vast oceans. (Reprinted with permission of John Holden)

Evidence from paleoclimatic records

FIGURE 3.4 Map of Pangaea, showing the distribution of coal deposits and reefs (indicating tropical environments), and sand-dune deposits and salt deposits (indicating subtropical environments). Note how deposits now on different continents align in distinct belts.



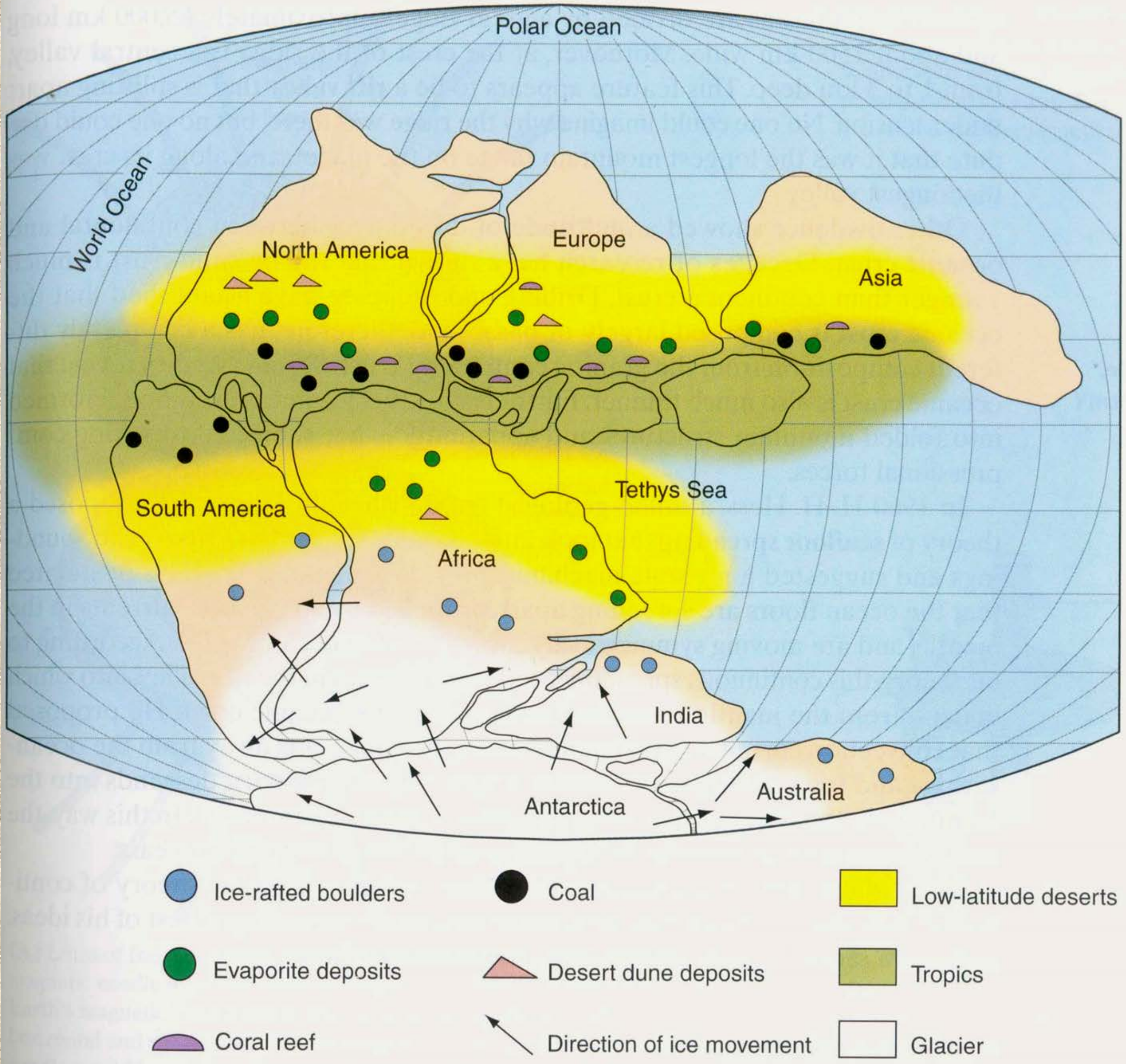


FIGURE 17.6 **Paleoclimatic evidence for continental drift** includes deposits of coal, desert sandstone, rock salt, wind-blown sand, gypsum, and glacial deposits. Each indicates a specific climatic condition at the time of its formation. The distribution of these deposits is best explained if we assume that the continents were grouped together at the end of the Paleozoic Era, as shown in this diagram. *(After American Association of Petroleum Geologists)*

Evidence from glaciation

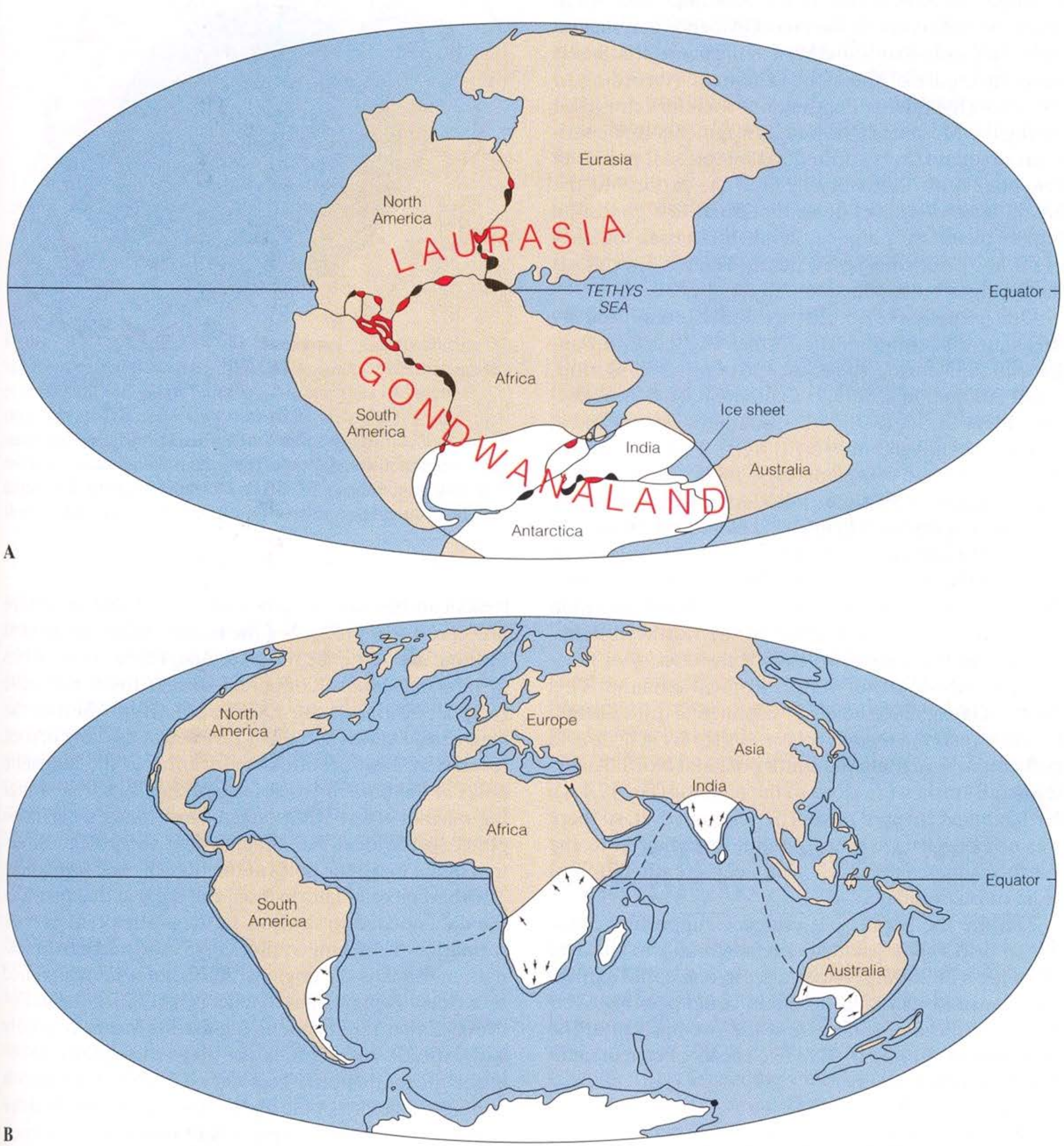


Figure 17.1 Pangaea The continents attained their present shapes when Pangaea broke apart 200 million years ago. A. The shape of Pangaea, determined by fitting together pieces of continental crust along a contour line 2000 m below sea level. (This is the line halfway down the continental slope, along which continental crust meets oceanic crust.) In a few places in this drawing, some overlap (black) occurs; elsewhere, small gaps (red) are found. These are places where post break-up events have modified the shapes of the continental margins. The white area is the region affected by continental glaciation 300 million years ago. B. Present continents and the 2000-m contour below sea level. The white areas are where evidence of the old ice sheets exists. Arrows show directions of movement of the former ice. The dashed line joining the glaciated regions indicates how large the ice sheet would have to have been if the continents were in their present positions at the time of glaciation.

Evidence from structure and rock types

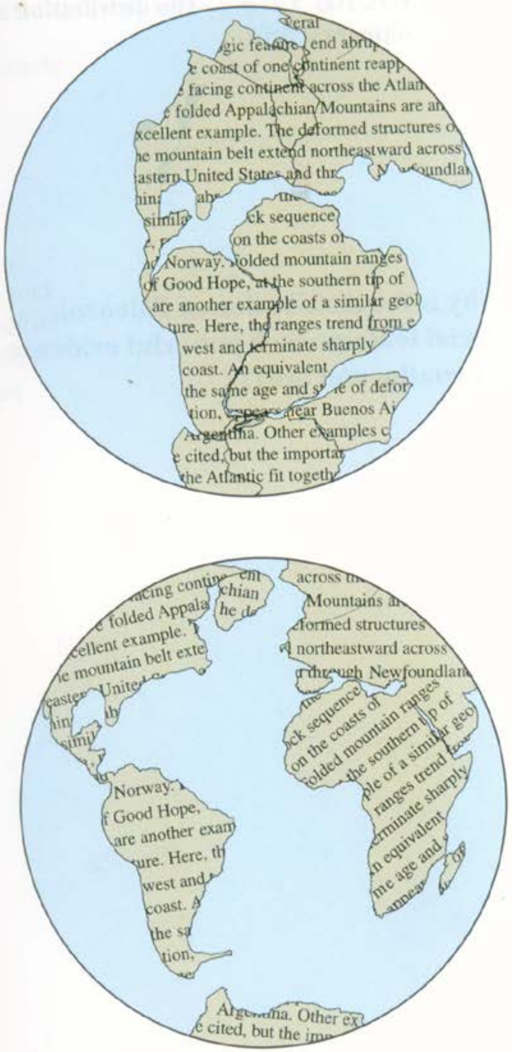
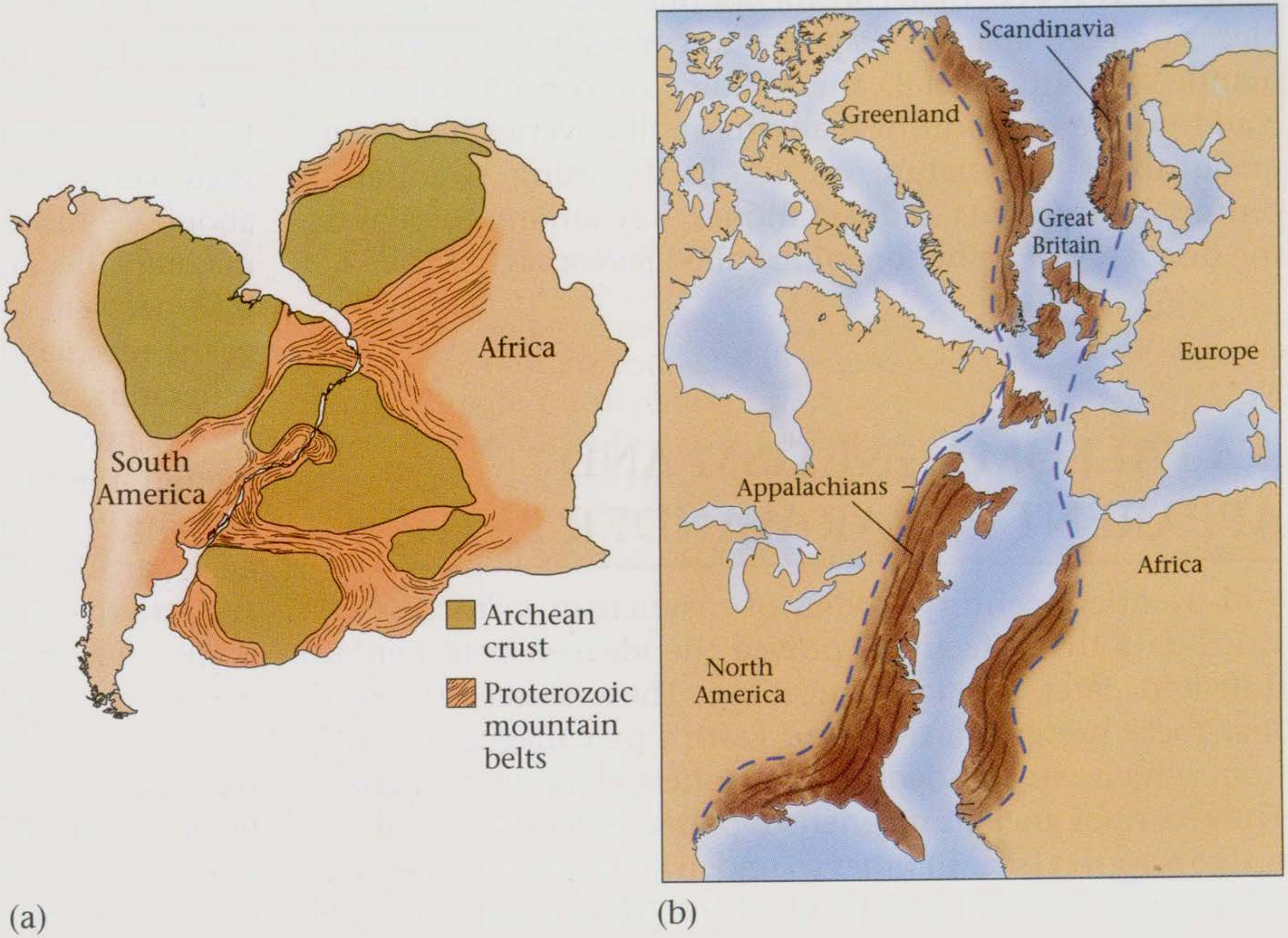
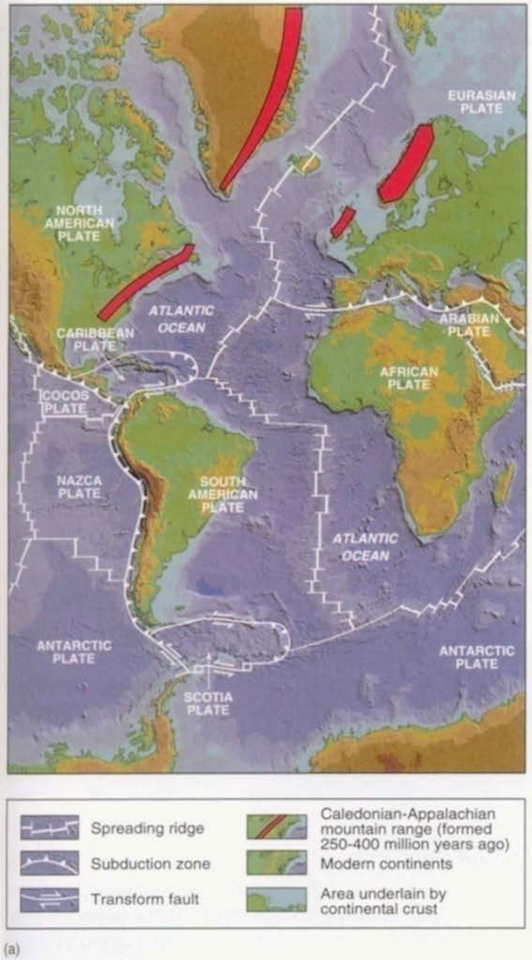


FIGURE 17.4 **When reconstructed, the continents fit together** like a jigsaw puzzle or pieces of a torn newspaper. Not only do the outlines of the torn pieces fit together, but the printing on them (analogous to the ages and structural features of the continents) also matches across their edges.

FIGURE 3.6 (a) Distinctive areas of rock units on South America link with those on Africa, as if they were once connected and later broke apart. (b) If the continents are returned to their positions in Pangaea by closing the Atlantic, mountain belts of the Appalachians lie adjacent to similar-age mountain belts in Greenland, Great Britain, Scandinavia, and Africa.





■ **FIGURE 7.11** The opening of the Atlantic Ocean basin. (a) The modern Atlantic Ocean and surrounding continents. (b) A continental reconstruction of 130 million years ago. Compare with the configuration of Pangaea at 255 million years ago shown in Figure 7.10. Africa and South America have moved east relative to North America. The South Atlantic has begun to open although opening of the Central Atlantic is well under way, and the Paraná and Etendeka flood basalts have already erupted. The North Atlantic has not yet started to open. (c) The Atlantic as it looked 80 million years ago. The ocean basin separating Africa, South America, and North America has developed and widened. The rift between northern Europe and North America (Greenland) has yet to develop. The position for the rifting of 60 million years ago is indicated by the future location of the North Atlantic flood basalt province. (d) By 36 million years ago, the North Atlantic has opened and separated the North Atlantic flood basalt province.

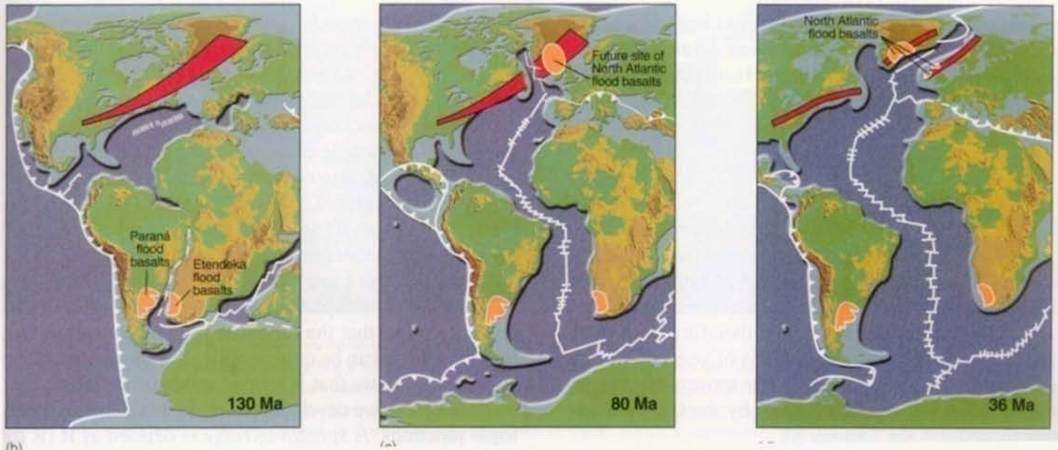


PLATE TECTONICS

The period between 1950 and 1960 was very important in bringing the revolution in earthscience field

The study of the *geology of ocean floor* and the *paleomagnetic studies* of rocks from continets and oceans during the above decade revived the theory of continental drift.

Two studies in paleomagnetism were very important:

1. **Apparent Polar Wandering**
2. **Patterns of Magnetic Reversals on the Sea Floor**

H.H. Hess

The man who gave the theory of sea floor spreading

SEA-FLOOR SPREADING

In 1960 H.H. Hess from Princeton University (USA) proposed a theory of *sea-floor spreading* which took into account the new data from echo soundings and also suggested a possible mechanism for continental drift.

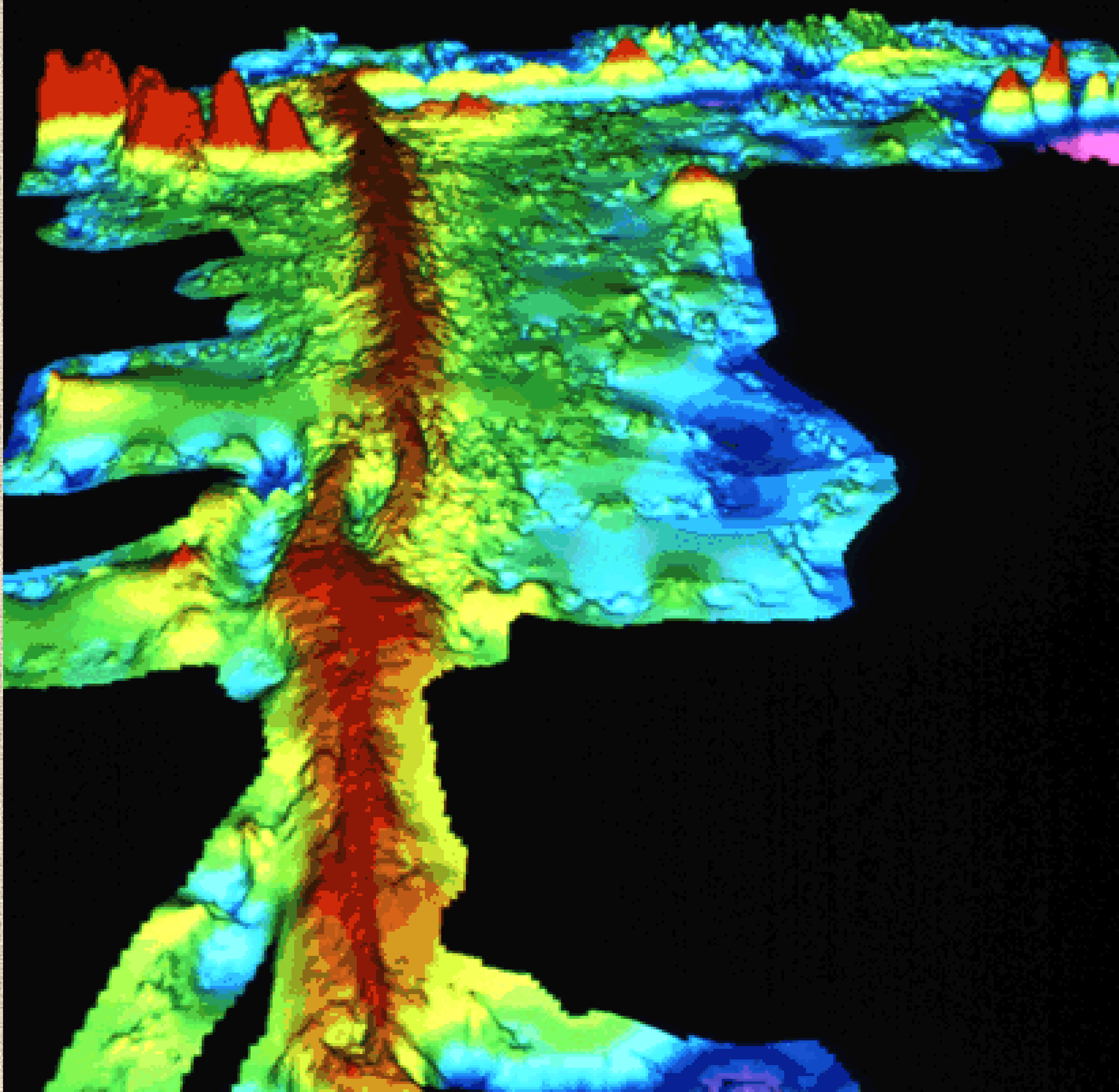
Rock magnetism: The study of rock magnetism developed during the 1950s with the perfection of new, highly sensitive magnetometers.

In 1963, Fred Vine **(graduate student) and** D.H. Matthews saw a way to test the idea of Sea-floor spreading put forth by Hess. If sea-floor spreading has occurred, they suggested, it would be recorded in the magnetism of the basalts in the oceanic crust. Investigations proved this theory.

Evidence from the ocean floor


GREENLAND
HUDSON BAY
ICELAND
NORTH AMERICA
ST. LAWRENCE
MONTREAL
ISLAND OF NEWFOUNDLAND
CHICAGO
BOSTON
NEW YORK
WASHINGTON
FLEMISH CAP
LAURENTIAN CONE
SOHM ABYSSAL PLAIN
NEW ORLEANS
BERMUDA
HATTERAS ABYSSAL PLAIN
MIAMI
BAHAMA ISLANDS
MID-ATLANTIC RIDGE
AZORES
MADEIRA ISLANDS
CANARY ISLANDS
CARIBBEAN SEA
CARACAS
BOGOTA
CAPE VERDE ISLANDS
DEMERARA ABYSSAL PLAIN
AMAZON CONE
GAMBIA ABYSSAL PLAIN
AFRICA
DAKAR
SOUTH AMERICA
AMAZON

East Pacific rise



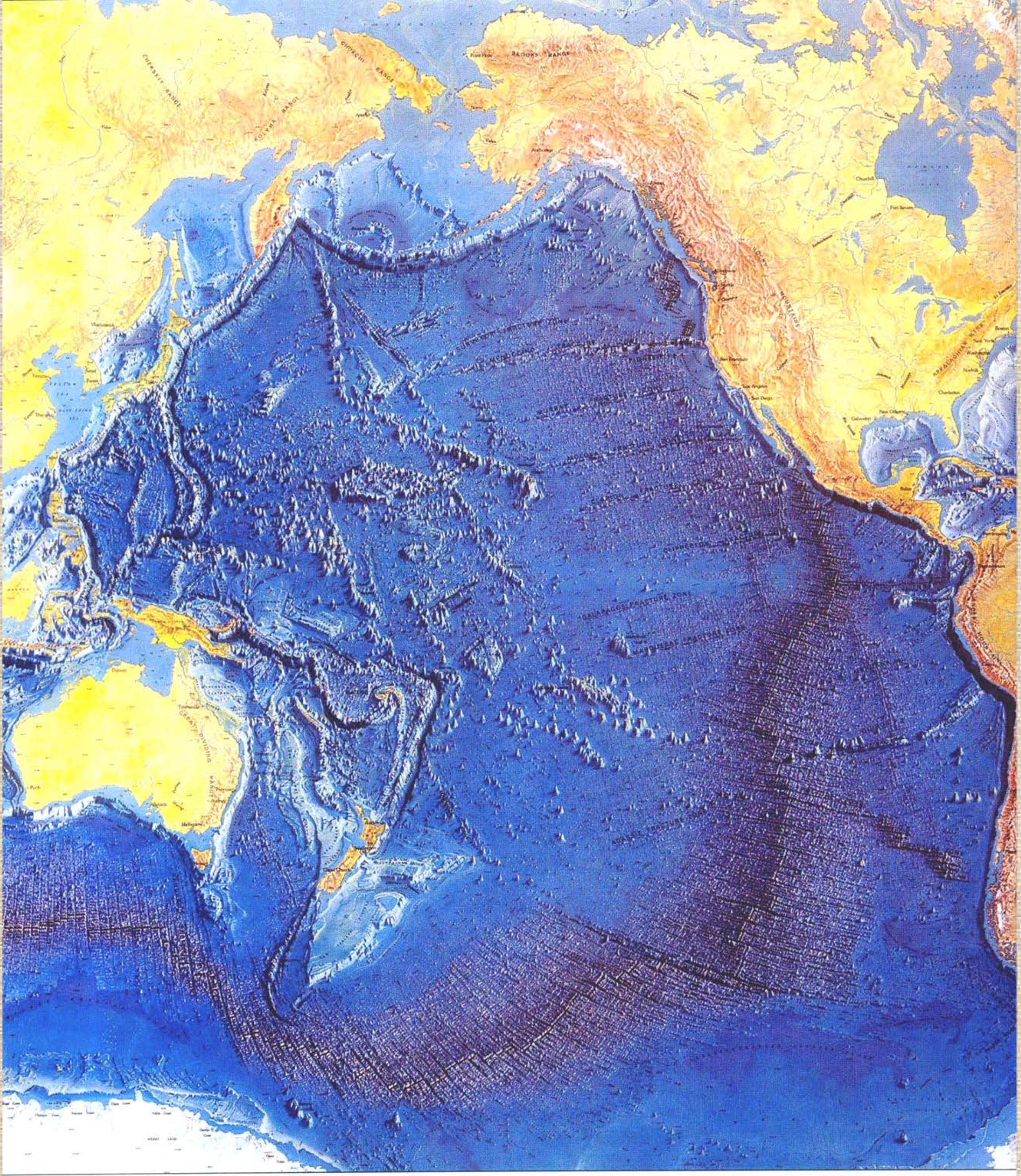
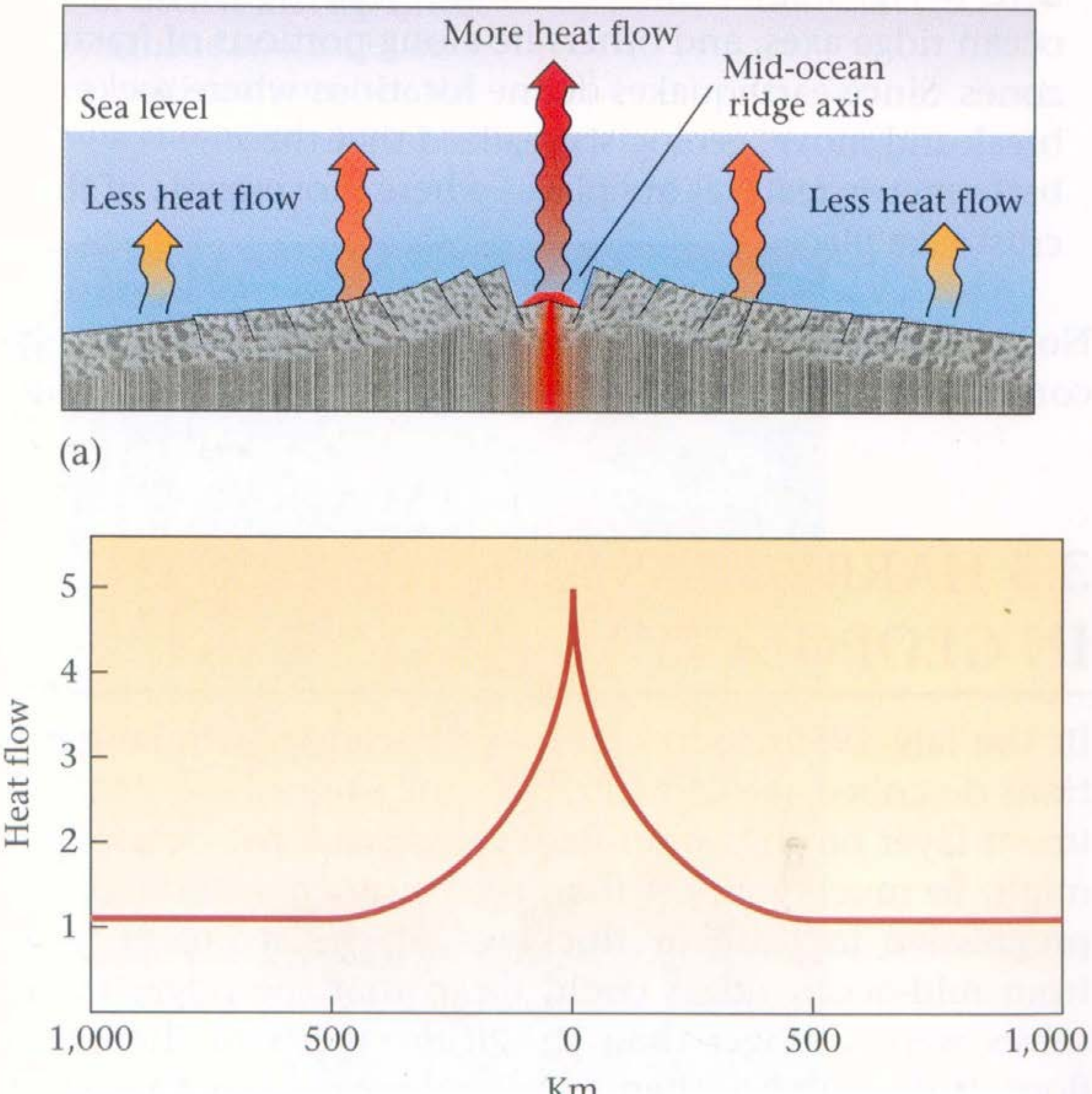
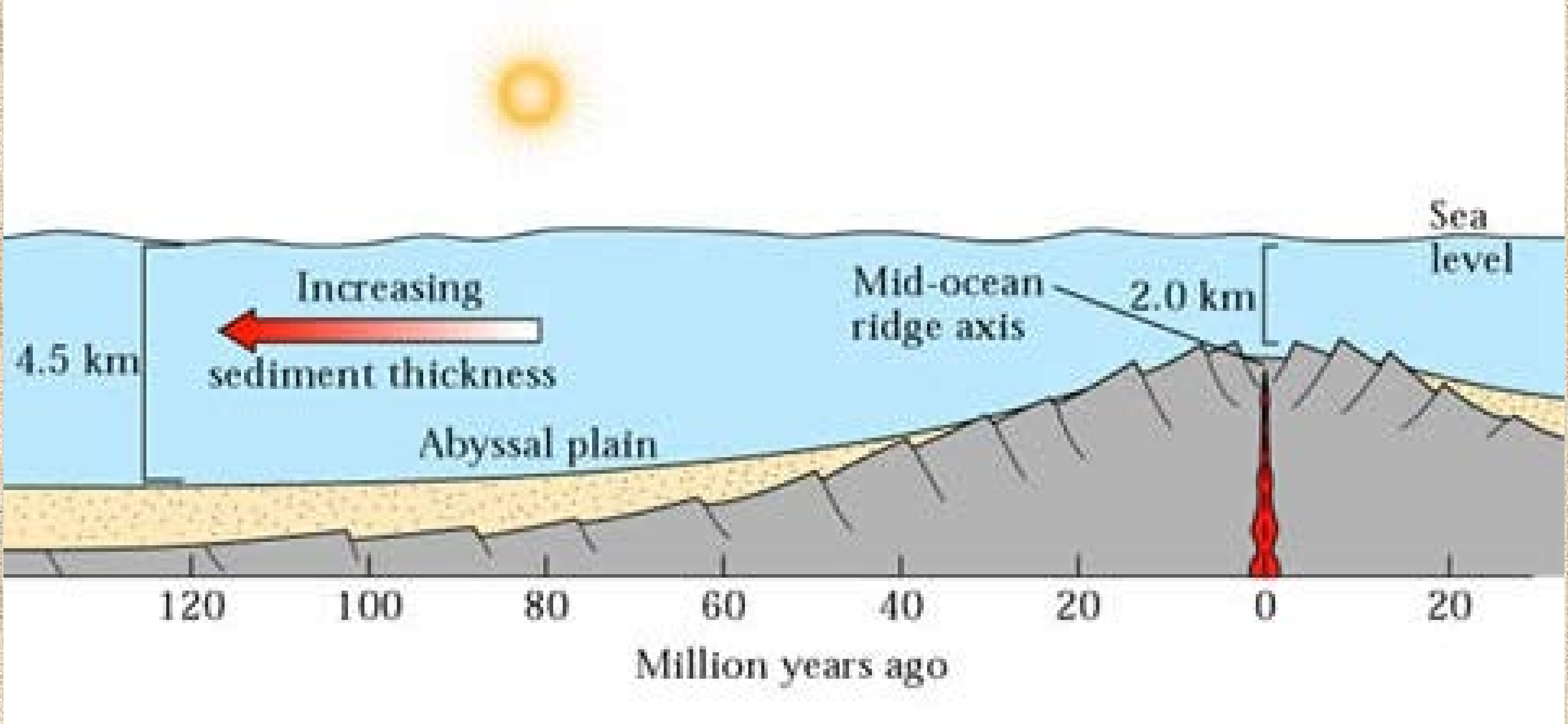

BROOKS RANGE
Anchorage
Churchill
Fort Severn
ROCKY MOUNTAINS
San Francisco
Los Angeles
San Diego
Galveston
New Orleans
Charleston
Norfolk
Washington
New York
Boston
APPALACHIAN MTNS
MENDOCINO
MURRAY
MOLOKAI
GALAPAGOS FRACTURE ZONE
MARQUESAS FRACTURE ZONE
FRACTURE ZONE
GREAT DIVIDING RANGE
Perth
Melbourne
Darwin

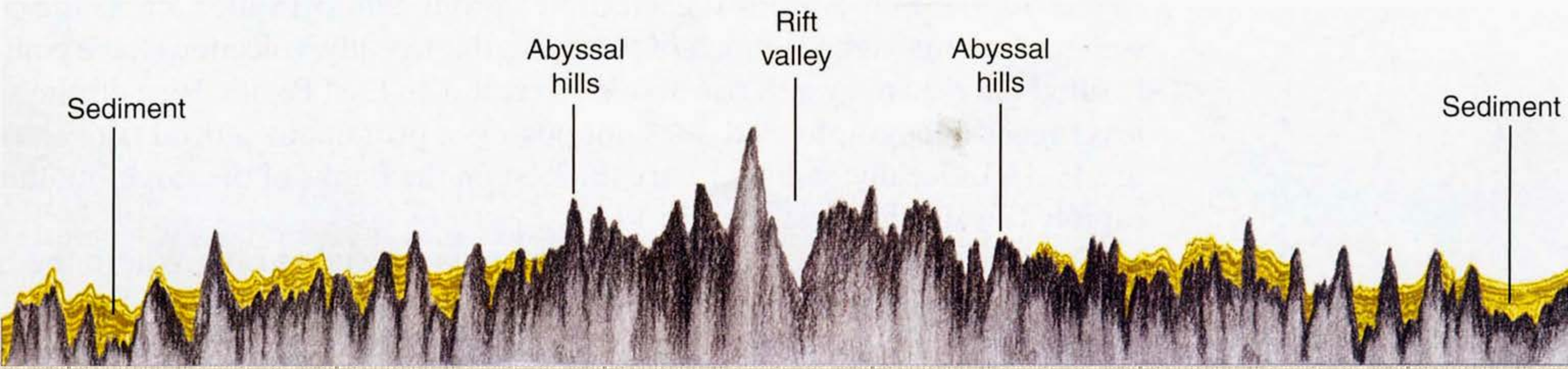
FIGURE 3.21 (a) In a mid-ocean ridge, heat from the mantle flows up through the crust; heat flow decreases away from the ridge axis. (b) The graph shows heat flow as a function of distance from the ridge axis. Heat flow is measured in heat-flow units, or HFU (1 HFU = 10^{-6} calories/cm/s).




Sea level
Mid-ocean ridge axis
2.0 km
Increasing sediment thickness
4.5 km
Abyssal plain
120
100
80
60
40
20
0
20
Million years ago

Evidence from sediments on the ocean floor

Glomar Challenger started drilling on the ocean bottom. Youngest sediments rest on the basalt of the ocean floor near the oceanic ridge, away from the ridge, the sediments that directly lie above the basalt becomes progressively older.


Rift valley
Abyssal hills
Abyssal hills
Sediment
Sediment

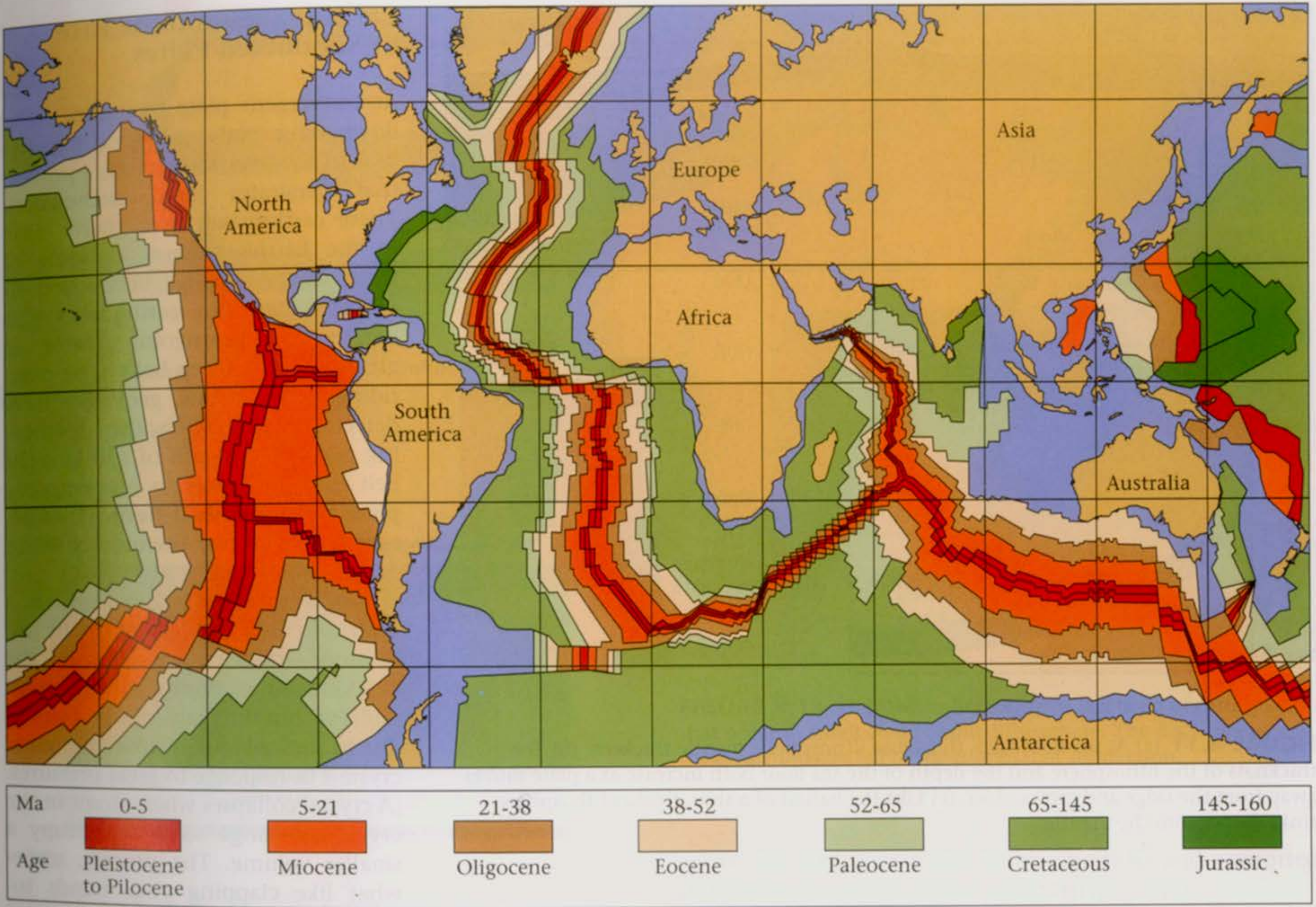


FIGURE 4.10 This map of the world shows the age of the sea floor. Note how the sea floor grows older with increasing distance from the ridge axis. (Ma = million years ago.)

Trenches

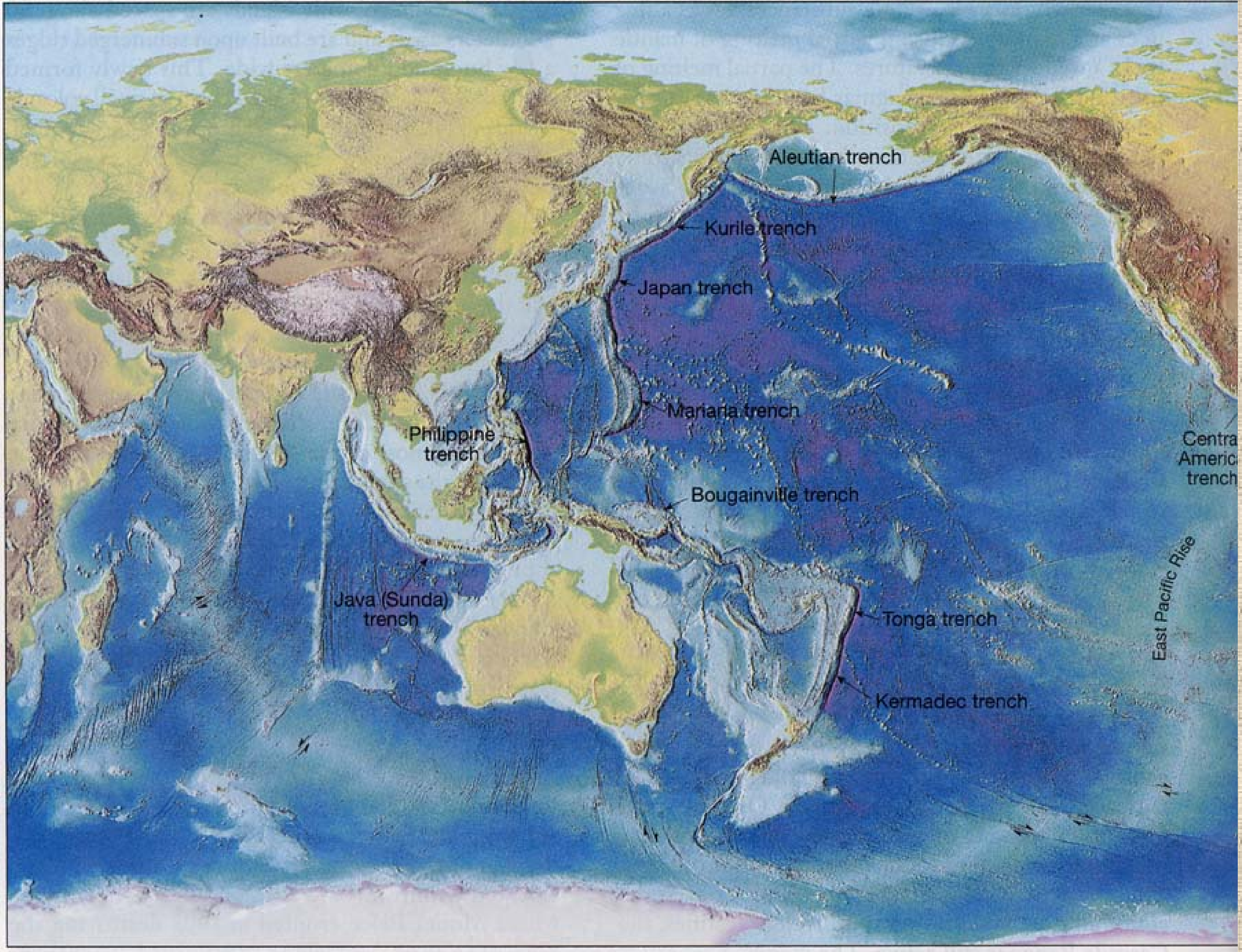
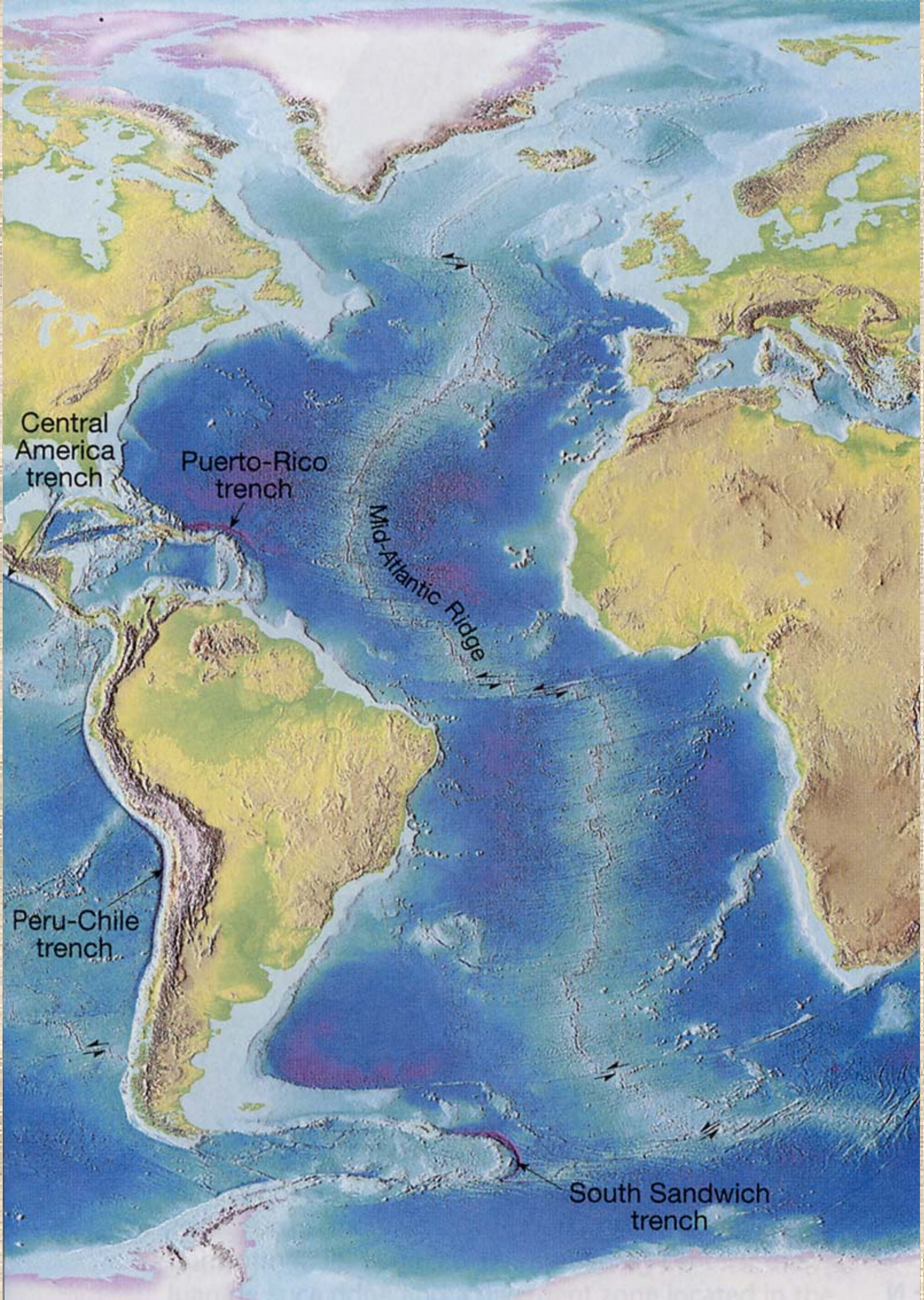


Figure 19.23 Distribution of the world's oceanic trenches, ridge system, fracture zones, and transform faults. Where transform faults offset ridge segments, they permit the ridge to change direction (curve) as can be seen in the Atlantic Ocean.

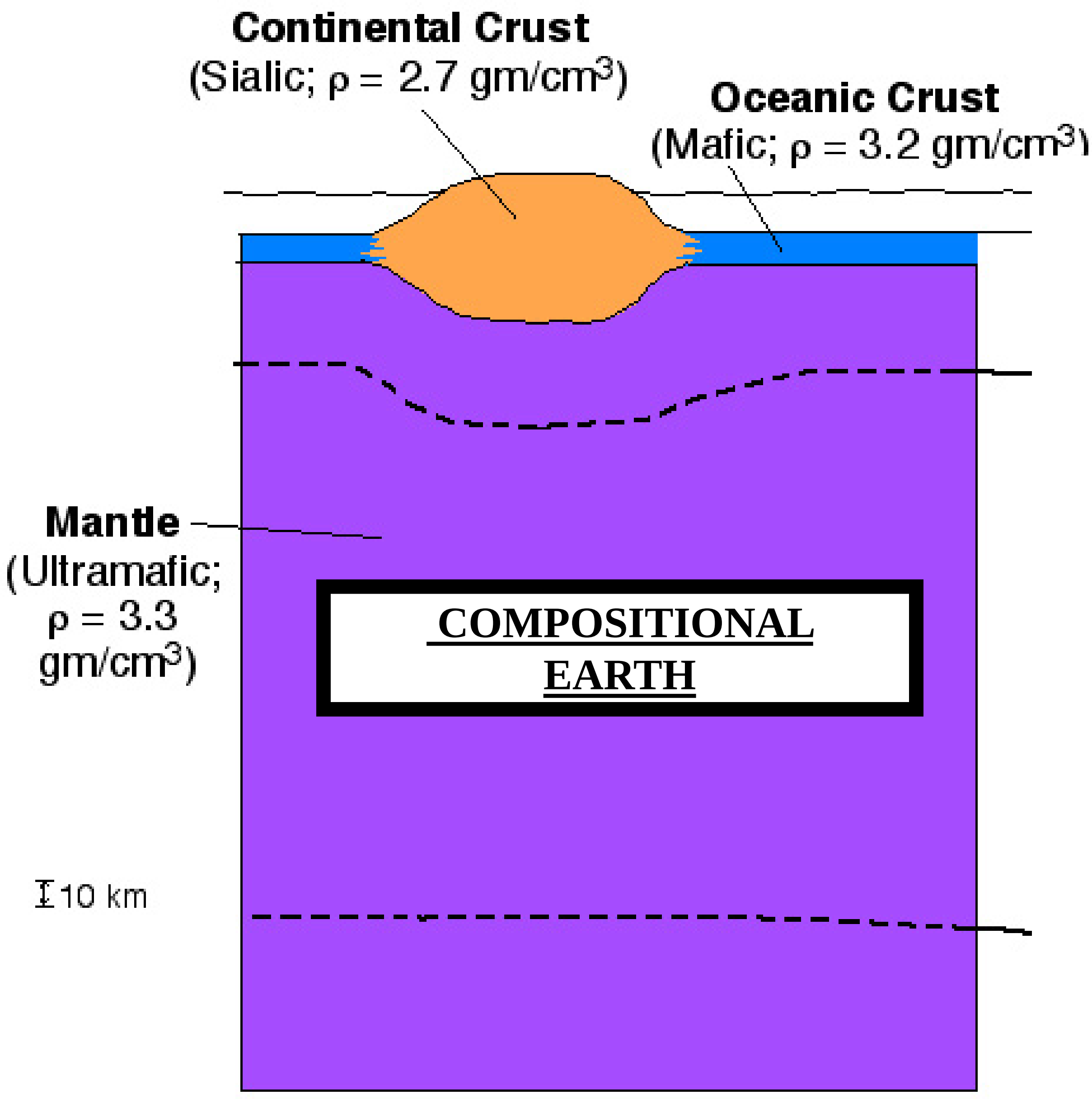

Central America trench
Puerto-Rico trench
Mid-Atlantic Ridge
Peru-Chile trench
South Sandwich trench

Lithosphere-Asthenosphere Interaction

When the concept of plate tectonics was developing in the late 1960's and early 1970's, the focus on the interior of the Earth became its behavior — not its composition.

We now draw contrast between the:

- compositional Earth, and
- the behavioral or rheological Earth.

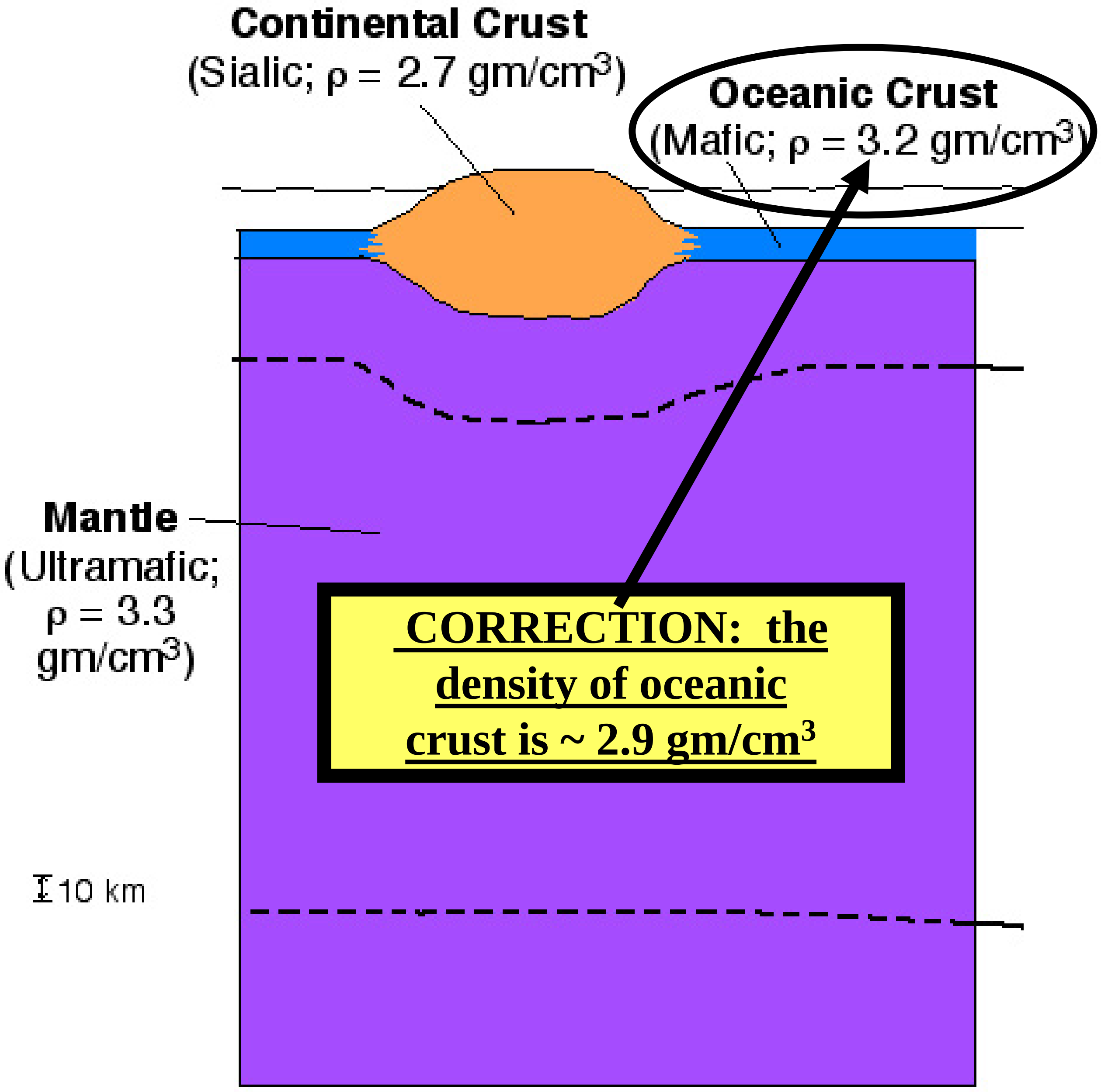


Distinctions made by composition

Silicic continental crust — rocks rich in oxygen (O), silicon (Si), and light metals (Al, Na, Ca, K)

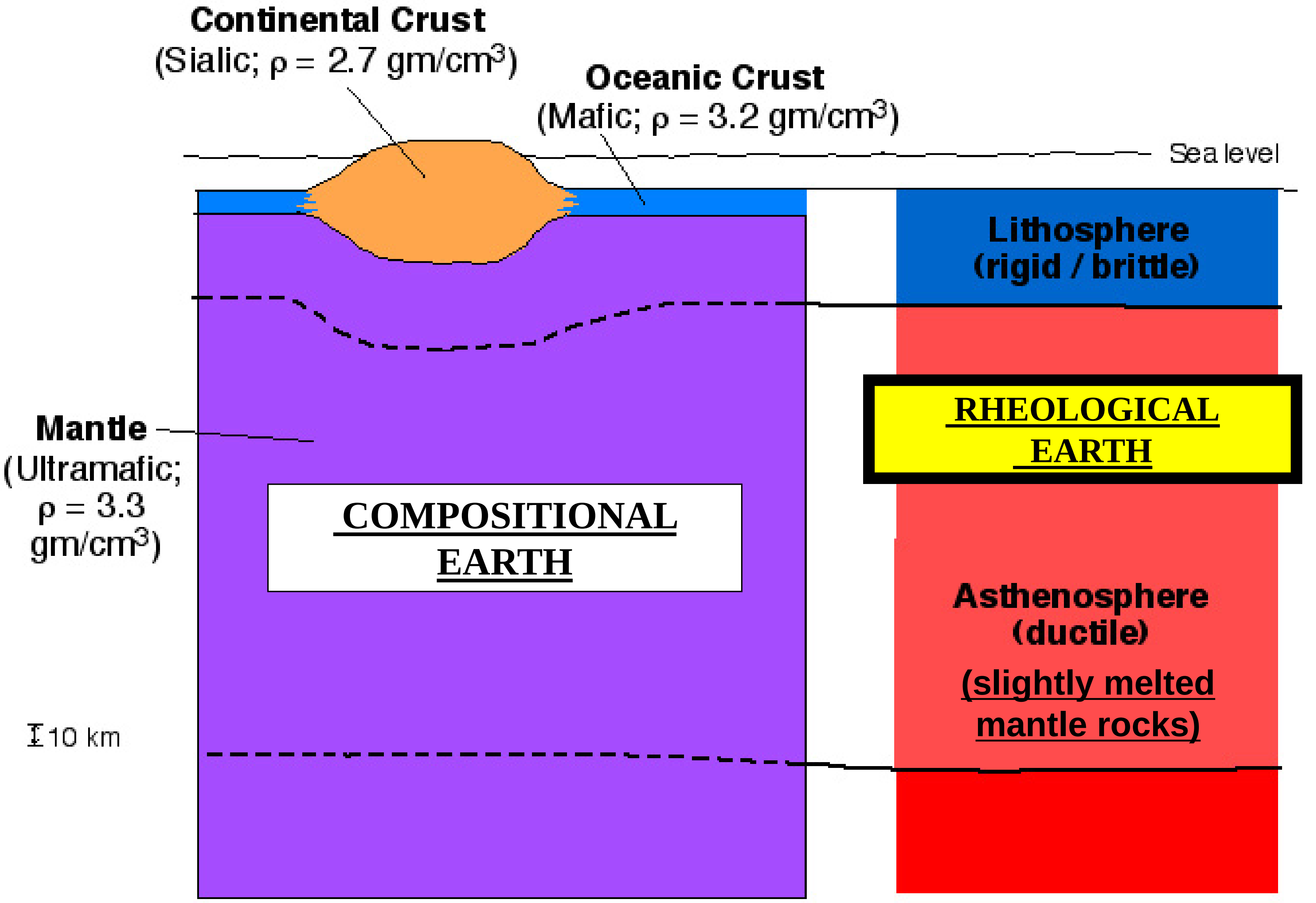
Mafic oceanic crust — silicate rocks rich in magnesium (Mg) and iron (Fe).

Ultramafic mantle rocks — silicate rocks very rich in magnesium and iron, with much lower amounts of oxygen, silicon, and light metals



CORRECTION: the density of oceanic crust is ~ 2.9 gm/cm^3

Distinctions made by composition



Continental Crust
(Sialic; $\rho = 2.7$ gm/cm^3)

Oceanic Crust
(Mafic; $\rho = 3.2$ gm/cm^3)

Sea level

Lithosphere
(rigid / brittle)

RHEOLOGICAL EARTH

Mantle
(Ultramafic;
$\rho = 3.3$
gm/cm^3)

COMPOSITIONAL EARTH

Asthenosphere
(ductile)

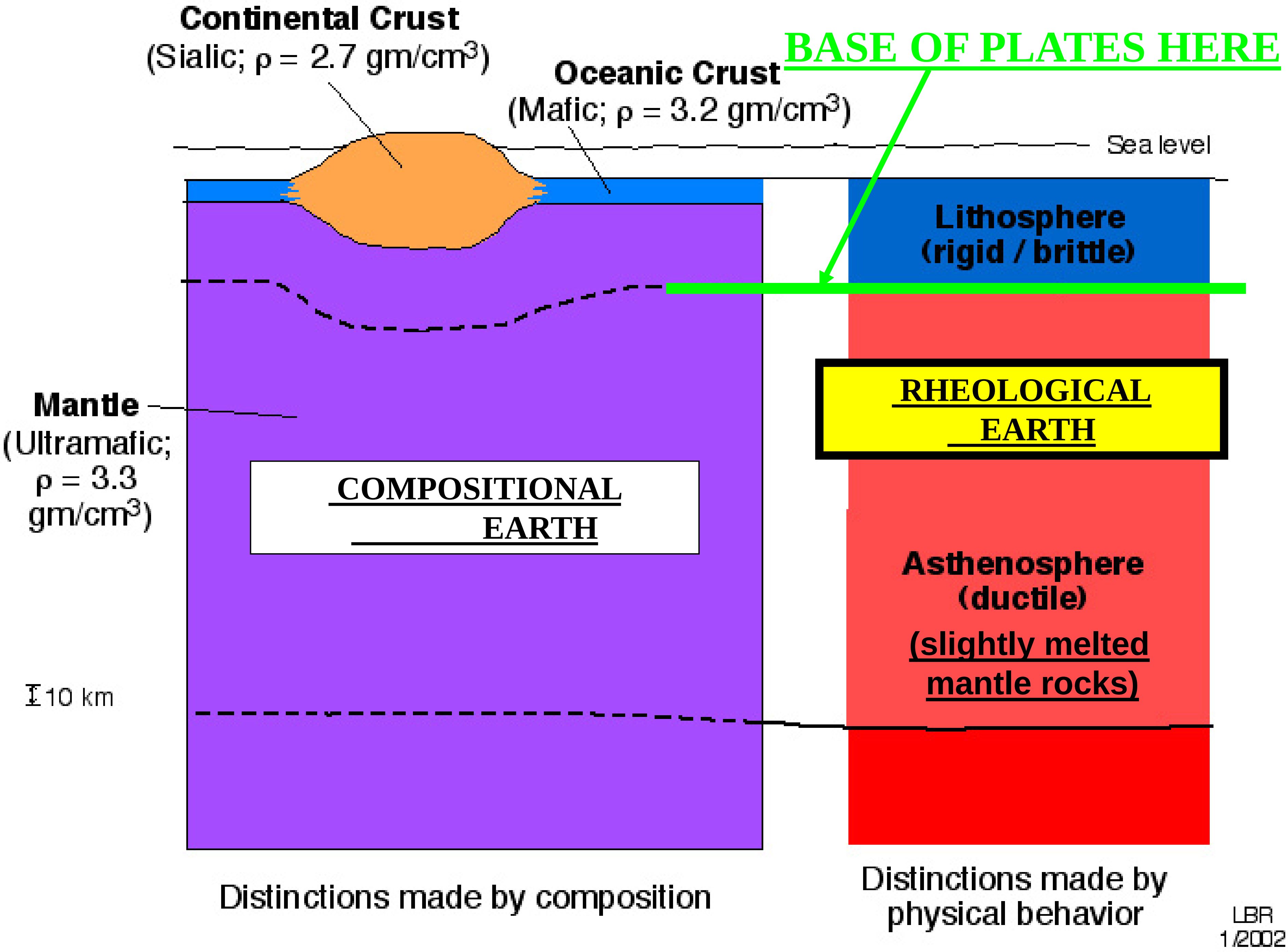
(slightly melted mantle rocks)

10 km

Distinctions made by composition

Distinctions made by physical behavior

LBR
1/2002



BASE OF PLATES HERE

RHEOLOGICAL EARTH

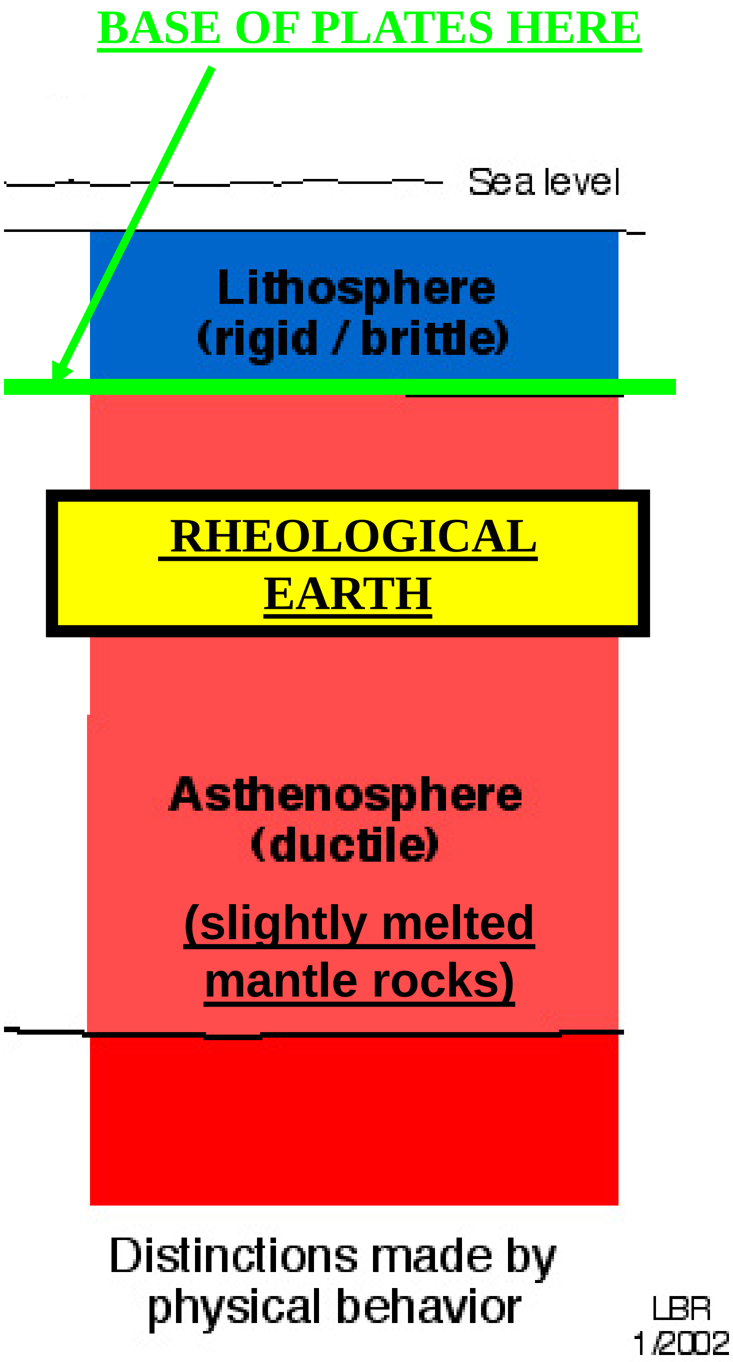
COMPOSITIONAL EARTH

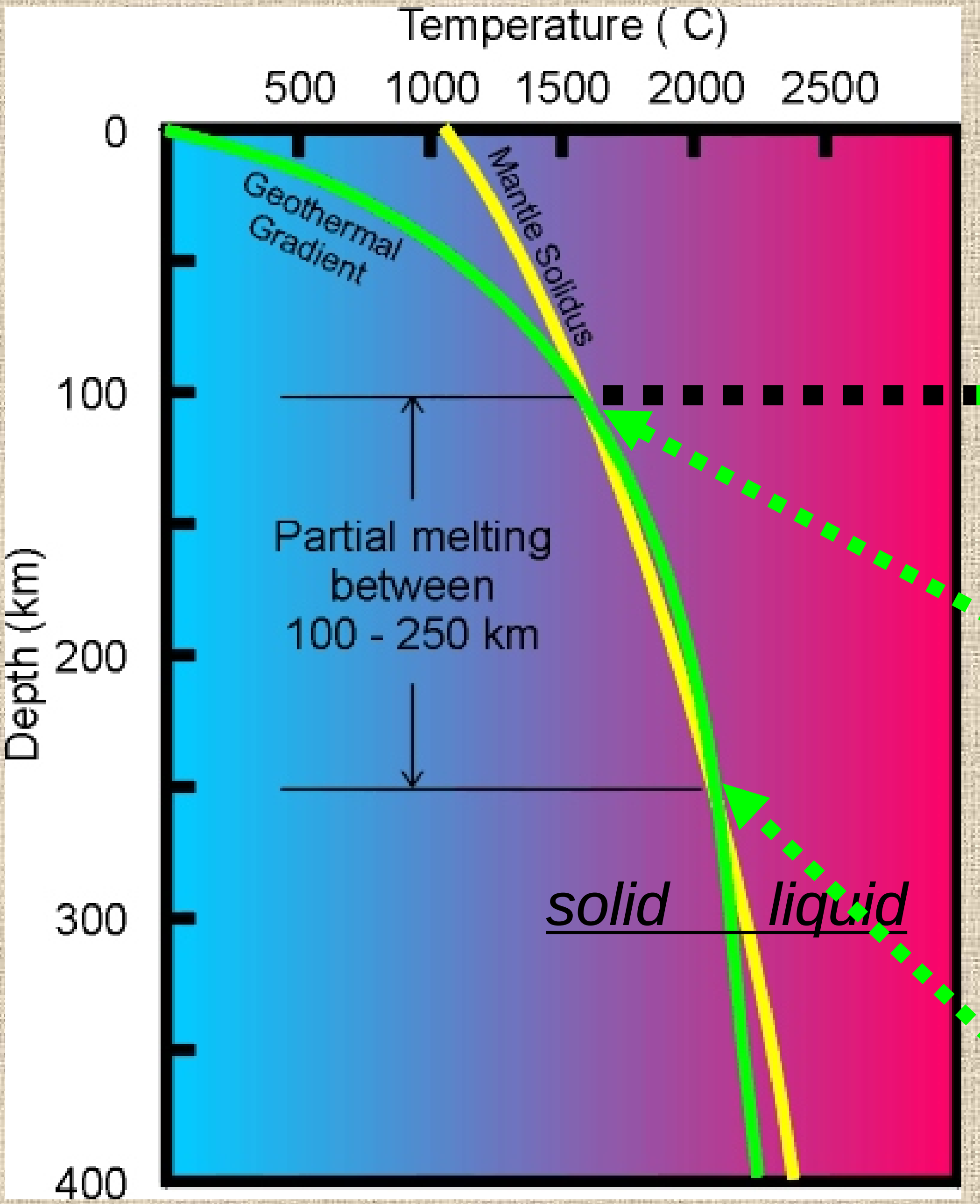
(slightly melted mantle rocks)

THE boundary between rigid mantle lithospheric rocks and underlying ductile rocks of the asthenosphere is temperature and pressure controlled.

Below this boundary the lithosphere has melted slightly (only a few % of molten rock).

This lowers the density of the asthenosphere and makes it behave in a more ductile manner in which mantle crystals change their shape and exhibit movement (flow).

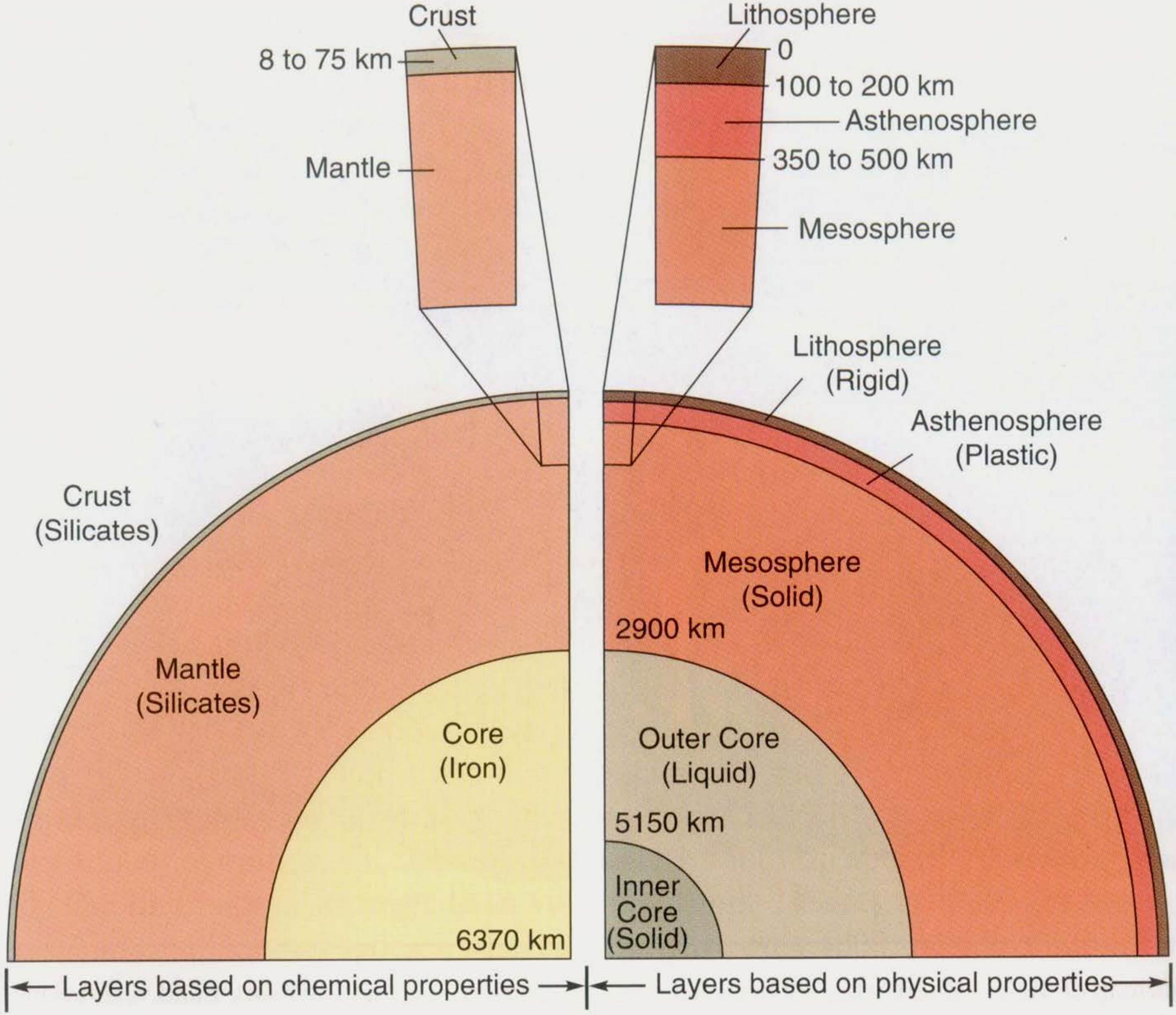




Lithosphere

Asthenosphere

Melting of mantle rocks requires an increase in volume (melts have lower density), but increasing pressure at depth generally prevents mantle melting from occurring — except in this depth range


Crust
8 to 75 km
Mantle
Lithosphere
0
100 to 200 km
Asthenosphere
350 to 500 km
Mesosphere
Lithosphere
(Rigid)
Asthenosphere
(Plastic)
Crust
(Silicates)
Mesosphere
(Solid)
2900 km
Mantle
(Silicates)
Core
(Iron)
Outer Core
(Liquid)
5150 km
Inner
Core
(Solid)
6370 km
Layers based on chemical properties
Layers based on physical properties

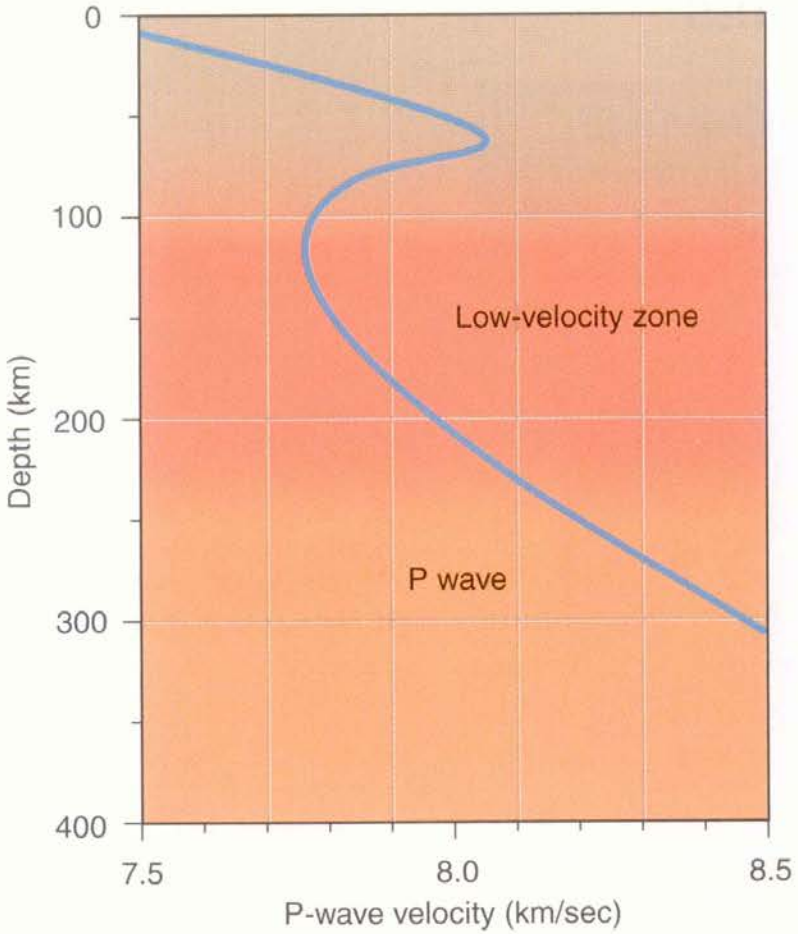


FIGURE 18.21 **The low velocity zone** is revealed by a drop in the velocities of both P waves (shown here) and S waves. This marks a zone of low strength in the upper mantle between about 100 and 250 km below the surface. The low-velocity zone is contained in the asthenosphere and marks part of the mantle that is very near its melting point and may be a zone of partial melting.

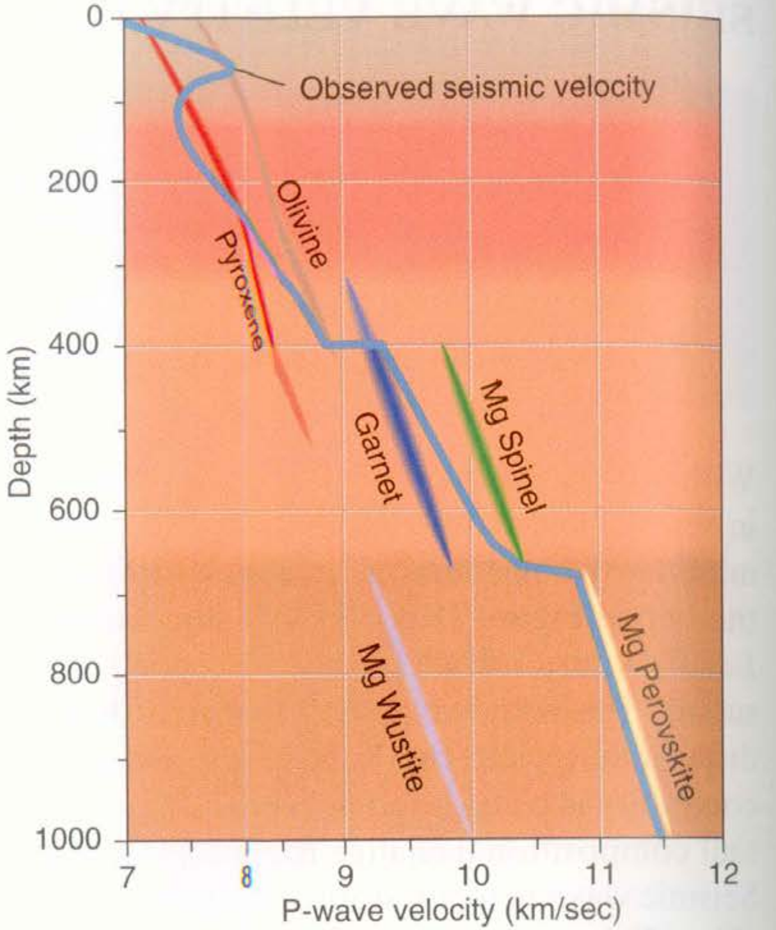


FIGURE 18.22 **Discontinuities** in seismic wave velocities may correspond to phase changes. The blue line shows how P wave velocities change with depth. The other lines show velocities for various minerals. The uppermost mantle is dominated by olivine. Below 400 km a velocity increase implies olivine is replaced by spinel. At greater depths, spinel is probably replaced by magnesium-perovskite. Each change increases the density of the mantle.

Inside The Earth

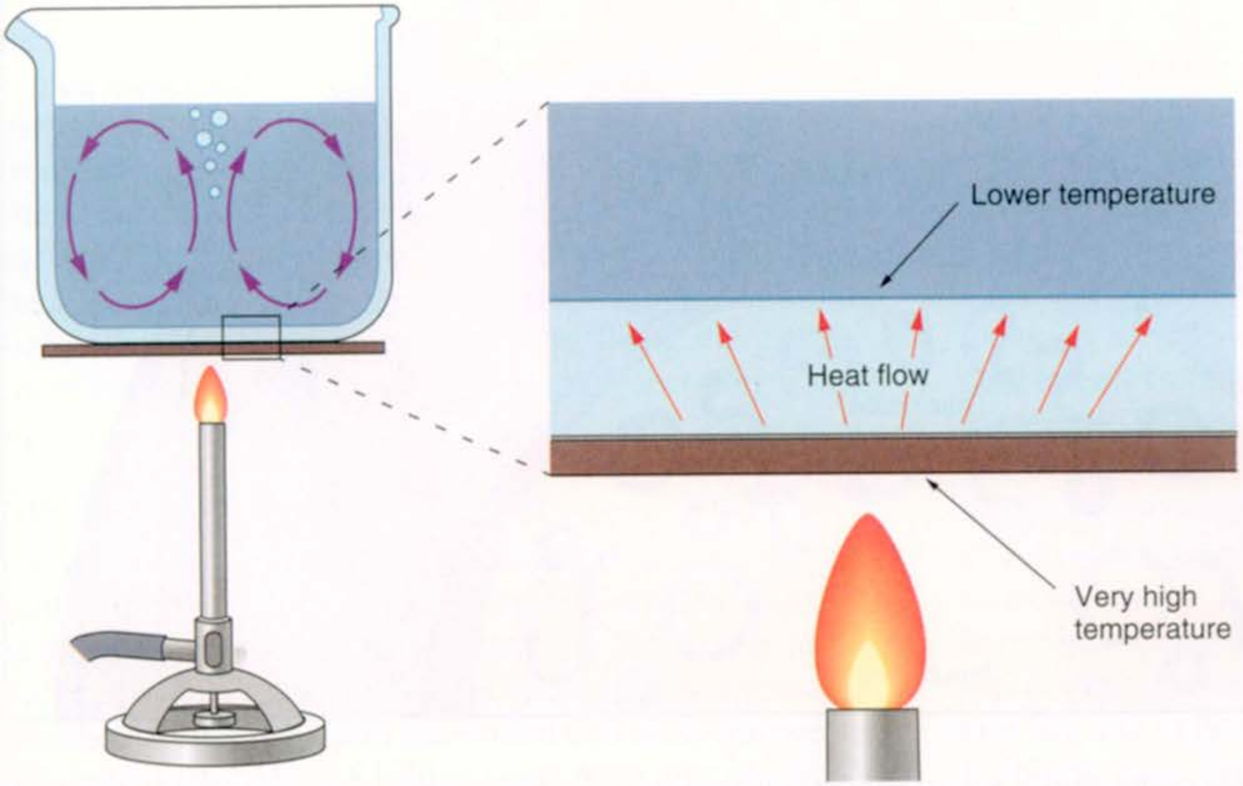
© Mexus Education

www.ikenstore.com

When the asthenosphere flows, the overlying lithosphere moves with it — like rafts on a river.

The patterns of flow produce a small number of “ rafts ” or plates that are moving with respect other — apart, together, or side-by-side past one another.

When the asthenosphere flows, the overlying lithosphere moves with it — like rafts on a river. The patterns of flow produce a small number of “rafts” or plates that are moving with respect other — apart, together, or side-by-side past one another.



(a) Convection

(b) Conduction

■ **FIGURE 2.25** (a) A familiar example of convection, in which soup is heated in a pot. Hot soup at the bottom of the pot above the flame expands and rises because of its buoyancy. It cools upon reaching the surface and sinks, completing the cycle. Within Earth, the heat is mainly supplied by radioactivity. (b) When the material through which heat flows is strong, like the base of a pot, the heat is transported by conduction. Conduction is the mechanism by which heat is transported across the lithosphere—the strong outer shell of Earth.

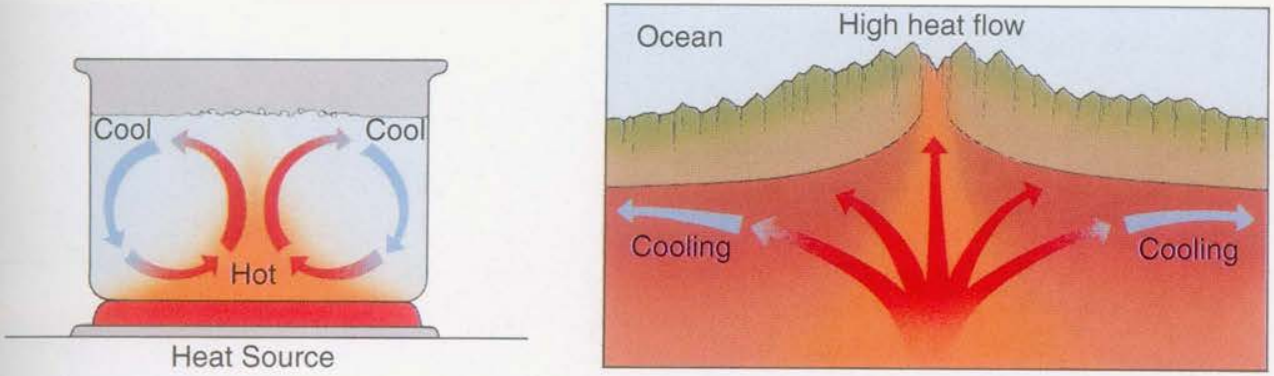


FIGURE 2.10 Convection in the mantle can be compared to convection in a pot of soup. Heat from below causes the material to expand and thus become less dense. The warm material rises by convection and spreads laterally. It then cools, and thus becomes denser, and sinks. It is reheated as it descends, and the cycle is repeated.

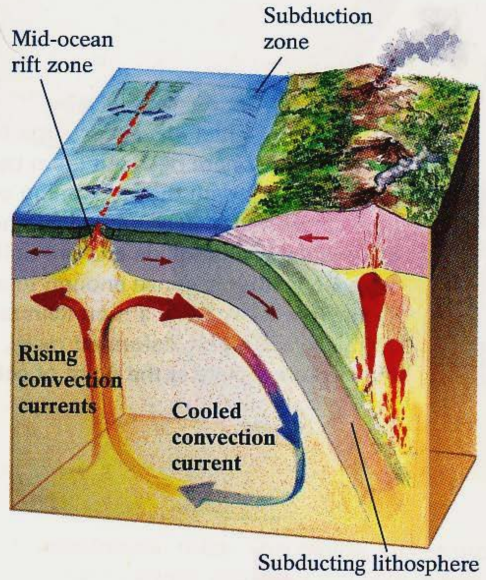


Figure 1-14 Convection cells and plate motion. Heat within the Earth's mantle results in rising ("convecting") currents of warm mantle material, which drag the lighter lithospheric plates along with them as they flow beneath the Earth's surface. As rising mantle material spreads beneath the lithospheric plates, it cools, becomes denser, and sinks back to the deeper interior, where it is reheated to rise again. Such a cycle, known as a convection cell, may be the principal driving mechanism of plate tectonics.

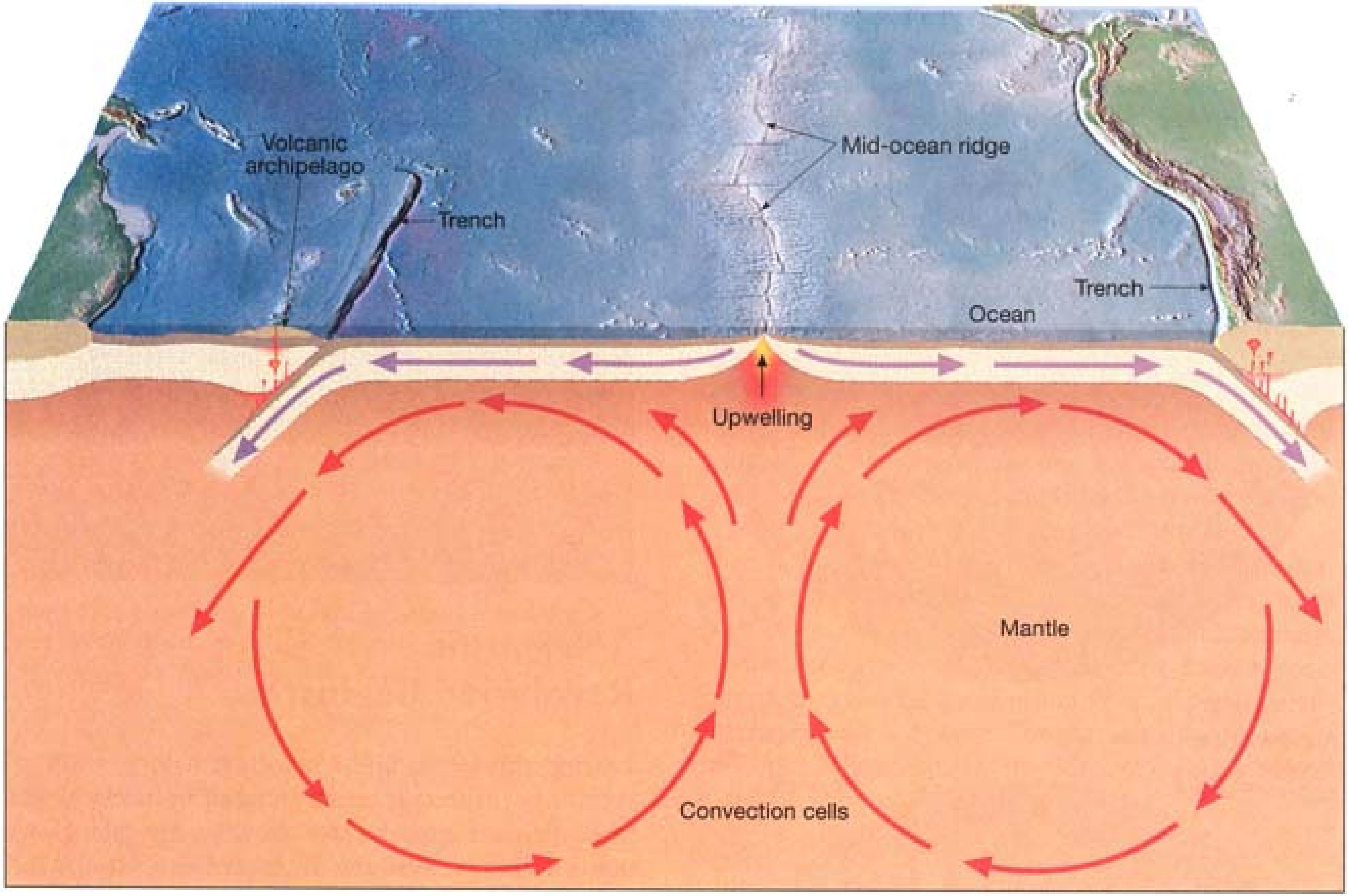


Figure 19.12 Seafloor spreading. Harry Hess proposed that upwelling of mantle material along the mid-ocean ridge system created new seafloor. The convective motion of mantle material carries the seafloor in a conveyor-belt fashion to the deep-ocean trenches, where the seafloor descends into the mantle.

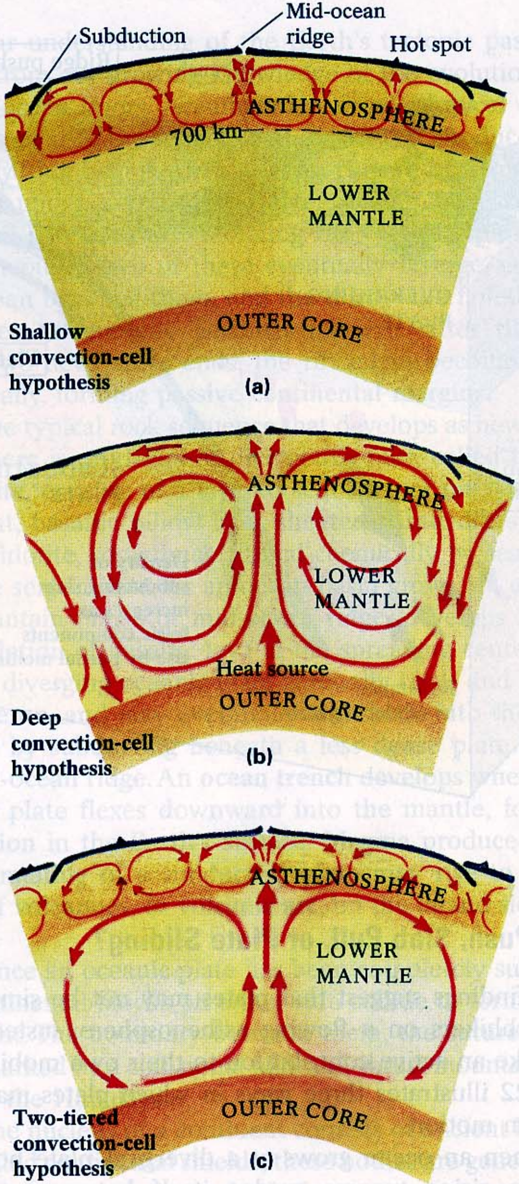


Figure 11-21 Hypotheses proposed to explain the configuration of the Earth's convection cells. **(a)** The cells may be shallow, confined to the asthenosphere. **(b)** The cells may extend through the entire mantle to the outer core. **(c)** Some hypotheses propose two sets of convection cells that meet at a depth of 670 kilometers (420 miles), the zone within the mantle where seismic waves are known to accelerate in response to changes in the chemistry and structure of mantle materials.

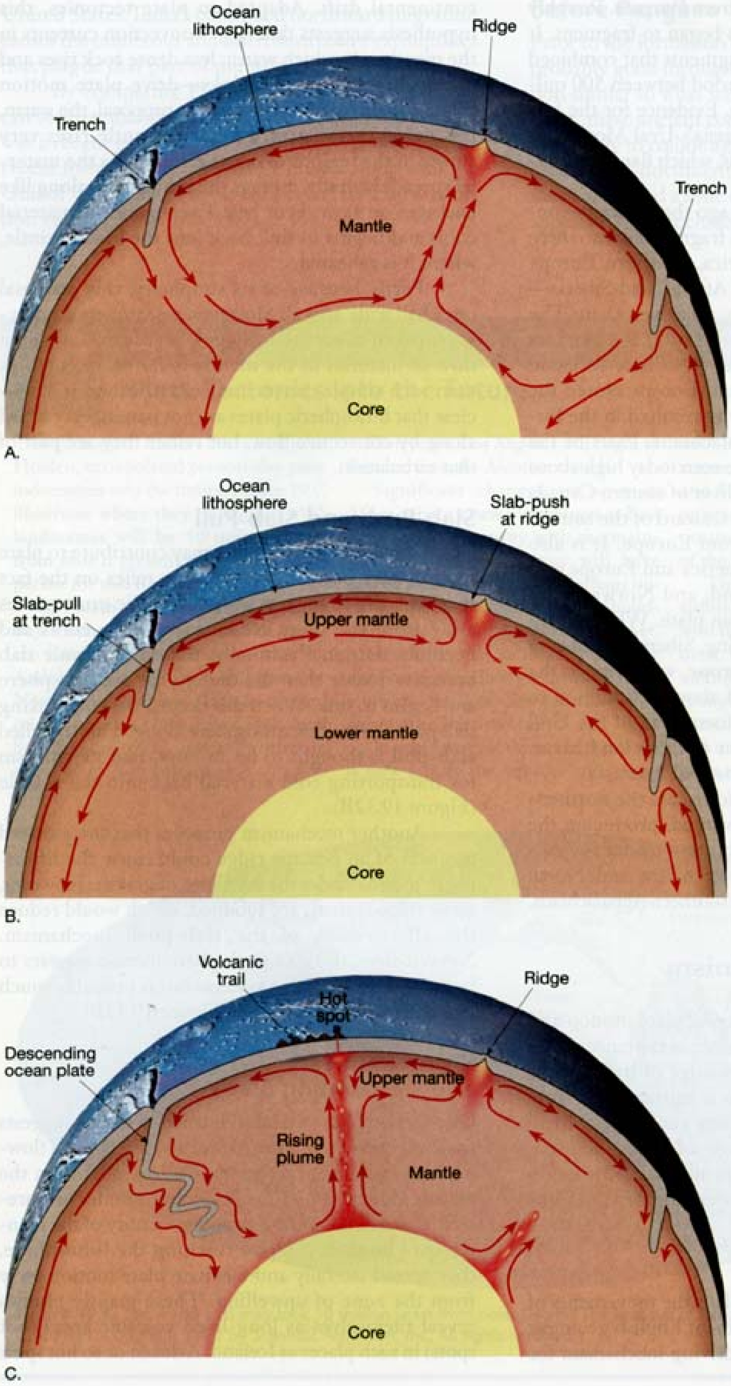


Figure 19.32 Proposed models of the driving force for plate tectonics. **A.** Large convection cells in the mantle may carry the lithosphere in a conveyor-belt fashion. **B.** Slab-pull results because the subducting slab is more dense than the underlying material. Slab-push is a form of gravity sliding caused by the elevated position of lithosphere at a ridge crest. **C.** The hot plume model suggests that all upward convection is confined to a few narrow plumes, while the downward limbs of these convection cells are the cold, dense subducting oceanic plates.

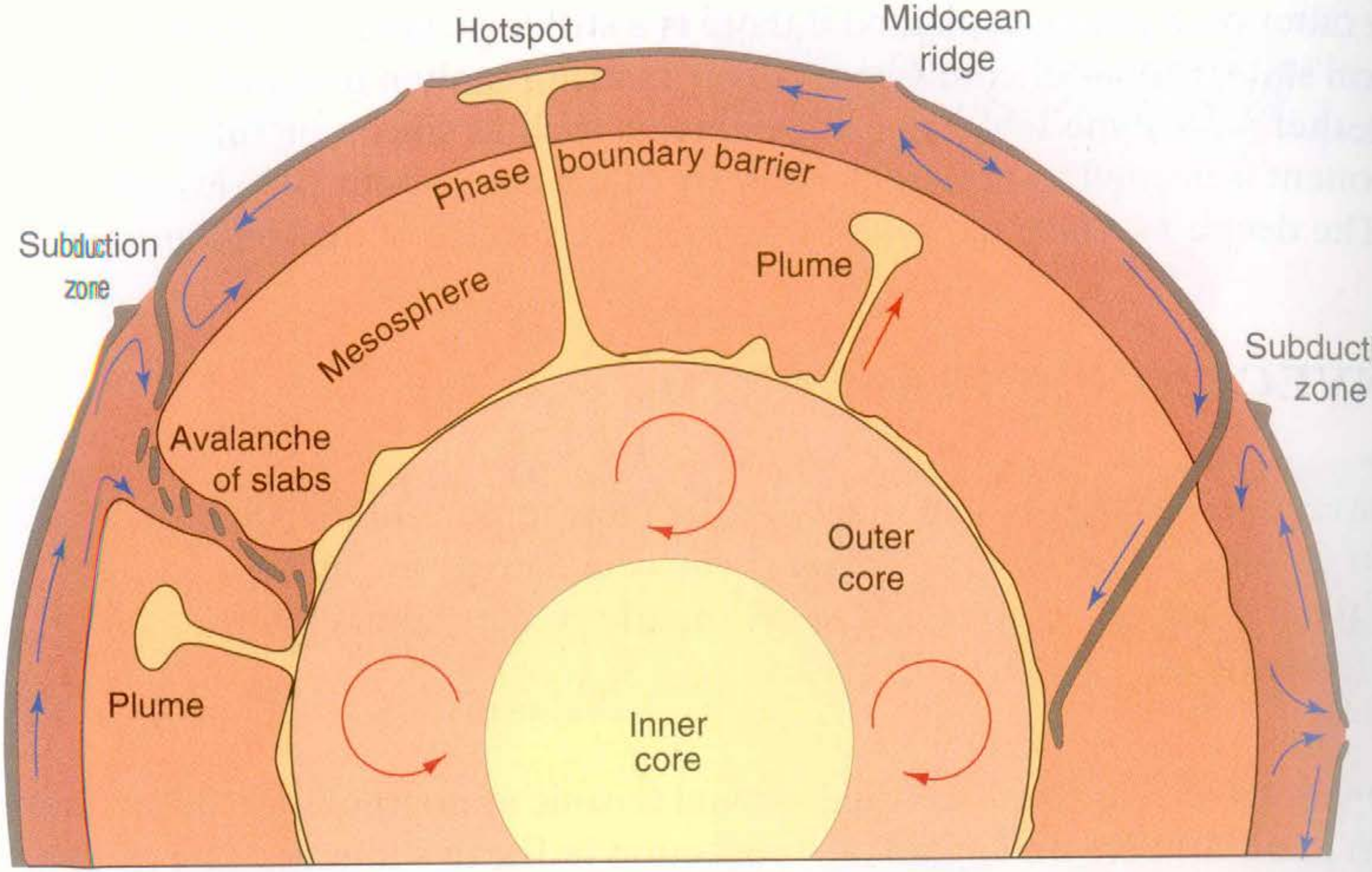


FIGURE 18.23 **Earth's thermal structure and convection** can be modeled using computers to complement the observations of seismic tomography. In one model, subducted slabs pass without pausing through the phase boundary at 660 km. In another model, the phase boundary is a temporary barrier that is broken down when enough subducted material accumulates and then flushes rapidly through the lower mantle. The lower mantle may convect by generating thin plumes that rise off of the core-mantle boundary. Some of the plumes may be triggered by the sinking of the dense overlying mantle.

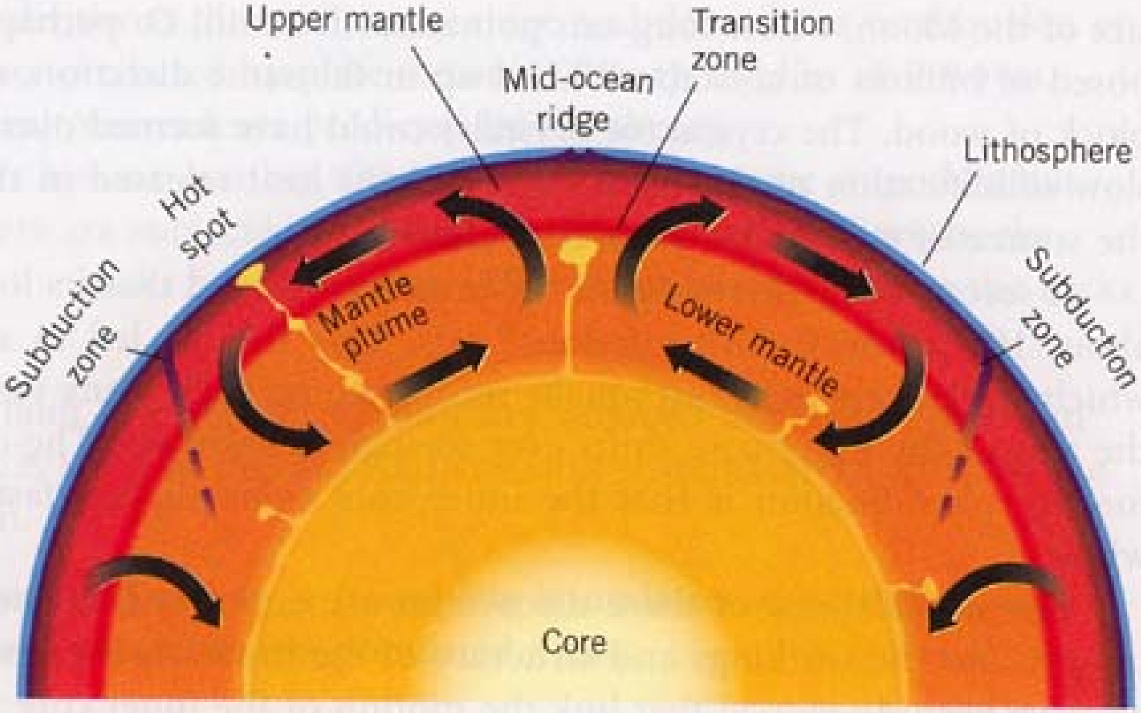


Figure 3.26 Mantle plumes play a key role in some models of whole-mantle convection. The plumes may rise to the surface as isolated hot spots or they may combine to initiate the crustal rifting that results in the formation of lithospheric plates.

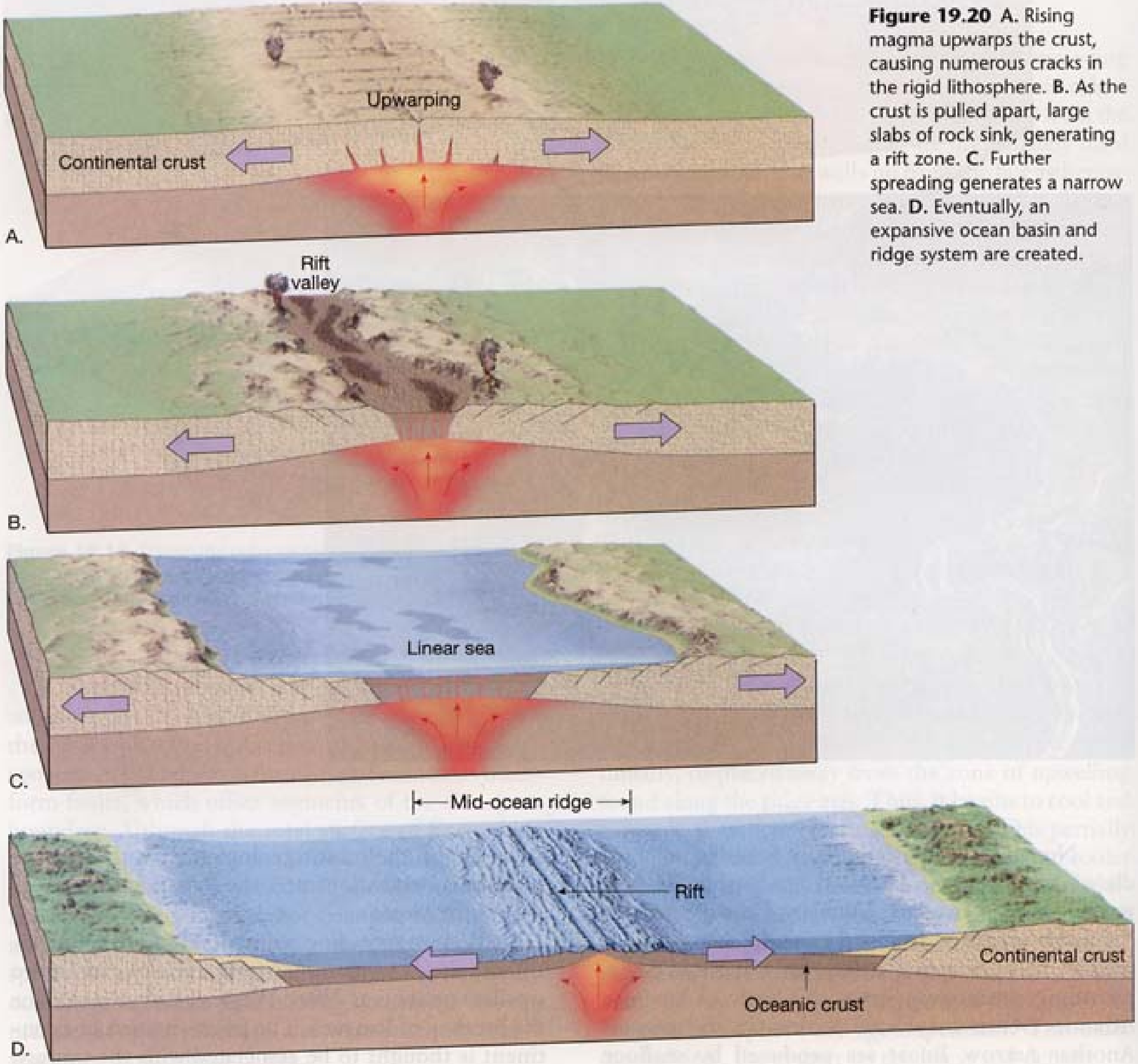


Figure 19.20 **A.** Rising magma upwarps the crust, causing numerous cracks in the rigid lithosphere. **B.** As the crust is pulled apart, large slabs of rock sink, generating a rift zone. **C.** Further spreading generates a narrow sea. **D.** Eventually, an expansive ocean basin and ridge system are created.

Figure 2.9 Spreading Center Splitting a Continent The African Rift Valley, which extends from the Red Sea in the north to Malawi in the south, is a gigantic rent in the Earth's surface marking the place where a spreading center is splitting Africa into two pieces. This photo is of a portion of the Rift Valley in central Kenya. To the east (right-hand side) is a plateau bounded by a jagged fracture. The two hills (rear and left-hand edge) are volcanoes.

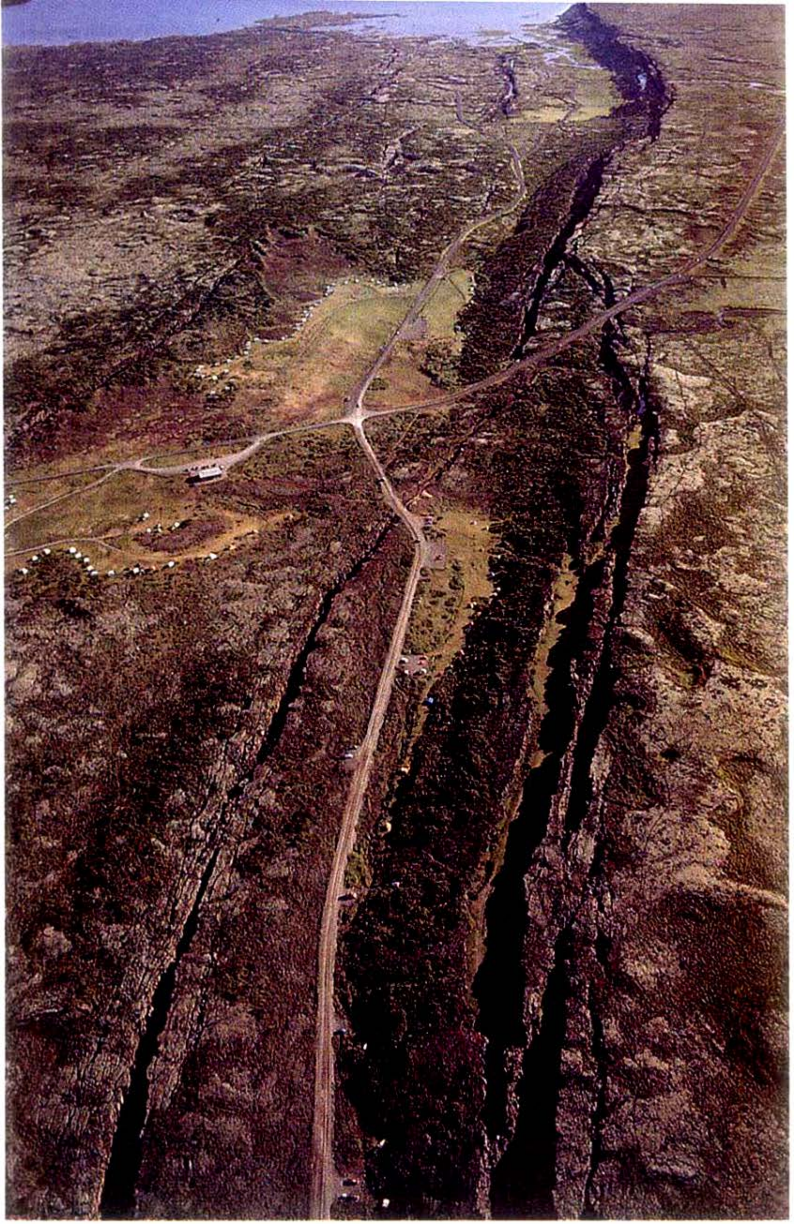


Figure 2.16 Midocean Ridges on Land Long, deep fractures that split Iceland mark the center of a midocean ridge. Iceland is on the Mid-Atlantic Ridge and is one of the few places in the world where the midocean ridge can be seen above sea level.

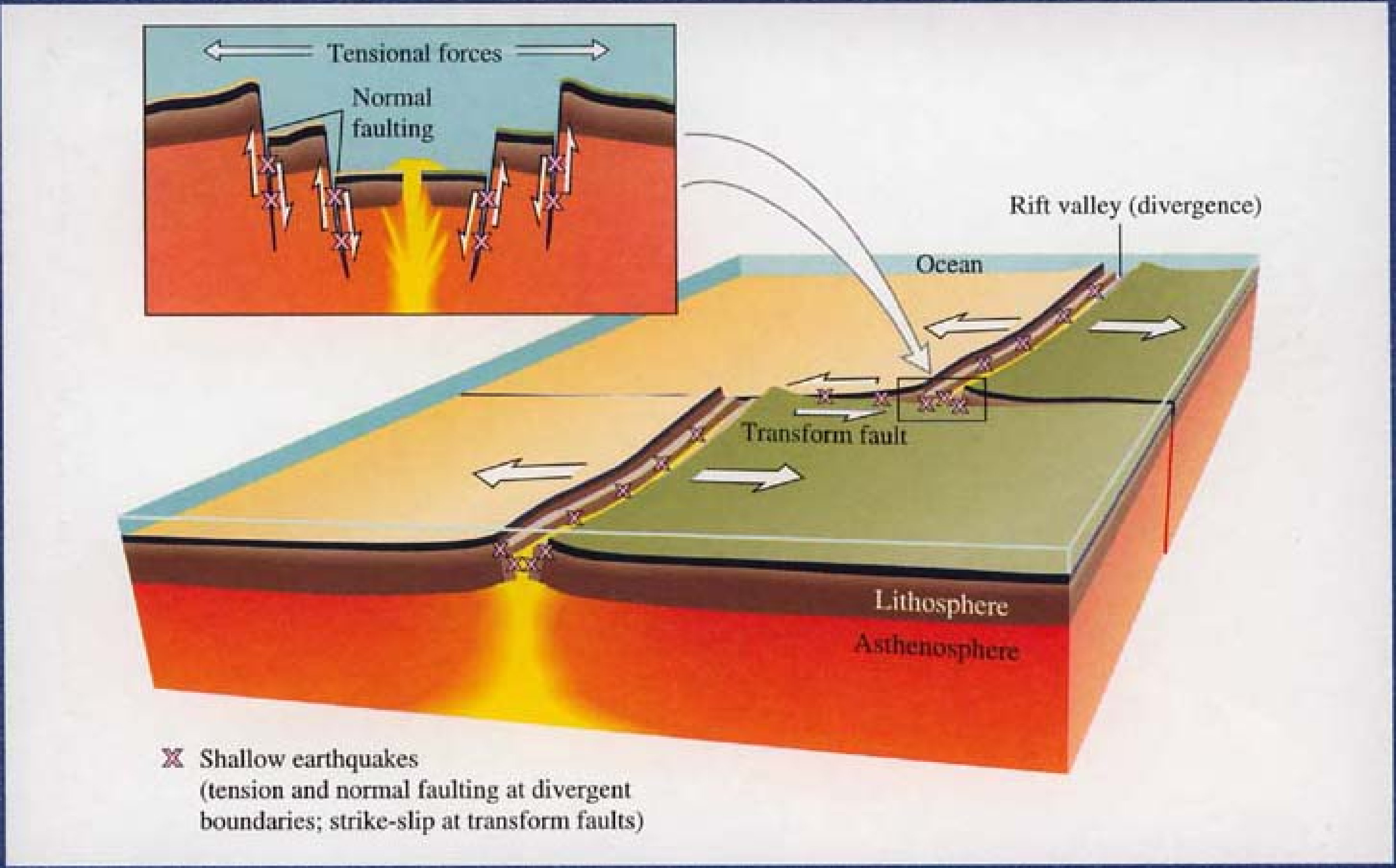
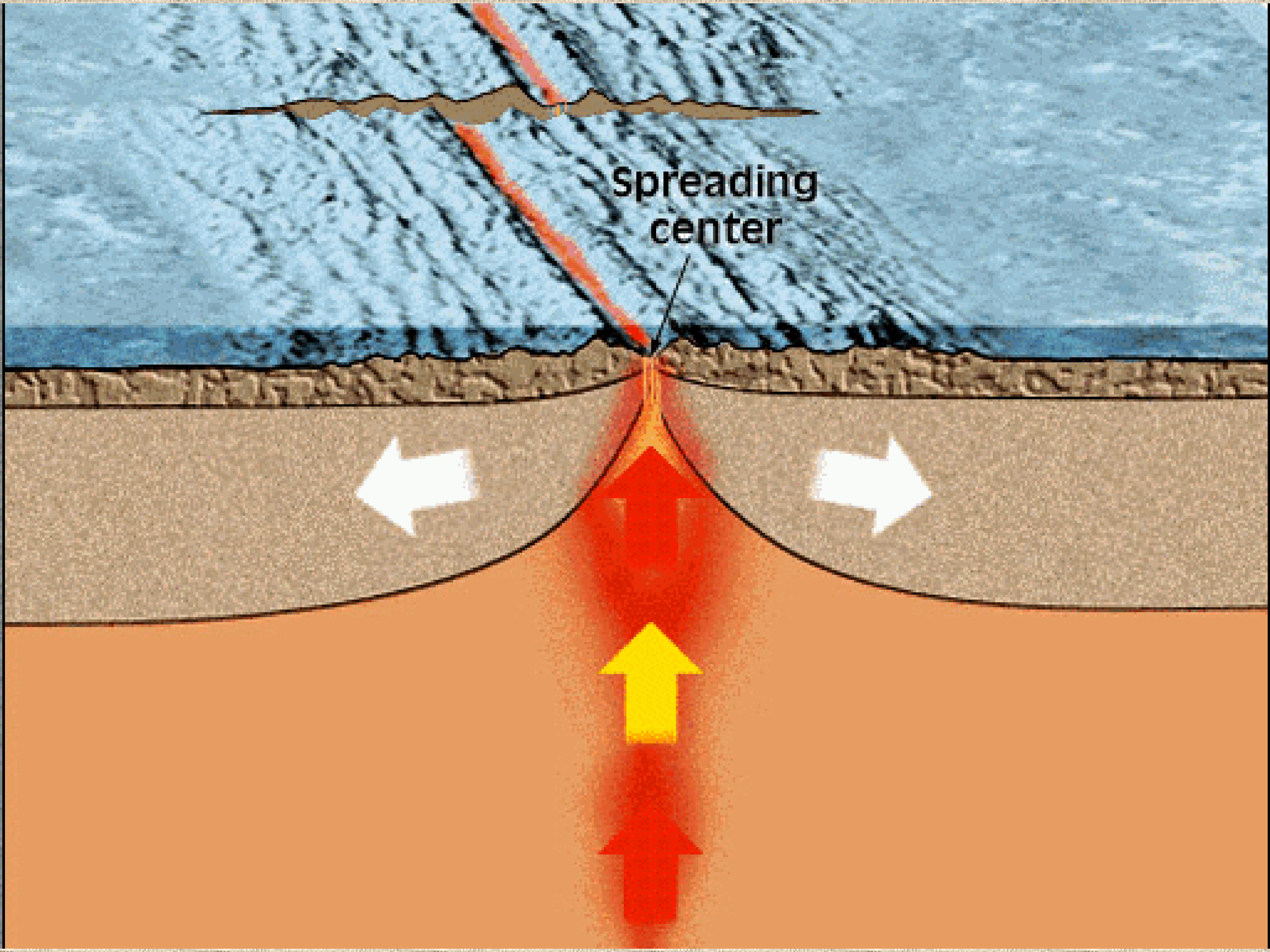
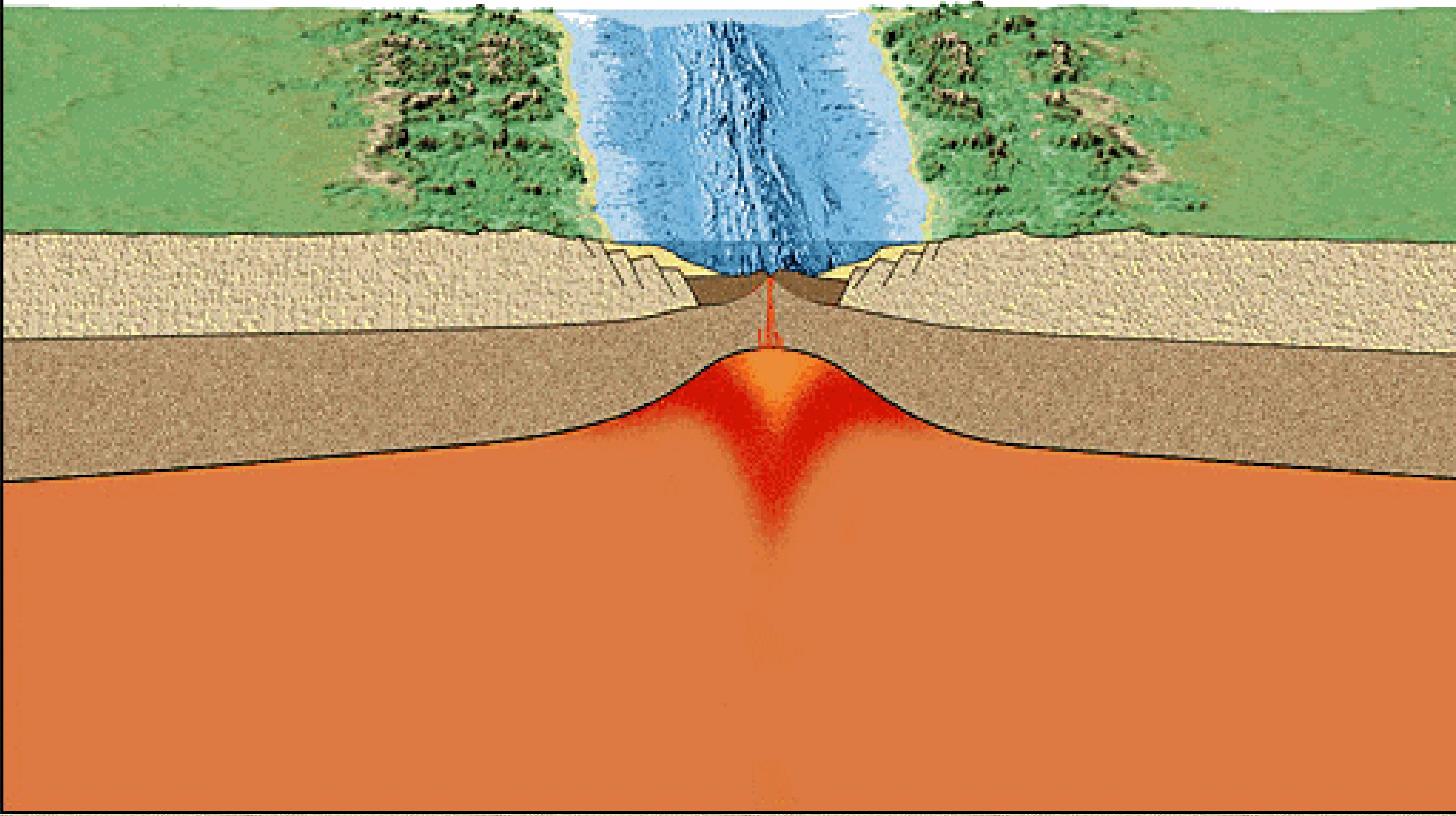
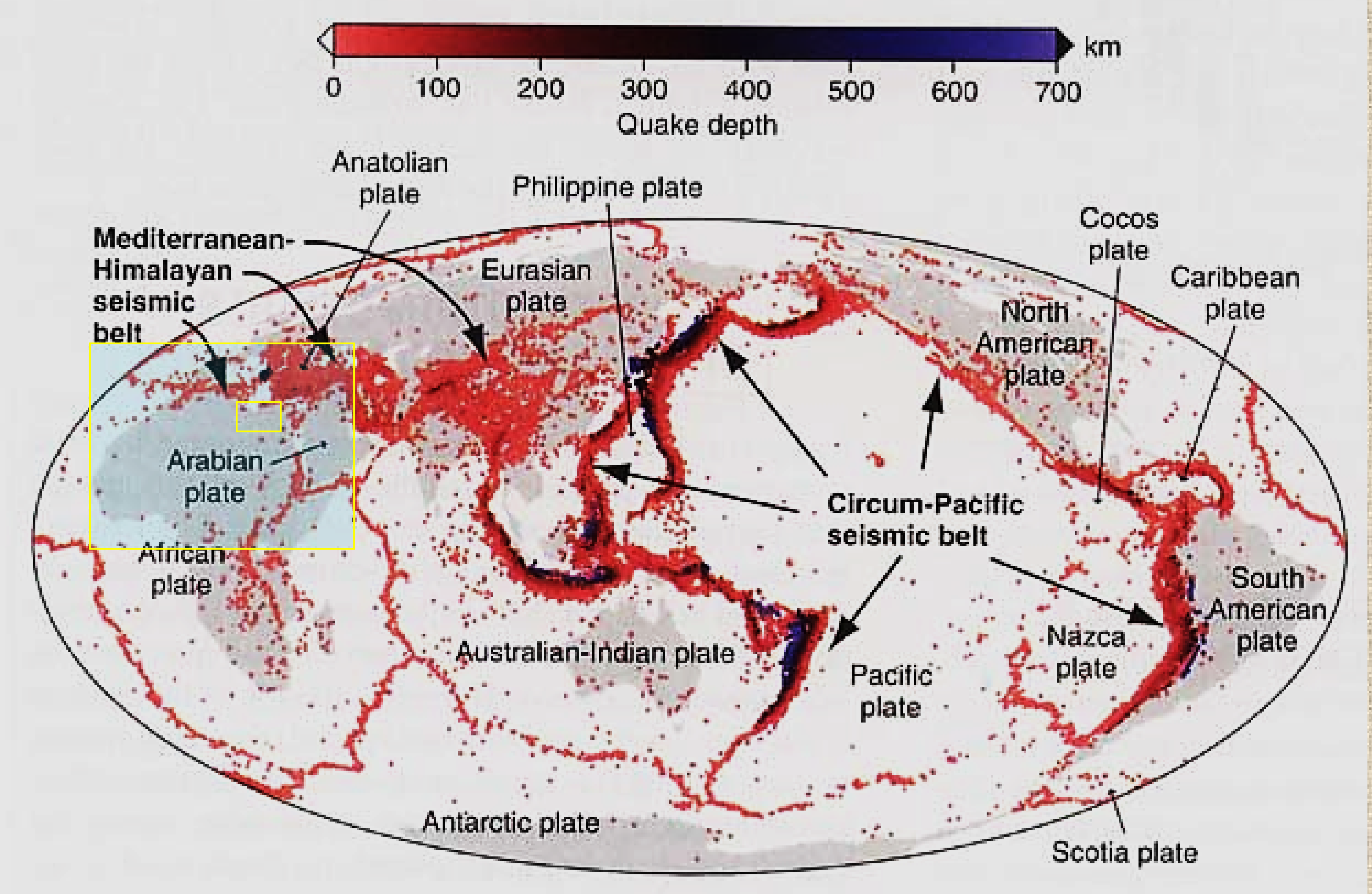


PLATE 12

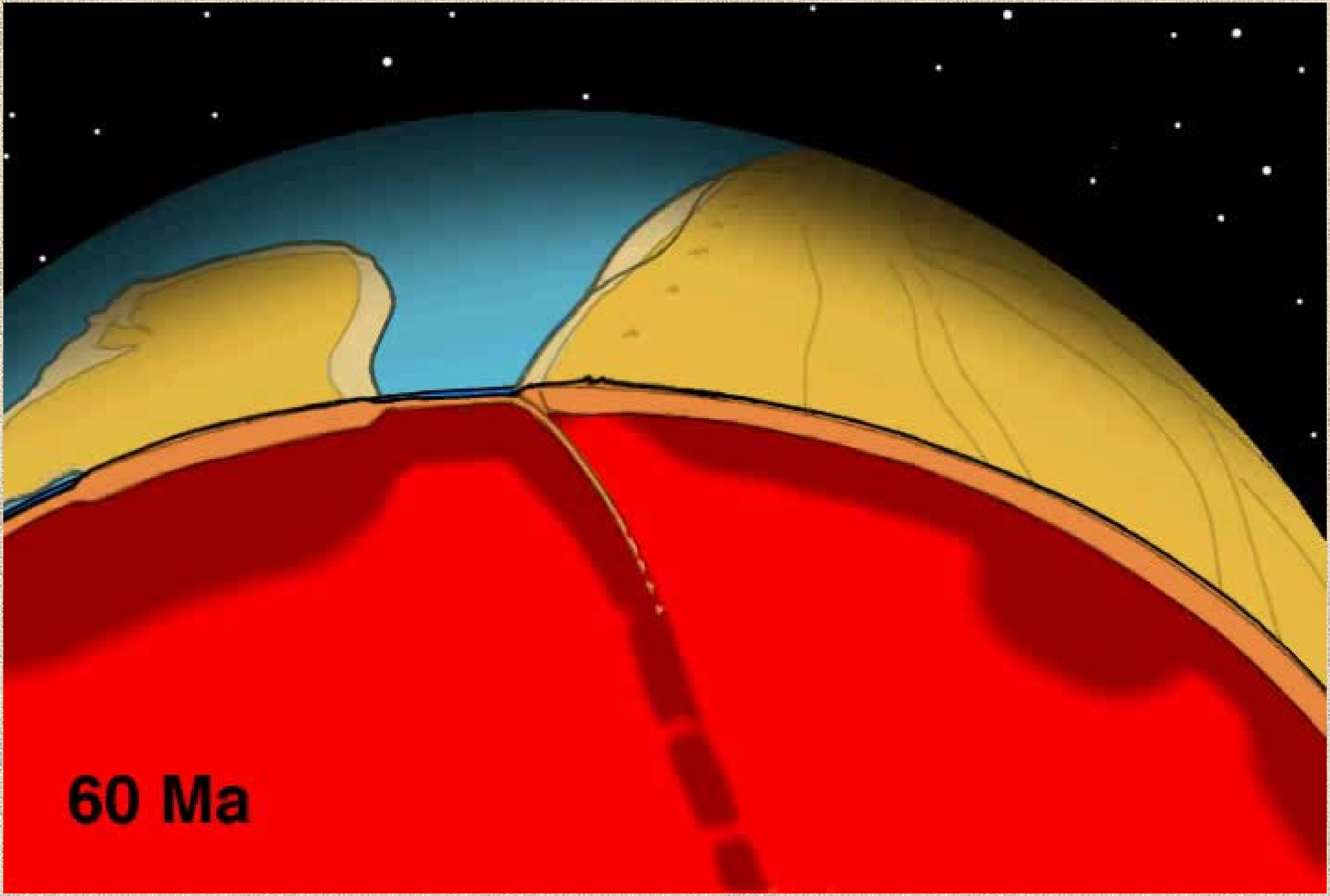
Earthquake sources associated with two types of plate boundaries: divergent boundaries of ocean ridges and transform faults. [From Press and Siever, *Understanding Earth*, Second ed., New York: W. H. Freeman and Co.,1998.]


Spreading center

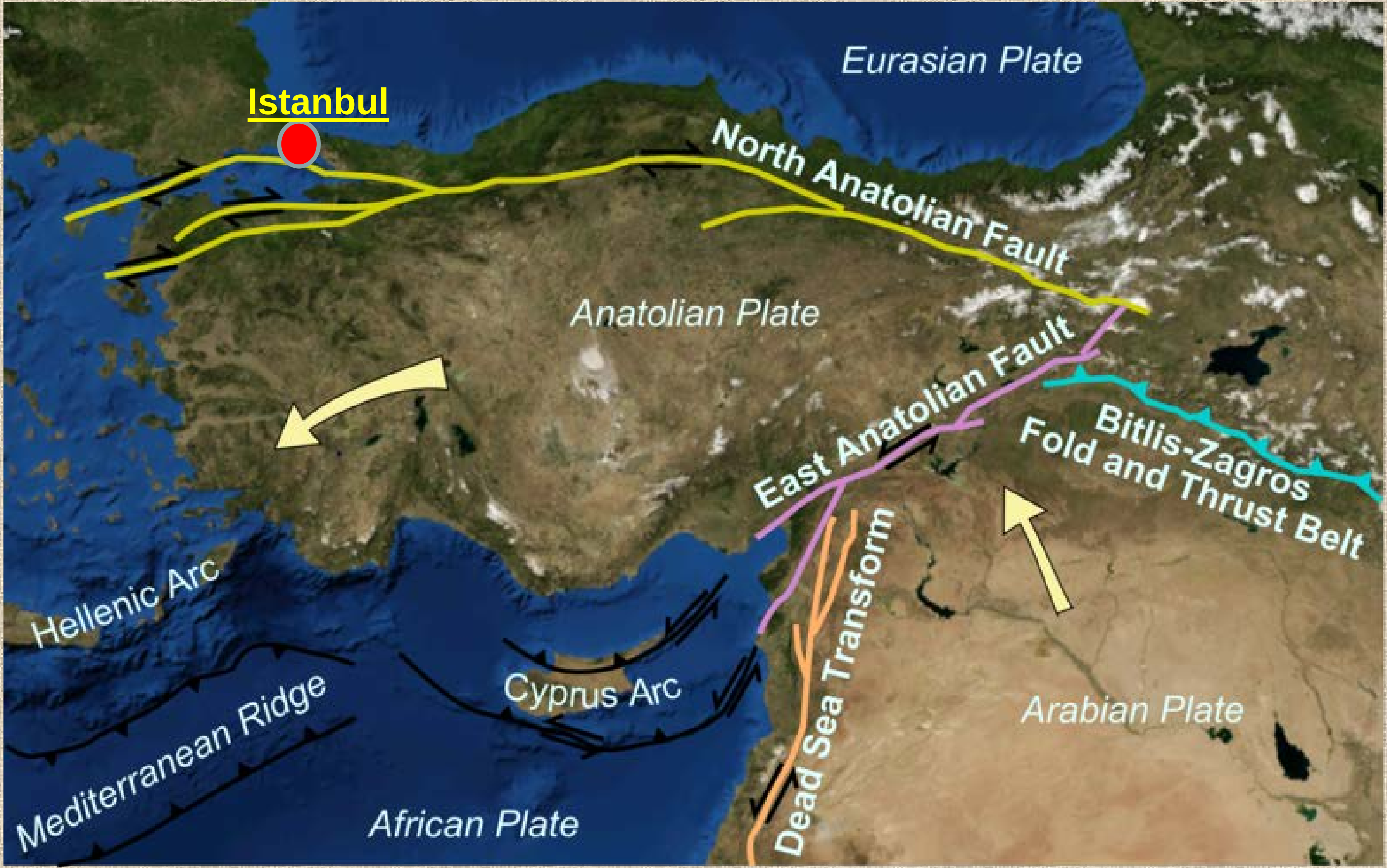




Earthquakes and plate margins. Earth's seismic activity outlines plate margins. This map shows earthquakes of magnitude 5.5 or greater from 1960 to 1989. Earthquakes foci are colour-coded for depth

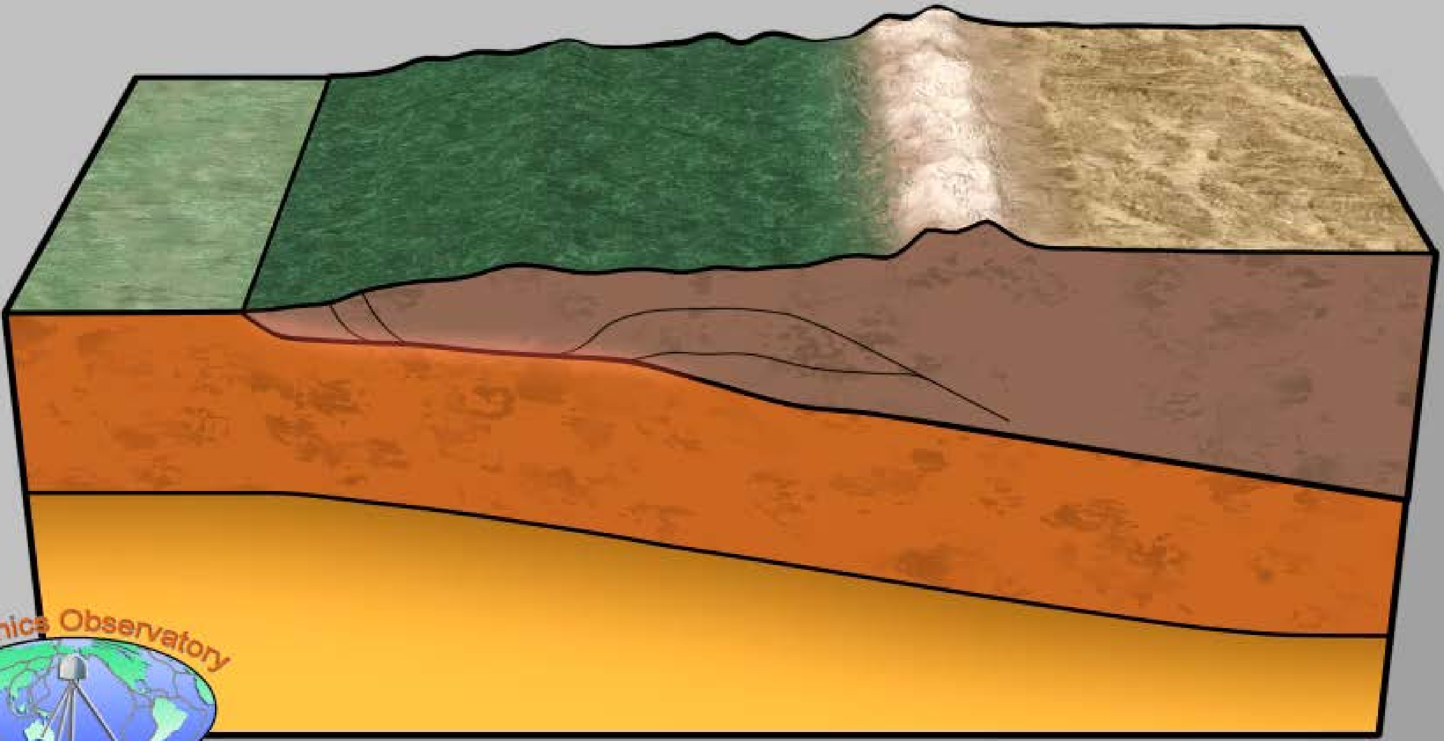


Courtesy: Jean-Philippe Avouac, Caltech, USA



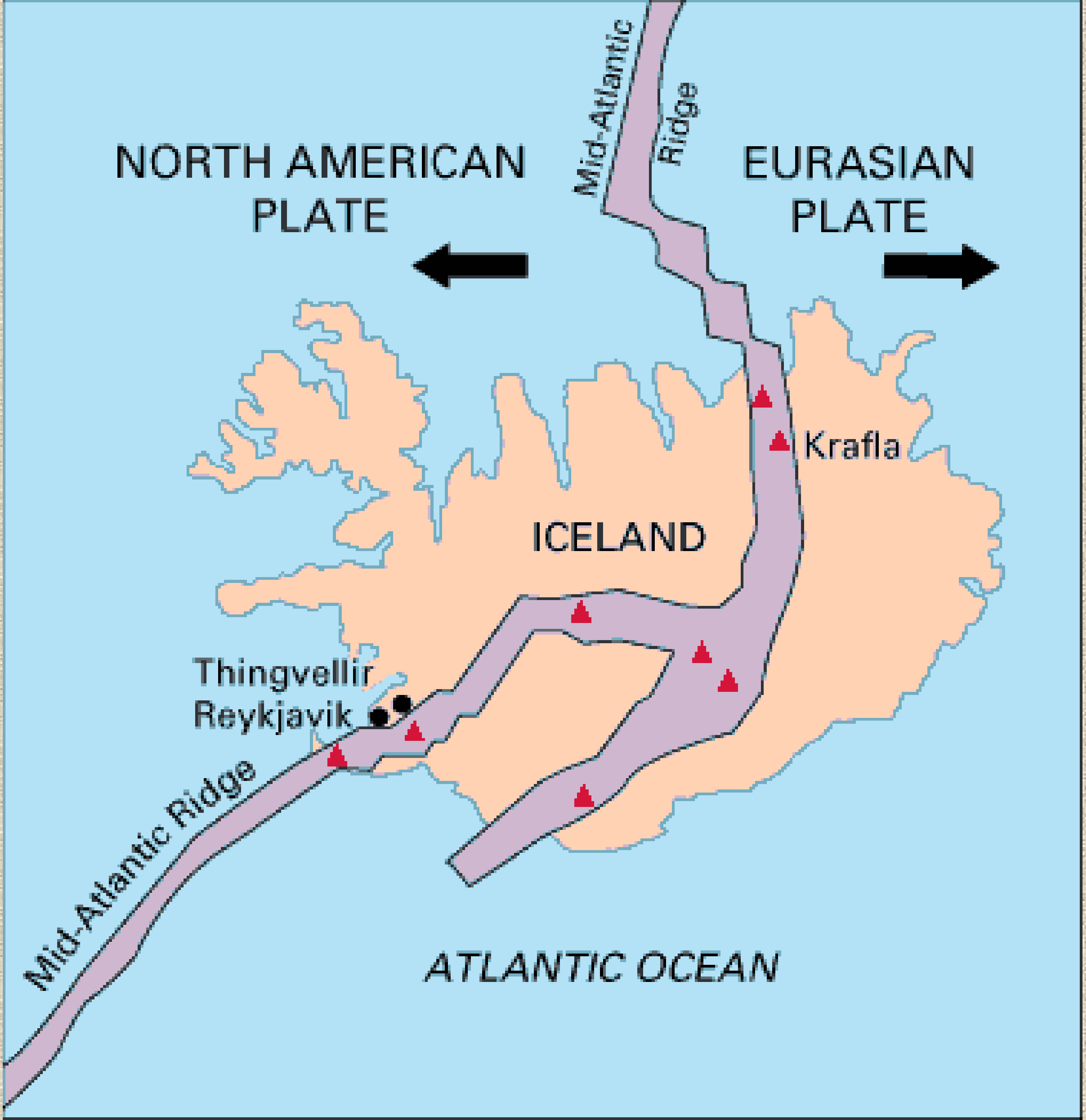
Map showing main tectonic structures around the Anatolian Plate on a base taken from a snapshot from Nasa's World Wind software. Arrows show displacement vectors of the Anatolian and Arabian Plates relative to the Eurasian Plate.

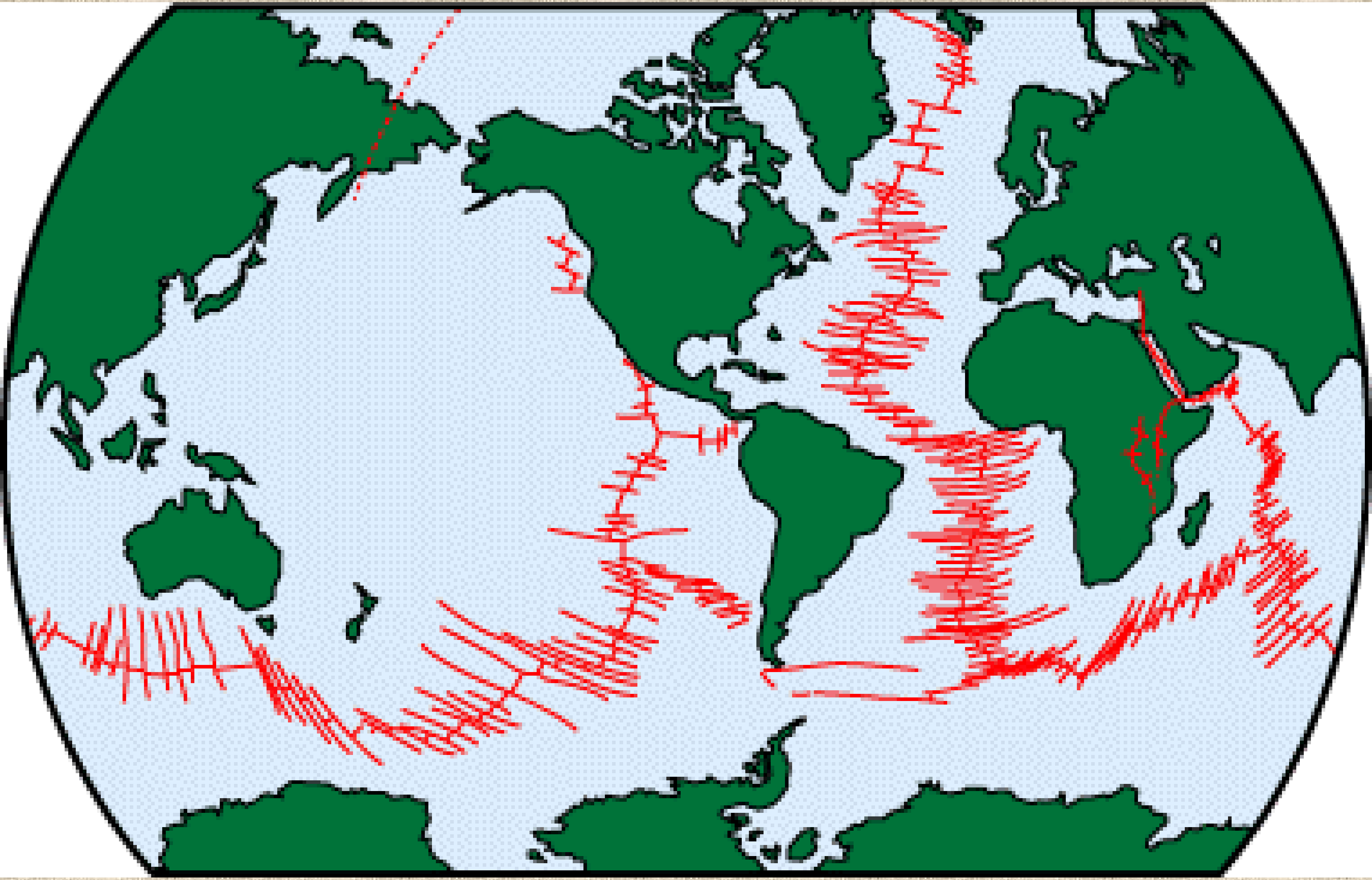
Map Image from Google Earth



Tectonics Observatory

California Institute of Technology


Mid-Atlantic Ridge
NORTH AMERICAN PLATE
EURASIAN PLATE
Krafla
ICELAND
Thingvellir
Reykjavik
Mid-Atlantic Ridge
ATLANTIC OCEAN



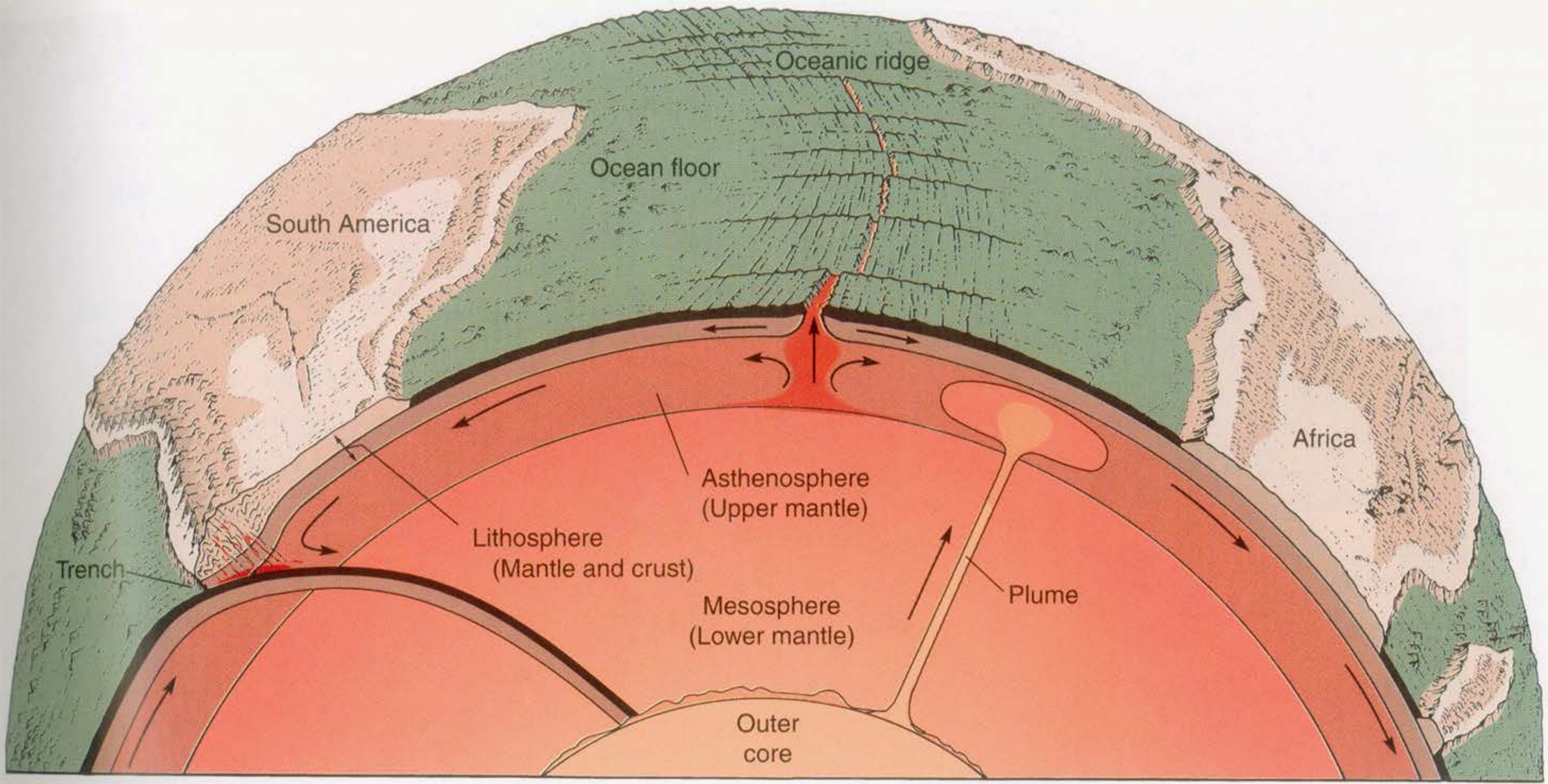


FIGURE 2.8 **The tectonic system** is powered by Earth's internal heat. The asthenosphere is more plastic than either the overlying lithosphere or the underlying lower mantle. Above the plastic asthenosphere, relatively cool and rigid lithospheric plates split and move apart as single mechanical units (along the ocean ridges). As this happens, molten rock from the asthenosphere wells up to fill the void between the lithospheric plates and thus creates new lithosphere. Very slow convection occurs in the mantle. Some plates contain blocks of thick, lower-density continental crust, which cannot sink into the denser mantle. As a result, where a plate carrying continental crust collides with another plate, the continental margins are deformed into mountain ranges. Plate margins are the most active areas on Earth—the sites of the most intense volcanism, seismic activity, and crustal deformation. Locally, convection in the deep mantle creates rising mantle plumes. *(After P. J. Wyllie)*

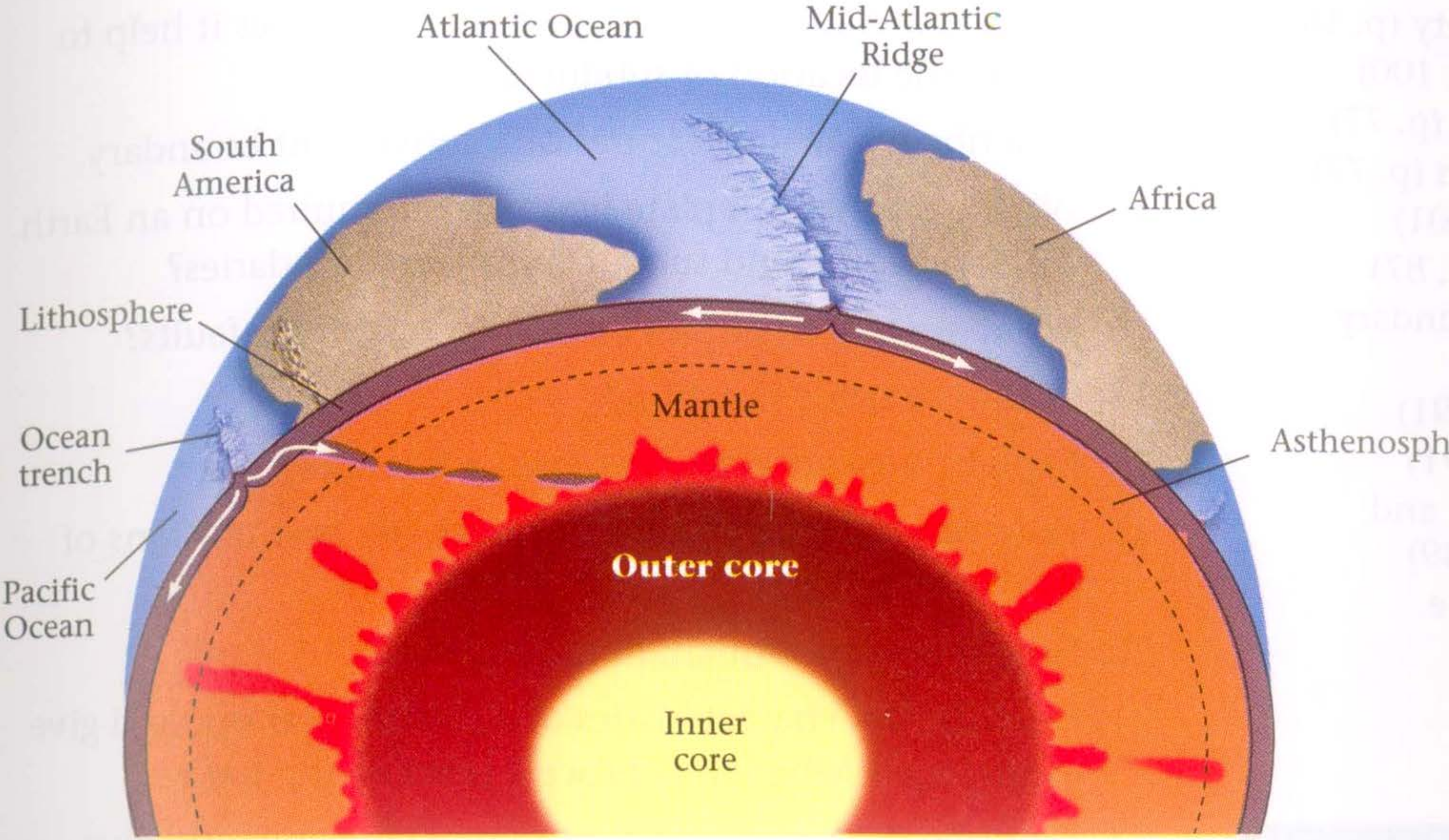
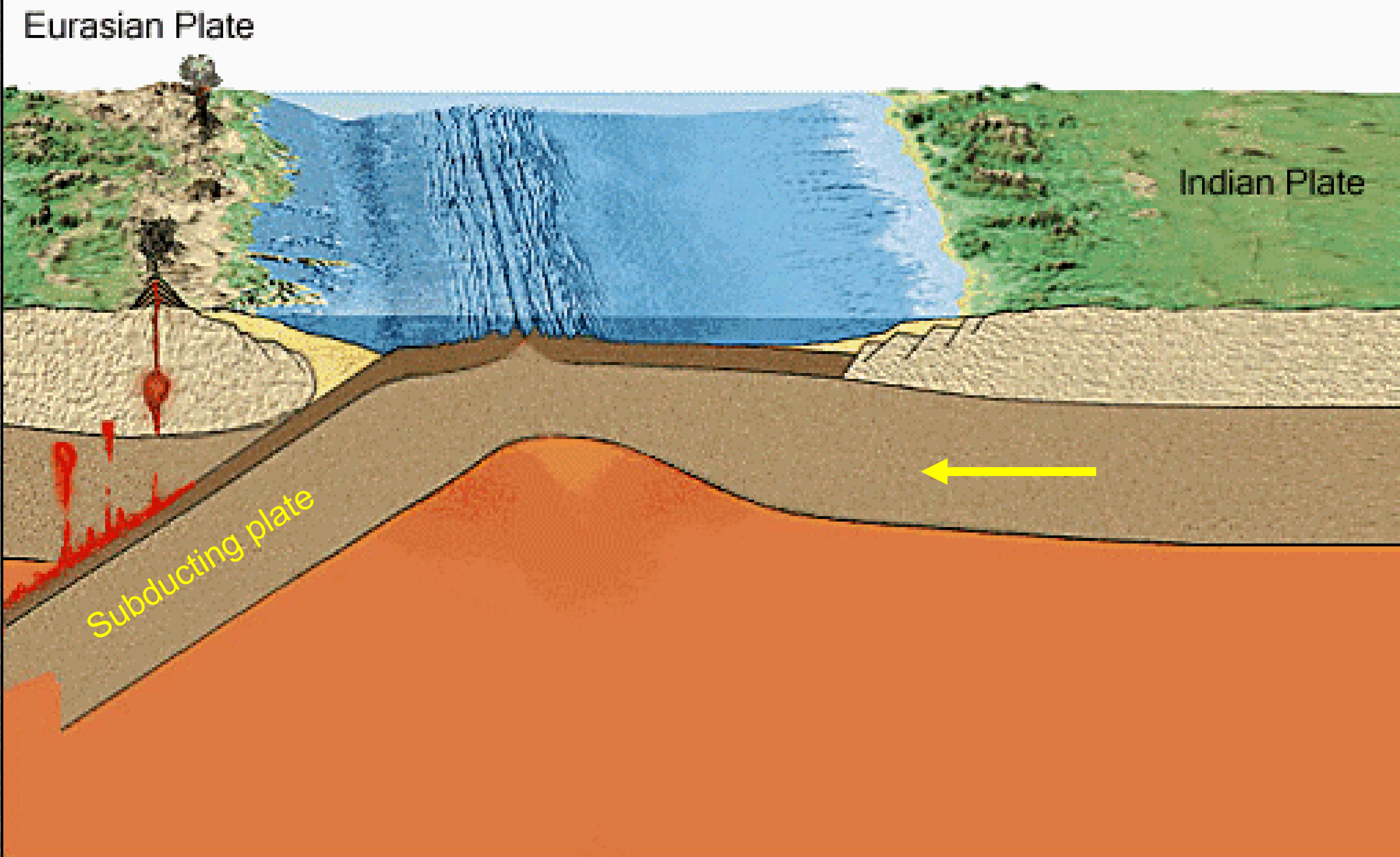


FIGURE 4.29 Plate tectonics involves the transfer of material from the mantle to the surface and back down again.


Eurasian Plate
Indian Plate
Subducting plate

natgeotv.com

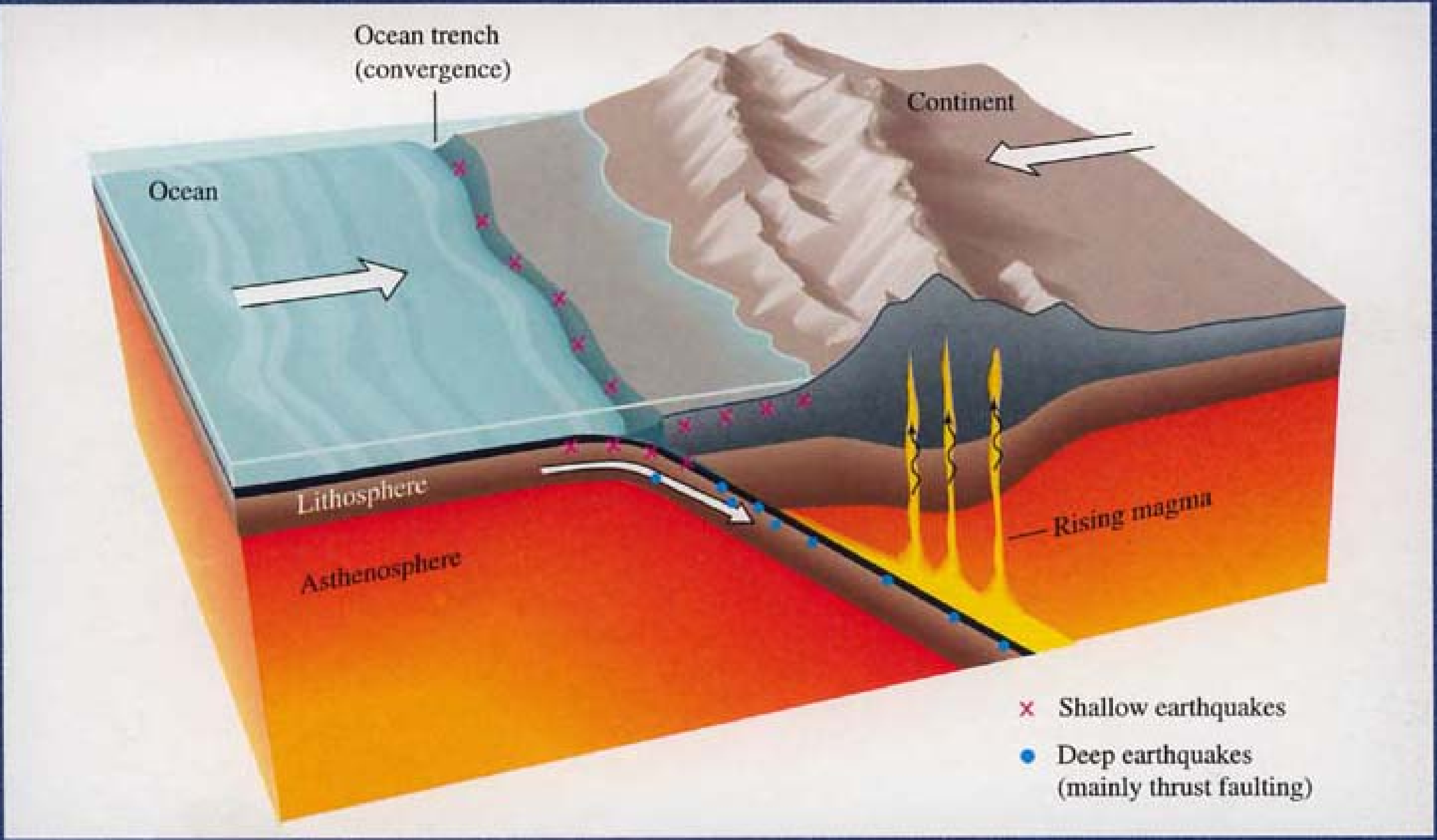


PLATE 13

Shallow- and deep-focus earthquakes along a convergent slab plunging underneath the upthrown mountain range. Magma is rising from the slab boundary at depth. [From Press and Siever, *Understanding Earth*, Second ed., New York: W. H. Freeman and Co., 1998.]

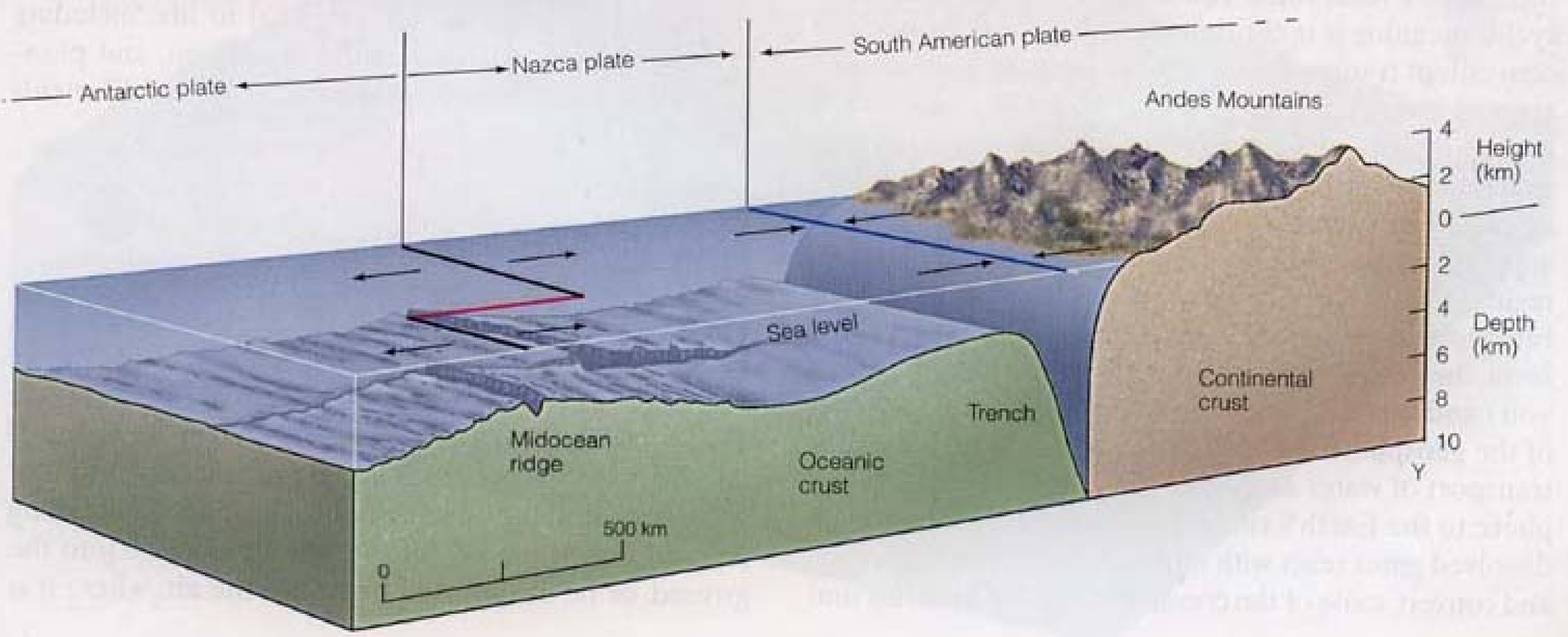


Figure 2.15 Three Plates Simplified diagram of a section across a portion of the Pacific Ocean margin of southern South America at about the latitude of Puerto Monte, Chile. Note that the side of the trench adjacent to the continent (to the right) is steeper than the oceanic side.

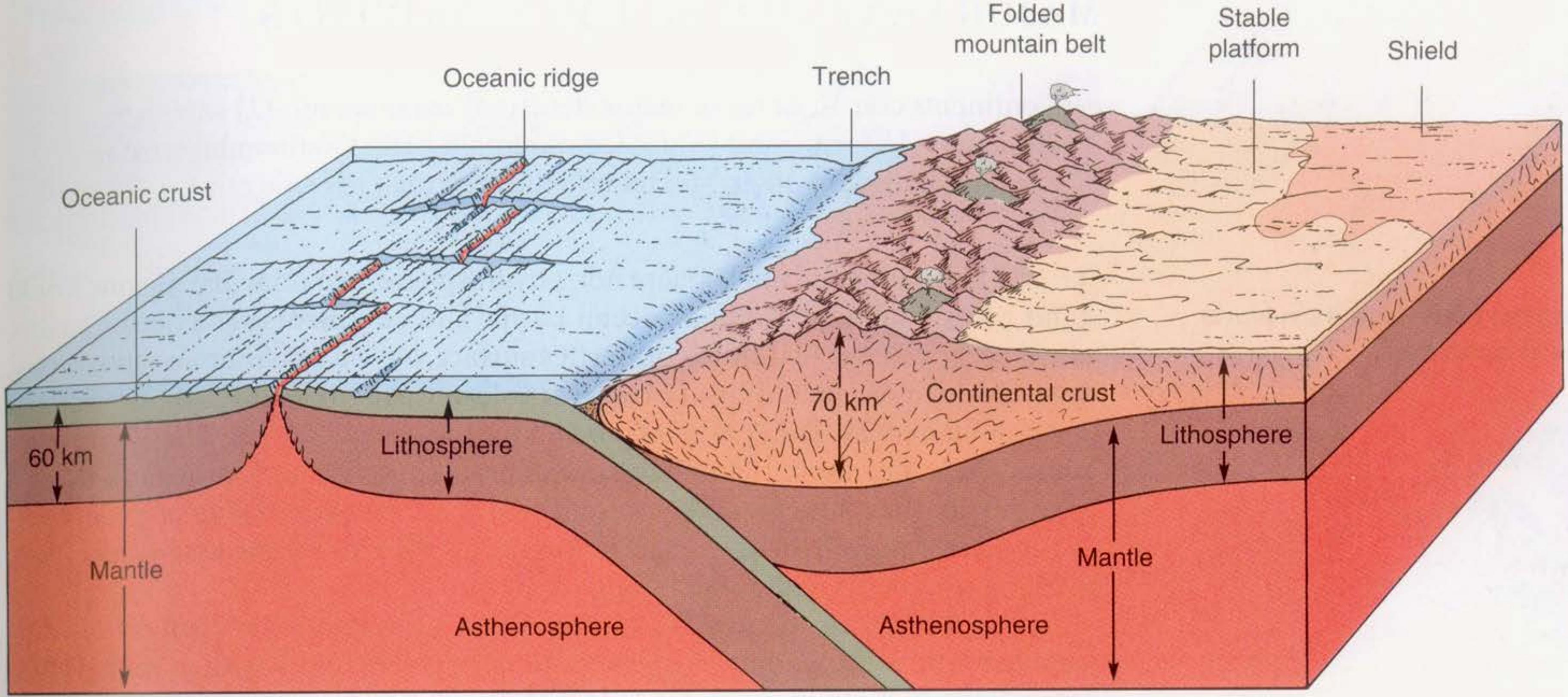
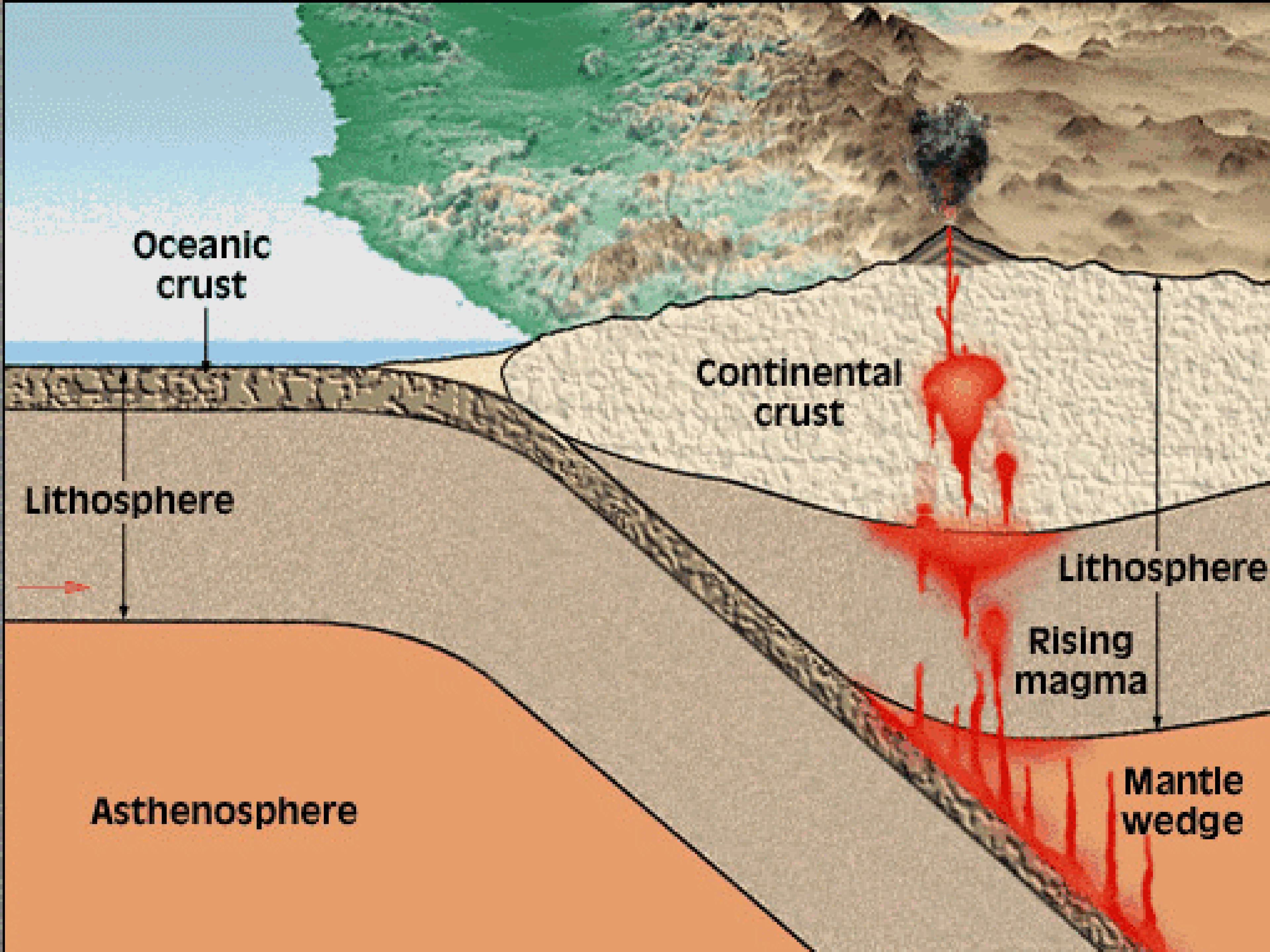
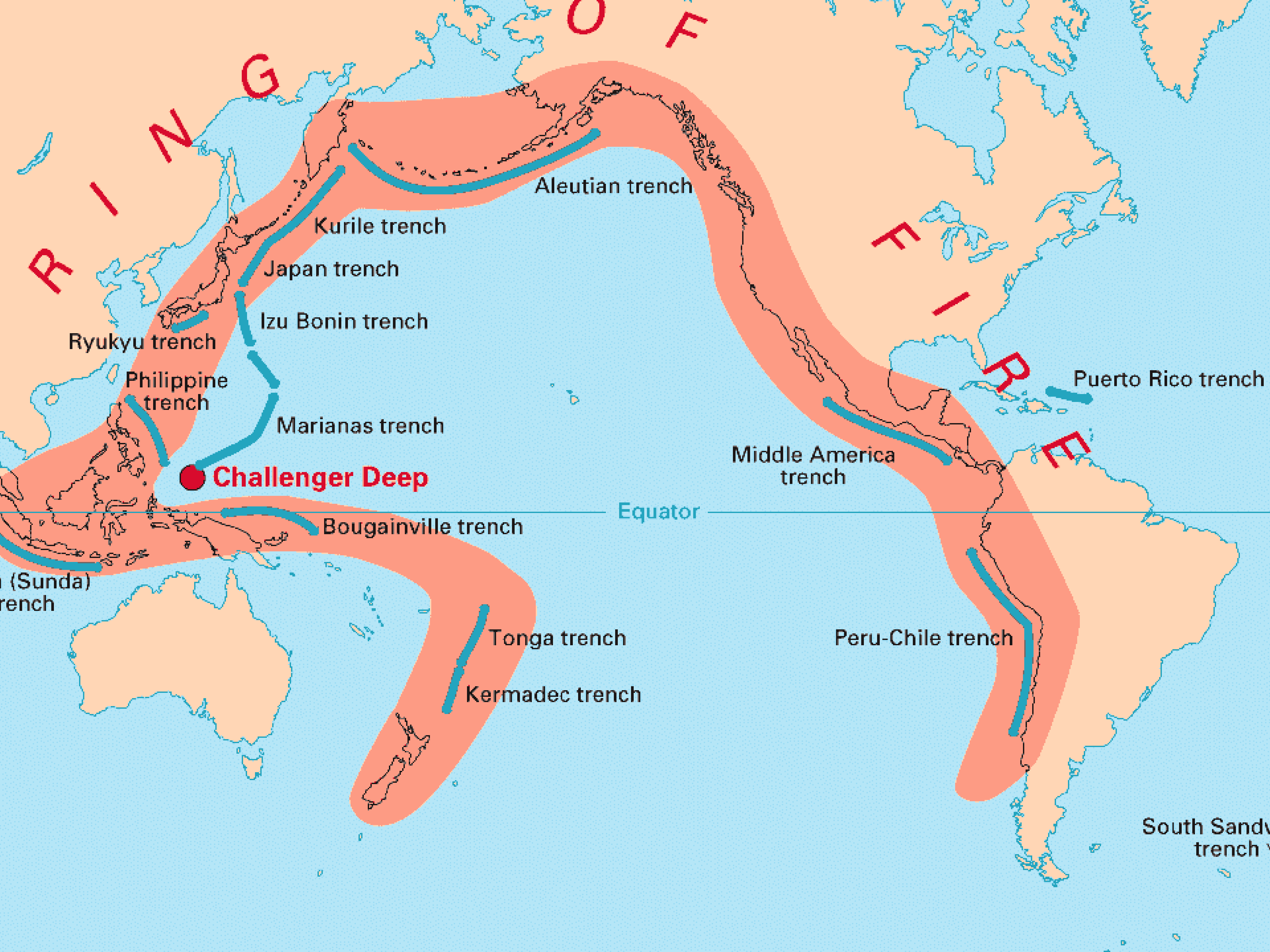
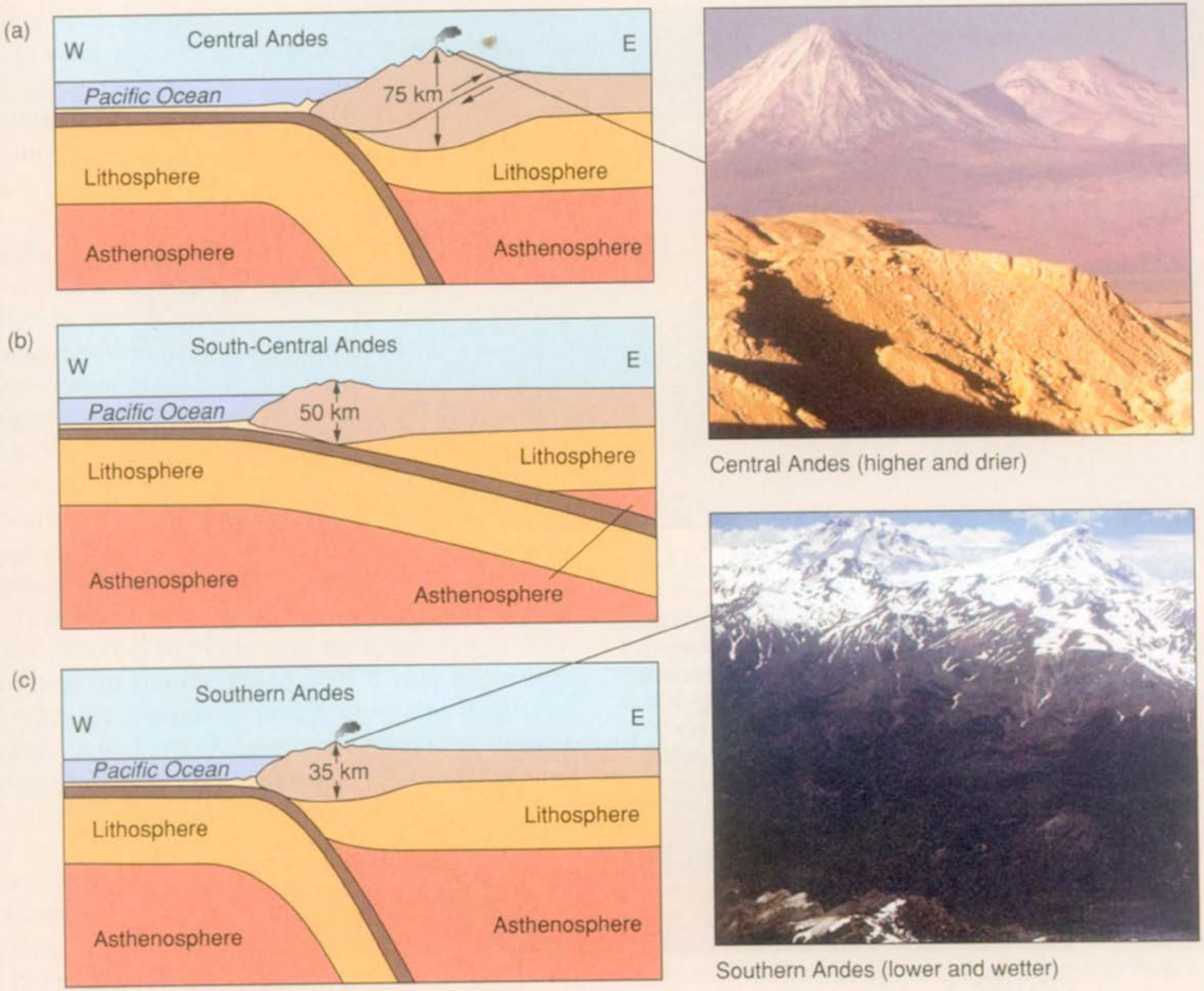


FIGURE 1.5 **The outermost layers of the solid Earth,** based on physical characteristics, are the asthenosphere and the lithosphere. The asthenosphere is hot, close to its melting point, and is capable of plastic flow. The lithosphere above it is cooler and rigid. It includes the uppermost part of the mantle and two types of crust: thin, dense oceanic crust and thick, buoyant continental crust.


Oceanic crust
Continental crust
Lithosphere
Lithosphere
Rising magma
Mantle wedge
Asthenosphere


RING OF FIRE
Aleutian trench
Kurile trench
Japan trench
Izu Bonin trench
Ryukyu trench
Philippine trench
Marianas trench
Challenger Deep
Equator
Bougainville trench
(Sunda)
rench
Tonga trench
Kermadec trench
Middle America trench
Puerto Rico trench
Peru-Chile trench
South Sandv
trench

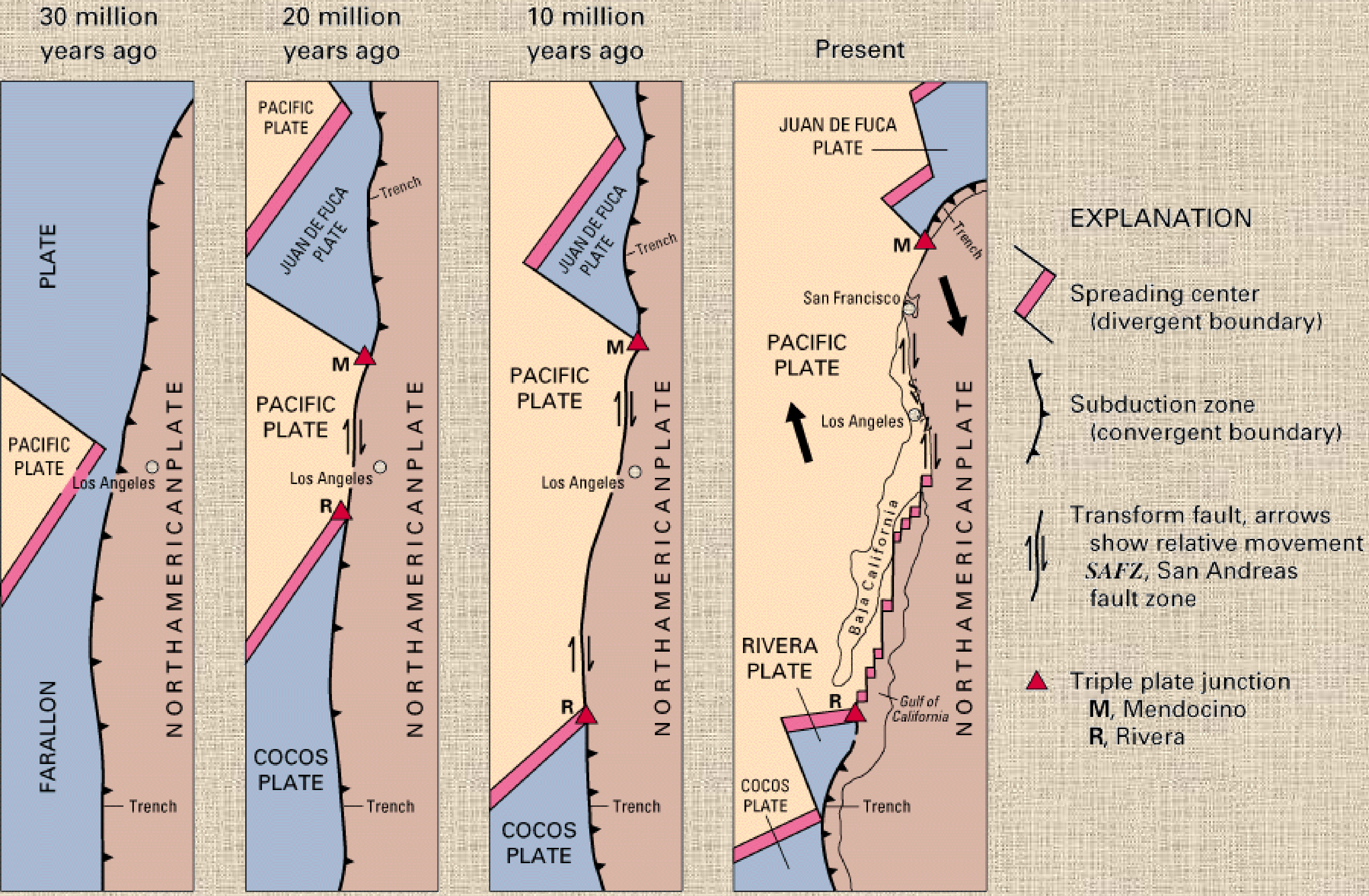


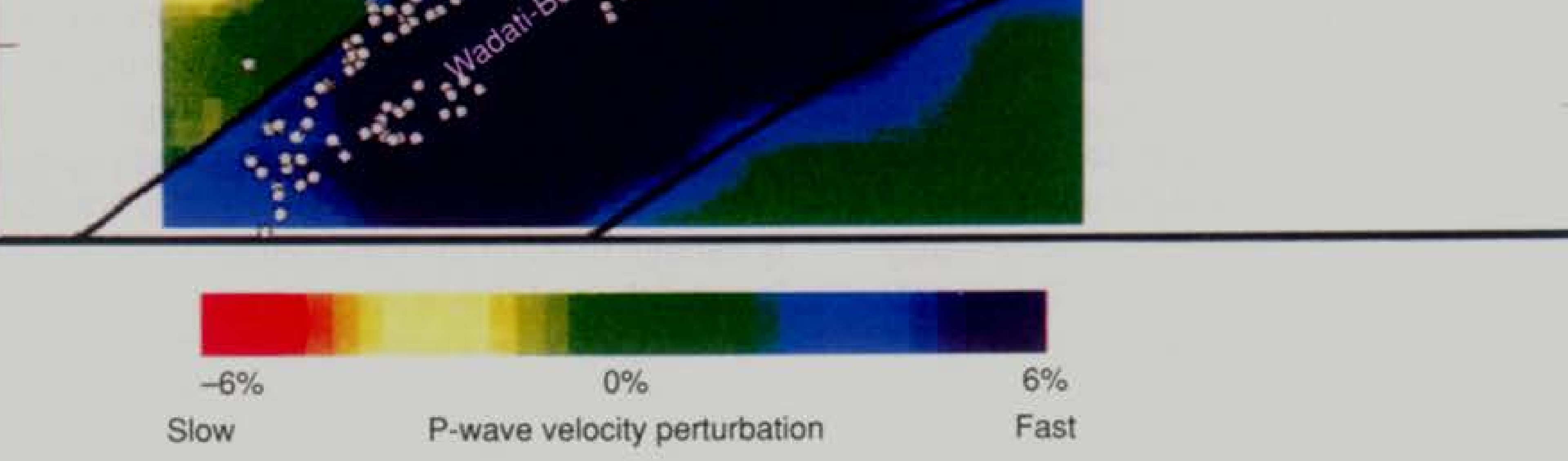
Central Andes (higher and drier)

Southern Andes (lower and wetter)

FIGURE 2

Cross sections of the Andes at different latitudes. Comparison among the three sections shows varying slab dip: steep slab dip in (a) and (c) and shallow slab dip in (b). Note that there is no active volcanism where the slab dip is shallow (see Fig. 1). This kind of shallow subduction may cause compression in the upper plate (compare to Fig. 10.2), leading to thrusting and crustal thickening, which has already happened farther north (a), with a subsequent increase in slab dip to today's configuration.


30 million years ago
20 million years ago
10 million years ago
Present
PLATE
PACIFIC PLATE
Los Angeles
FARALLON
Trench
NORTH AMERICAN PLATE
PACIFIC PLATE
JUAN DE FUCA PLATE
Trench
M
PACIFIC PLATE
Los Angeles
R
COCOS PLATE
Trench
NORTH AMERICAN PLATE
JUAN DE FUCA PLATE
Trench
M
PACIFIC PLATE
Los Angeles
R
COCOS PLATE
Trench
NORTH AMERICAN PLATE
JUAN DE FUCA PLATE
M
Trench
San Francisco
PACIFIC PLATE
Los Angeles
Baja California
RIVERA PLATE
R
Gulf of California
COCOS PLATE
Trench
NORTH AMERICAN PLATE
EXPLANATION
Spreading center (divergent boundary)
Subduction zone (convergent boundary)
Transform fault, arrows show relative movement
SAFZ, San Andreas fault zone
Triple plate junction
M, Mendocino
R, Rivera



E 10.3 (a) Distribution of earthquakes in a subduction zone, which is related to zones of tension and compressi
llow depths, earthquake hypocenters are located near the top of the subducted lithosphere. At greater depths, earthq
ubducted slab. Note that some earthquakes also occur in the upper plate, probably due to stresses generated by conta
omographic image of the subduction zone beneath Japan. A color-coded scale defines the percentage of deviation in P
average value. Blue colors indicate fast seismic velocities (velocities that are up to 6 percent faster than the assum
slab because it is relatively cool and dense. Yellow and red colors indicate P-wave velocities that are slower than th
r particularly beneath volcanoes. This probably indicates partial melting of the mantle, which would slow the vel
nquake locations are marked by the open circles.

Rock magnetism

The study of rock magnetism developed during the 1950s with the perfection of new, highly sensitive magnetometers. Two studies in paleomagnetism were very important:

1. **Apparent Polar Wandering**
2. **Patterns of Magnetic Reversals on the Sea Floor**

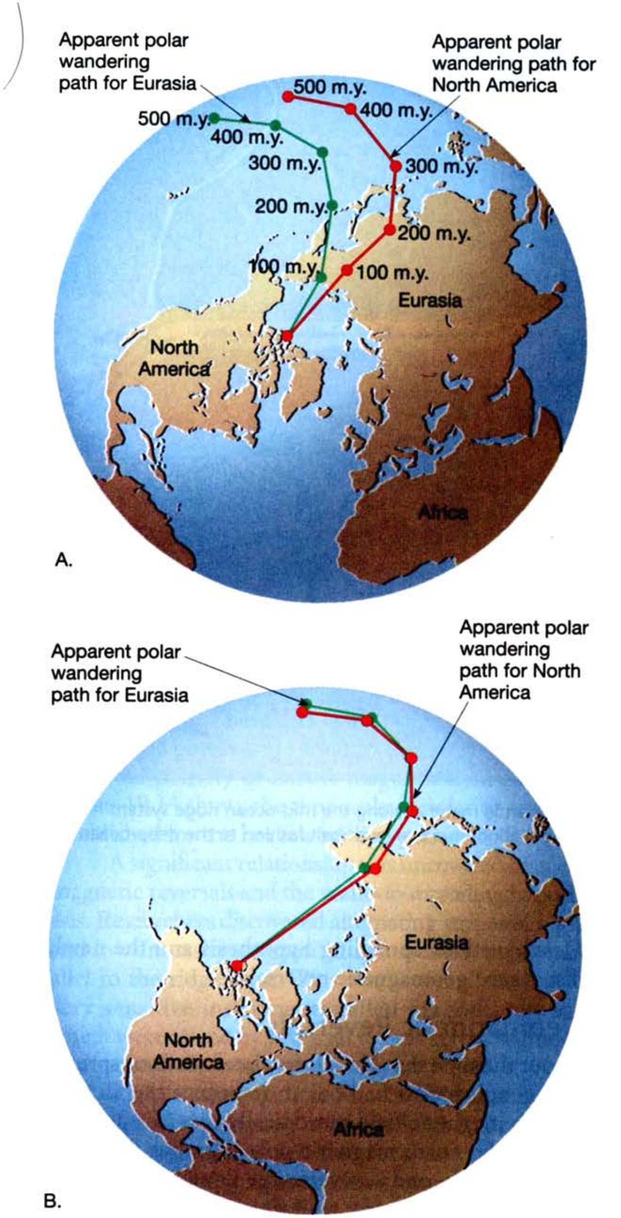
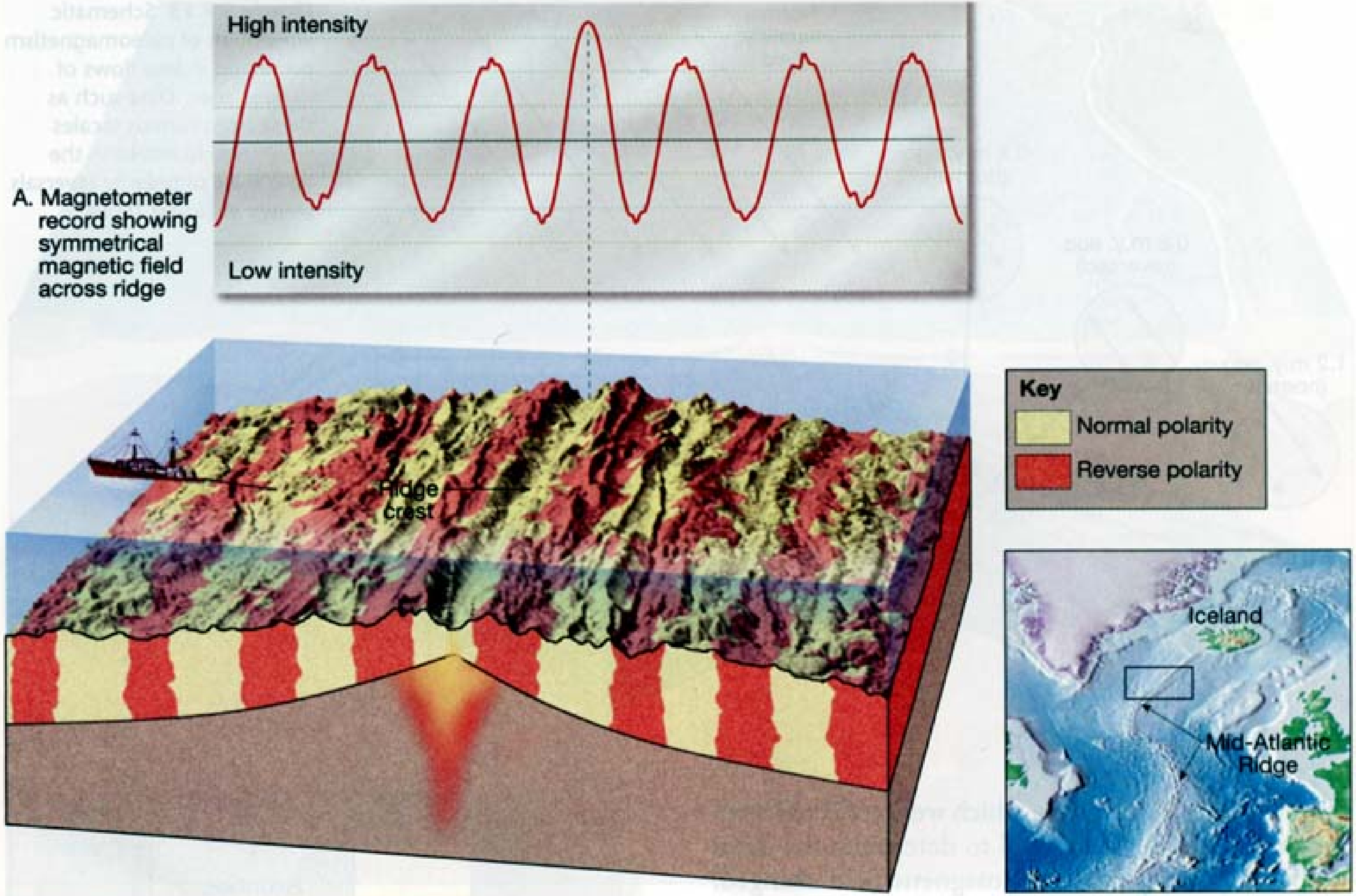


Figure 19.11 Simplified apparent polar-wandering paths as established from North American and Eurasian paleomagnetic data. **A.** The more westerly path determined from North American data was caused by the westward movement of North America by about 24 degrees from Eurasia. **B.** The positions of the wandering paths when the landmasses are reassembled.

In 1963, Fred Vine (a graduate student) and D.H. Matthews (super visor) **saw a way to test the idea of Sea-floor spreading put forth by Hess. If sea-floor spreading has occurred, they suggested , it would be recorded in the magnetism of the basalts in the oceanic crust. Investigations proved this theory.**

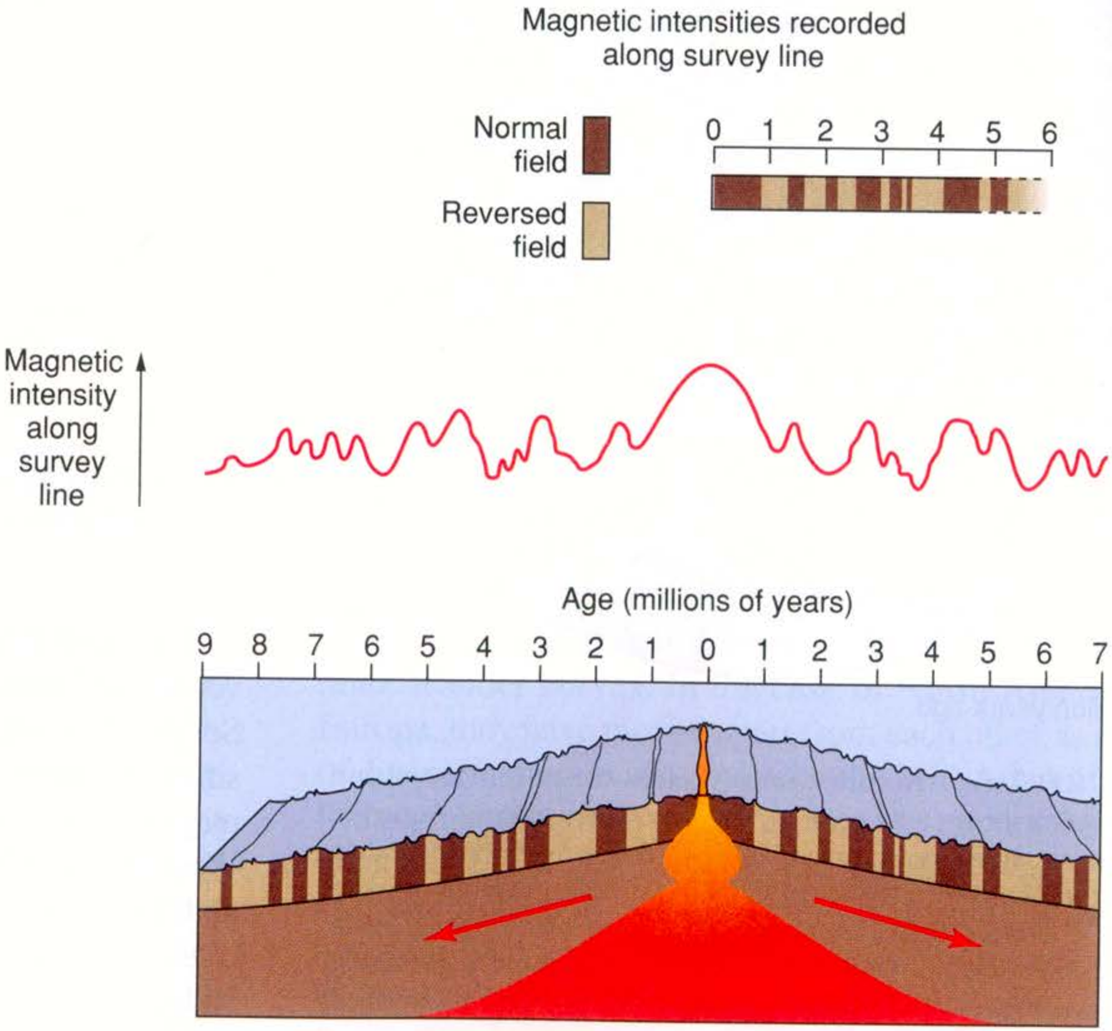


A. Magnetometer record showing symmetrical magnetic field across ridge

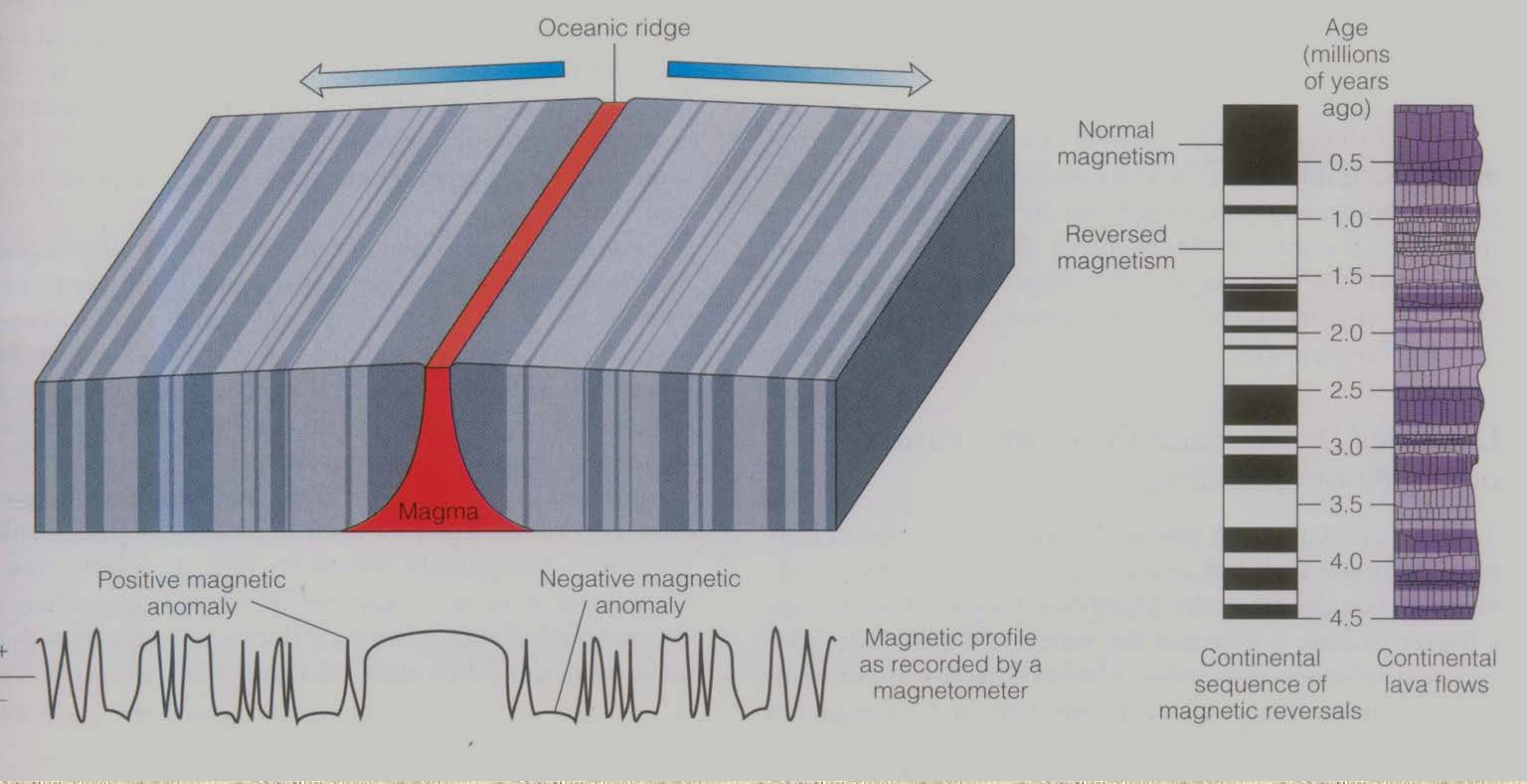
B. Research vessel towing magnetometer across ridge crest

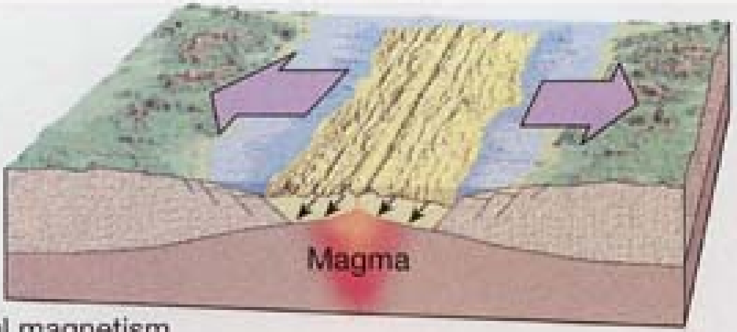
C. Location map

Figure 19.15 The ocean floor as a magnetic tape recorder. **A.** Schematic representation of magnetic intensities recorded as a magnetometer is towed across a segment of the Mid-Atlantic Ridge. **B.** Notice the symmetrical stripes of low- and high-intensity magnetism that parallel the ridge crest. Vine and Matthews suggested that the stripes of high-intensity magnetism occur where normally magnetized oceanic basalts enhance the existing magnetic field. Conversely, the low-intensity stripes are regions where the crust is polarized in the reverse direction, which weakens the existing magnetic field.

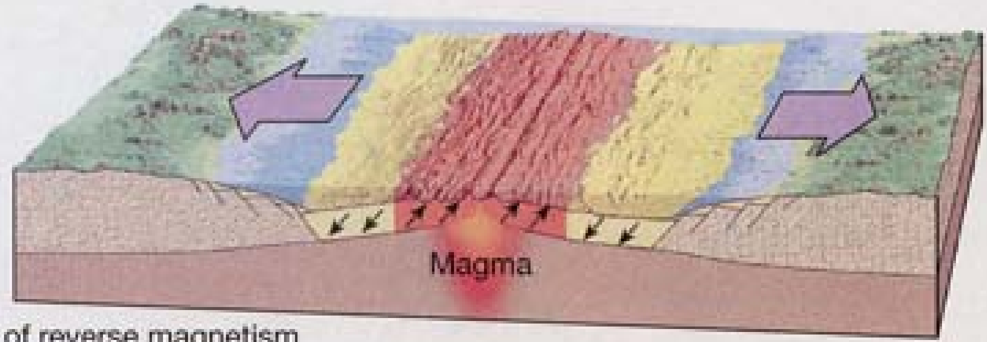


■ **FIGURE 7.7** Magnetic reversals recorded in rocks of the oceanic crust. (a) Location of a magnetic survey across the Reykjanes Ridge—part of the Mid-Atlantic Ridge—near Iceland. Dark-shaded bands represent crust with a normal polarity magnetic field; light blue–shaded areas are reversed. (b) Magnetic-field intensity variations along the survey line. High- and low-intensity fields correspond to normal and reversed polarity, respectively, as summarized in the strip at the bottom of the figure. Ages are determined by correlation with sequences of lavas on land (Fig. 7.6), which were dated isotopically using the potassium-argon (K-Ar) method.

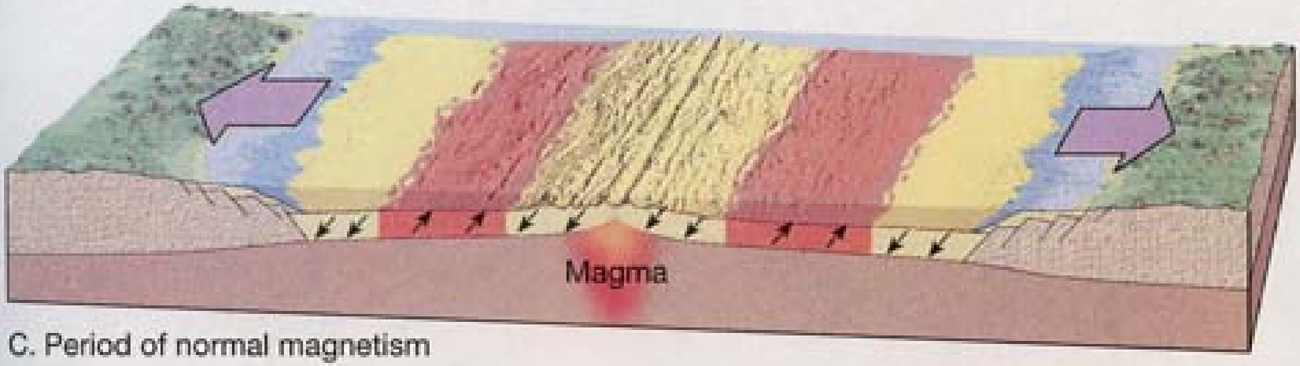

Oceanic ridge
Magma
Positive magnetic anomaly
Negative magnetic anomaly
+
−
Magnetic profile as recorded by a magnetometer
Age (millions of years ago)
Normal magnetism
Reversed magnetism
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Continental sequence of magnetic reversals
Continental lava flows



A. Period of normal magnetism



B. Period of reverse magnetism



C. Period of normal magnetism

Figure 19.16 As new basalt is added to the ocean floor at mid-ocean ridges, it is magnetized according to Earth's existing magnetic field. Hence, it behaves much like a tape recorder as it records each reversal of the planet's magnetic field.

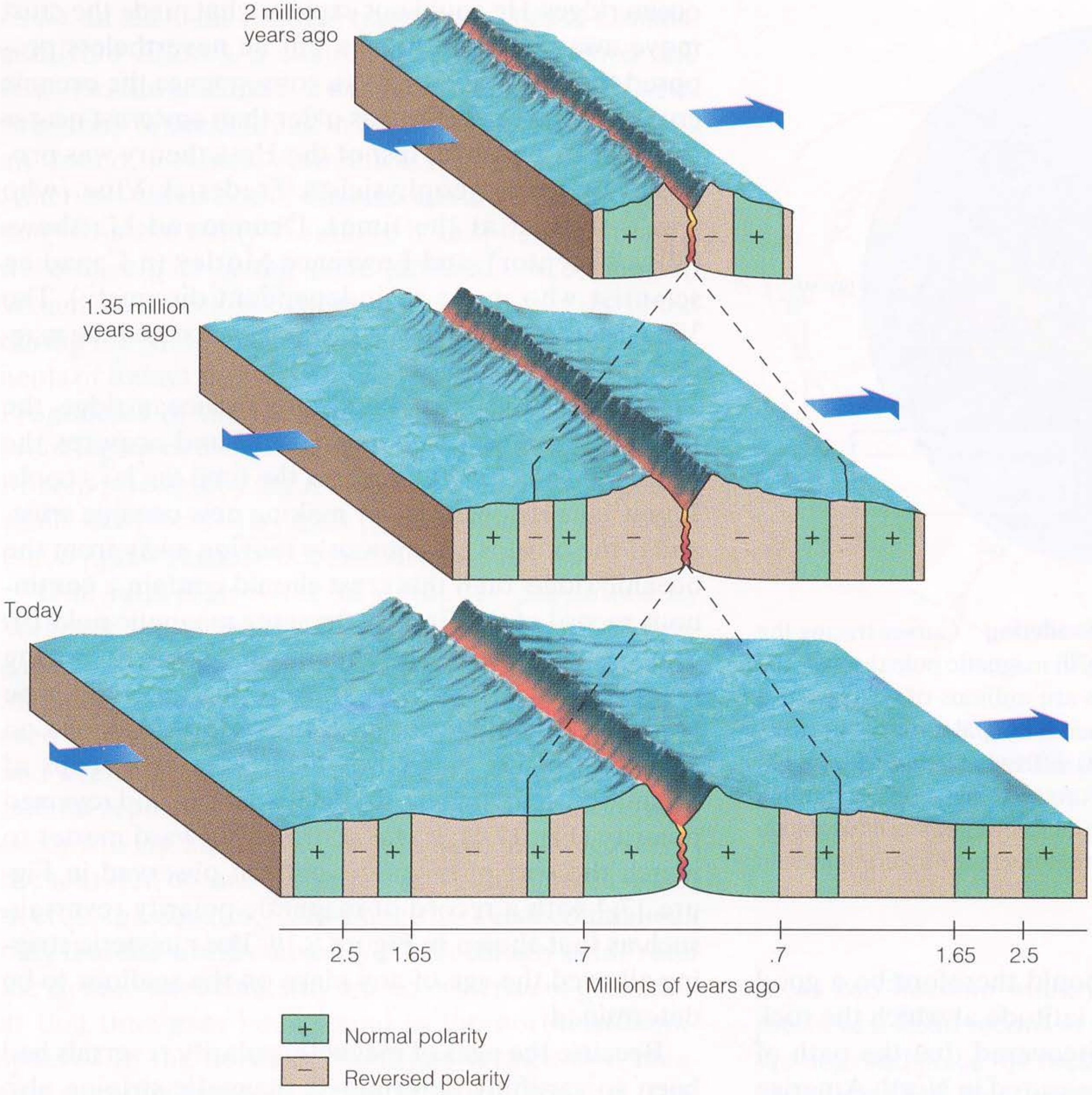
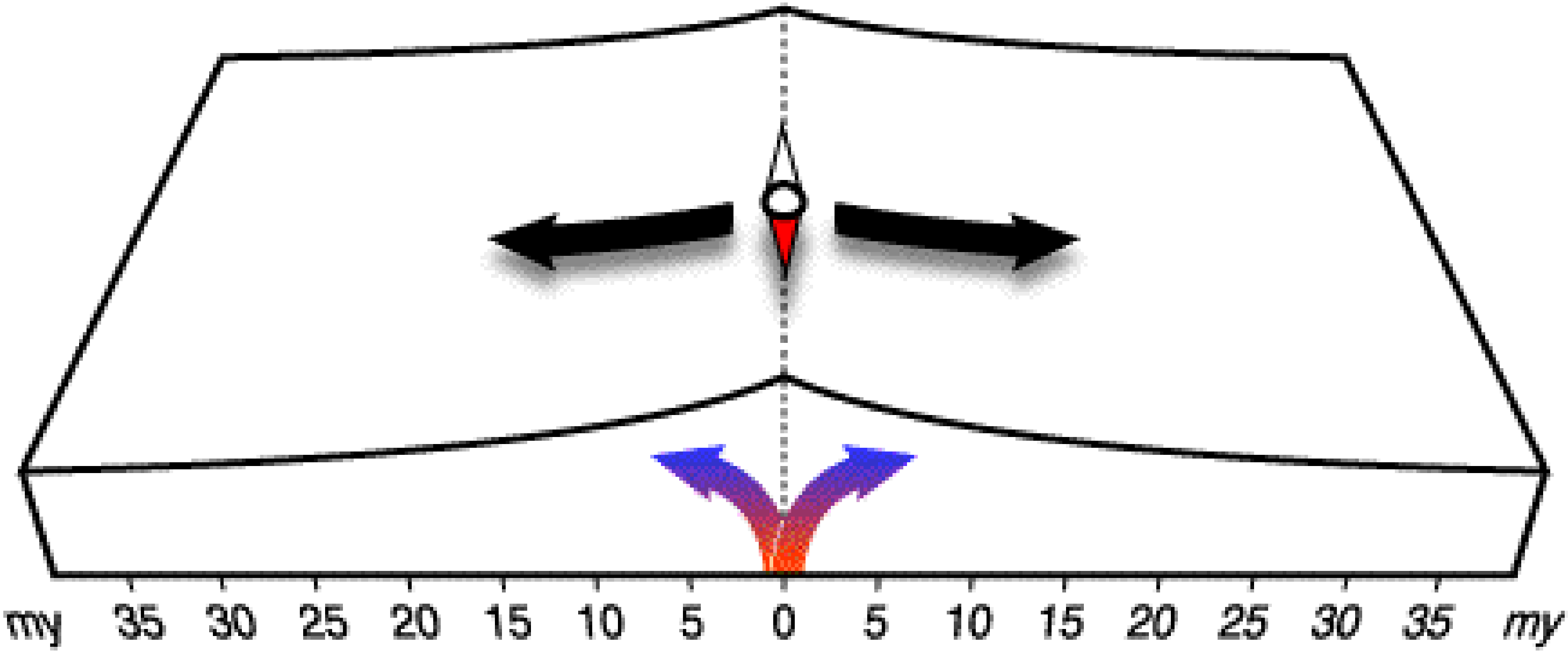


Figure 17.4 Oceanic Crust Records Magnetic Reversals Schematic diagram of oceanic crust. Lava extruded along an oceanic ridge forms new oceanic crust. As the lava cools, it becomes magnetized with the polarity of the Earth's magnetic field. Successive strips of oceanic crust have alternate normal (green) and reversed (brown) polarity. The ages of the reversals are the same as those in the magnetic polarity time scale shown in Figure 8.19.

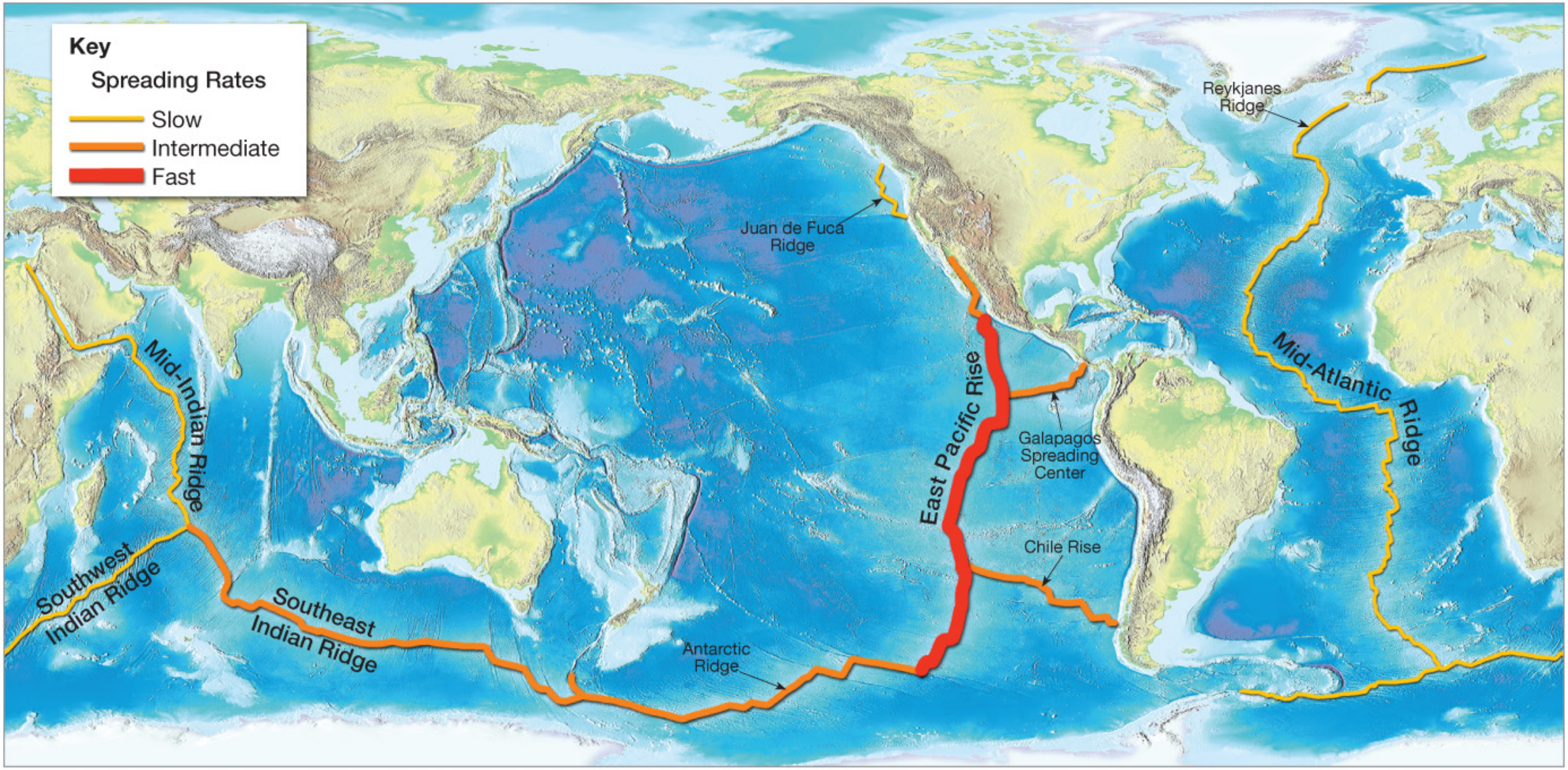

my
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
my

PLATES

The outer rigid layer of earth - the *lithosphere* is divided into a mosaic of seven major plates and a number of smaller subplates.

Plate boundaries are the most significant structural elements of the planet Earth because they reflect the internal dynamics of the planet.

The new geography of *tectonic plates* is much different than the classical physical geography of our planet (distribution of continents and oceans) and more important in Geology.



© 2011 Pearson Education, Inc.

Continental rifting leading to complete continental separation is always accompanied by the development of new ocean lithosphere (crust + mantle) between the fragments. This process when mantle-born mafic magma rises along the pre-separation rift, is known as “sea-floor spreading” and it occurs along slow-spreading ridges and fast-spreading rises.

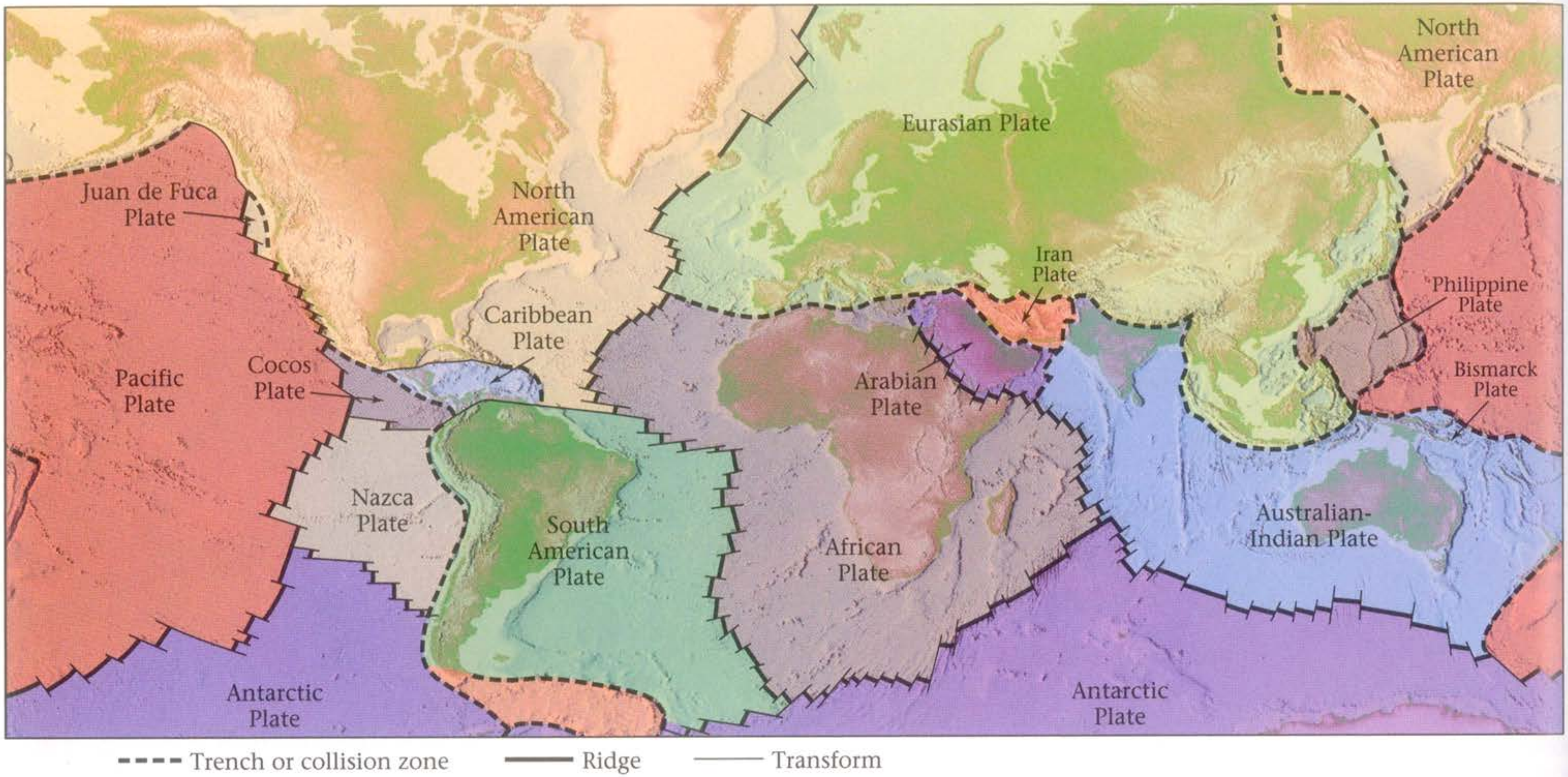
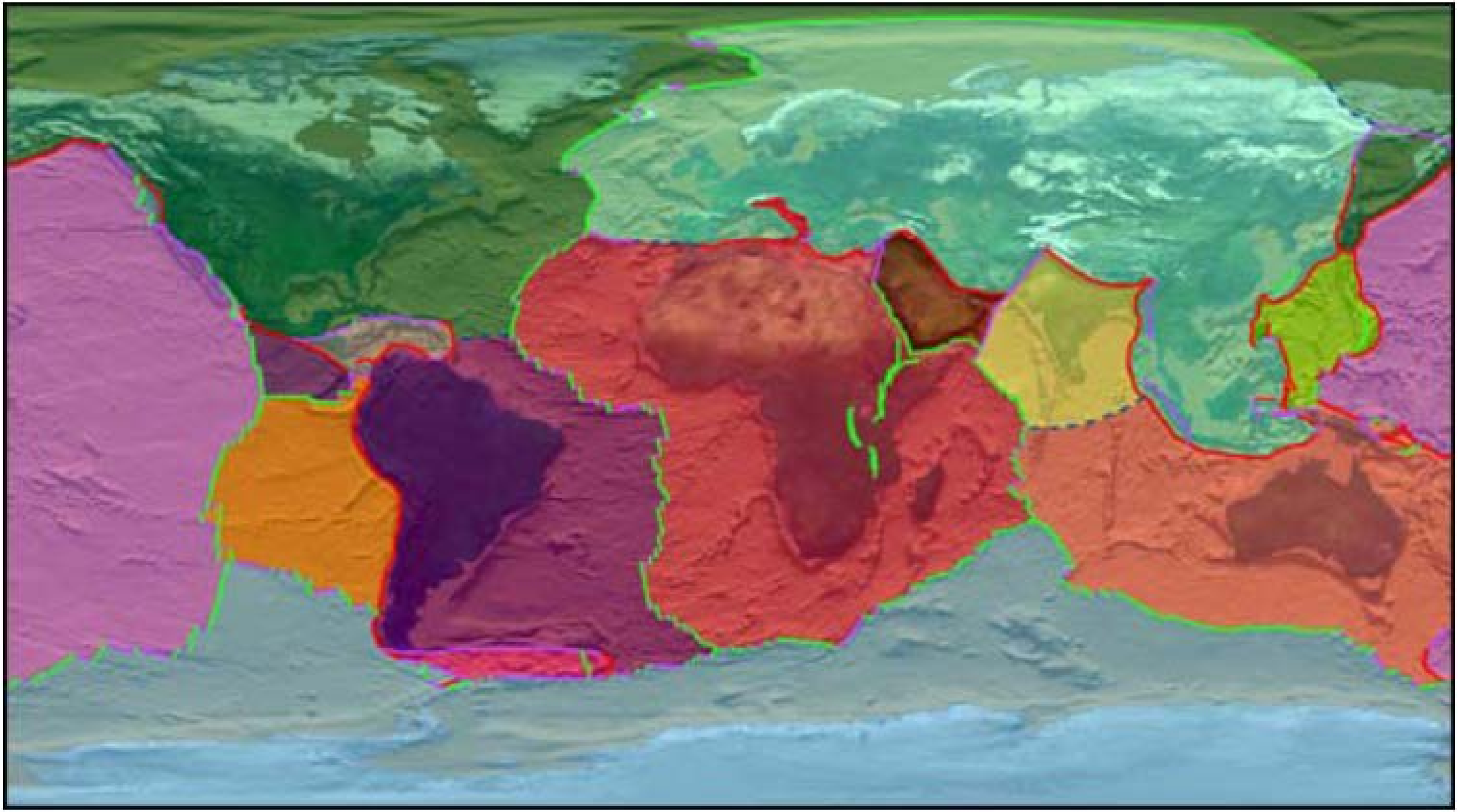


FIGURE 4.3 The major plates making up the lithosphere. Note that some plates are all ocean floor, while some contain both continents and oceans. Thus, some plate boundaries lie along continental margins (coasts), while others do not. For example, the eastern border of South America is not a plate boundary, but the western edge is.

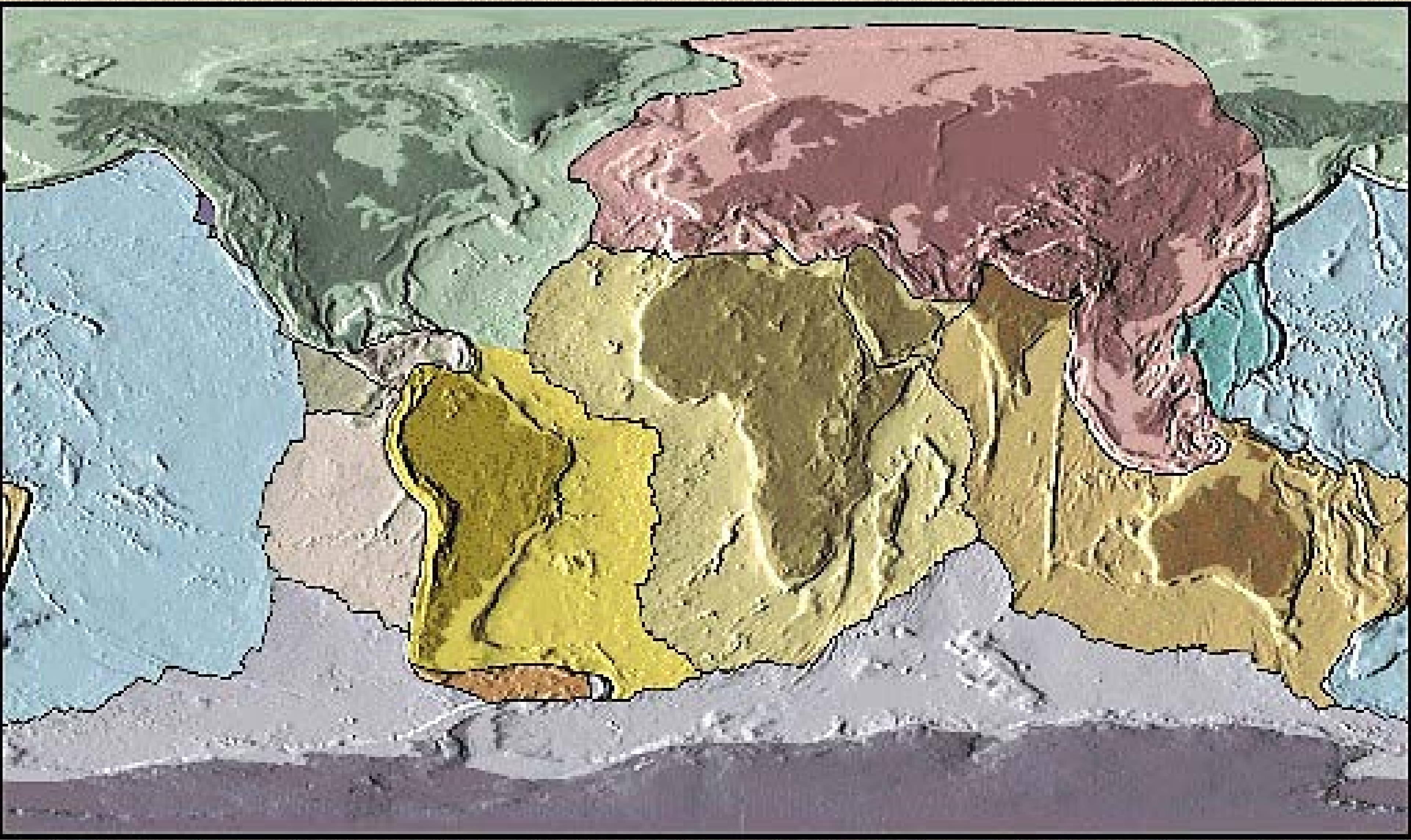


🟩 Divergent plate boundaries

🟥 Convergent plate boundaries

🟪 Transform plate boundaries

Courtesy Greg Davis



The earth’s uppermost layer, called Lithisphere, is divided into different blocks called plates. The mosaic of lithospheric plates of Earth

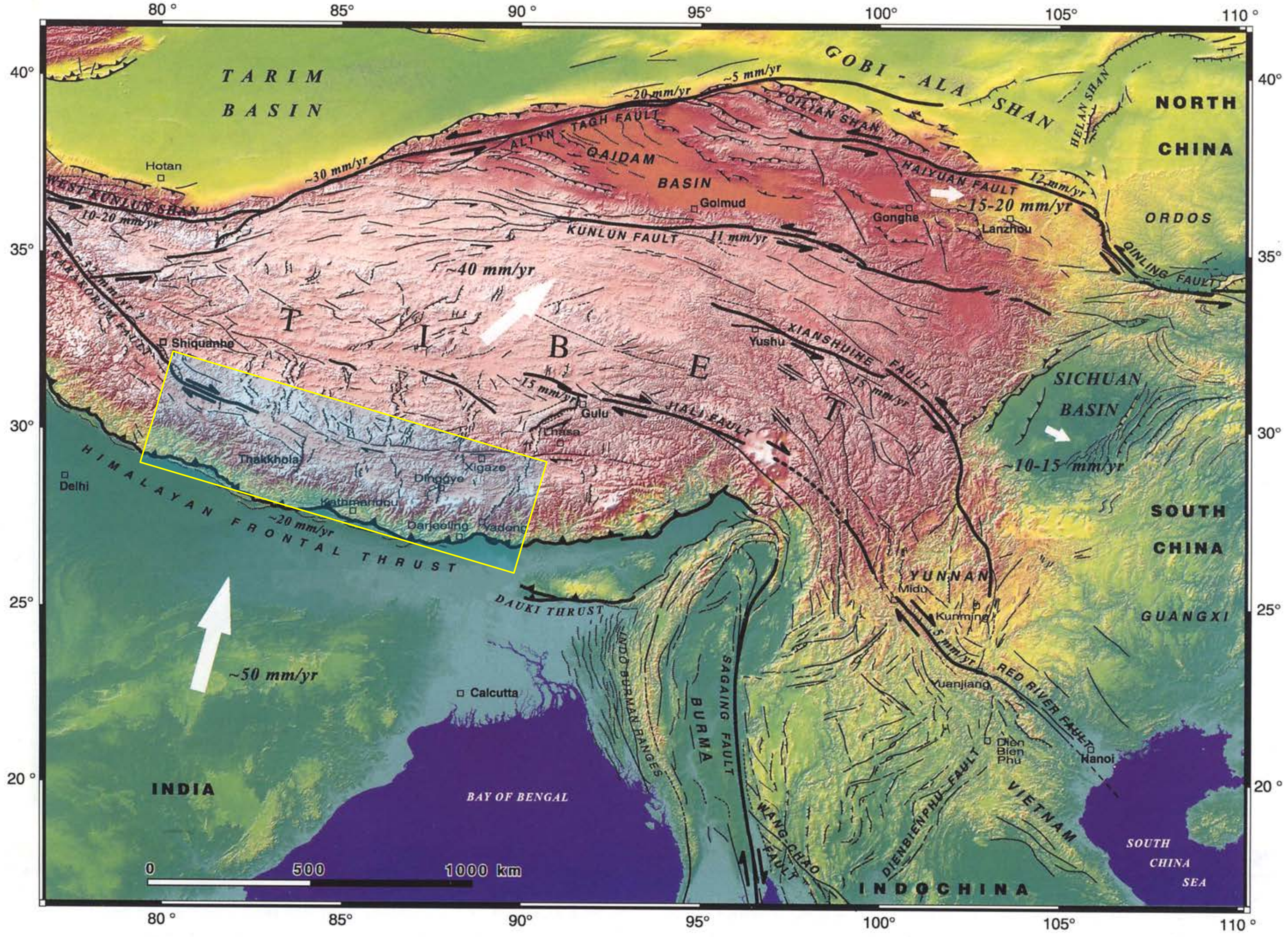


Fig. 1. Topography (*3*) and principal active faults of Tibet and adjacent regions (*1*, *2*, *4*, *12*, *21–27*, *53*, *54*, *56*, *57*, *99*). Bold lines are faults that slip at 5 mm/year or more. Bold numbers indicate rates where known. Thin lines, slower slipping faults. Dashed thin lines, inferred faults. Dotted lines, recent or growing folds. White arrows indicate motions of India, central Tibet, northeasternmost Tibet, and Sichuan relative to Siberia (*56*, *57*, *94*, *100*).

Tapponnier et al. 2001

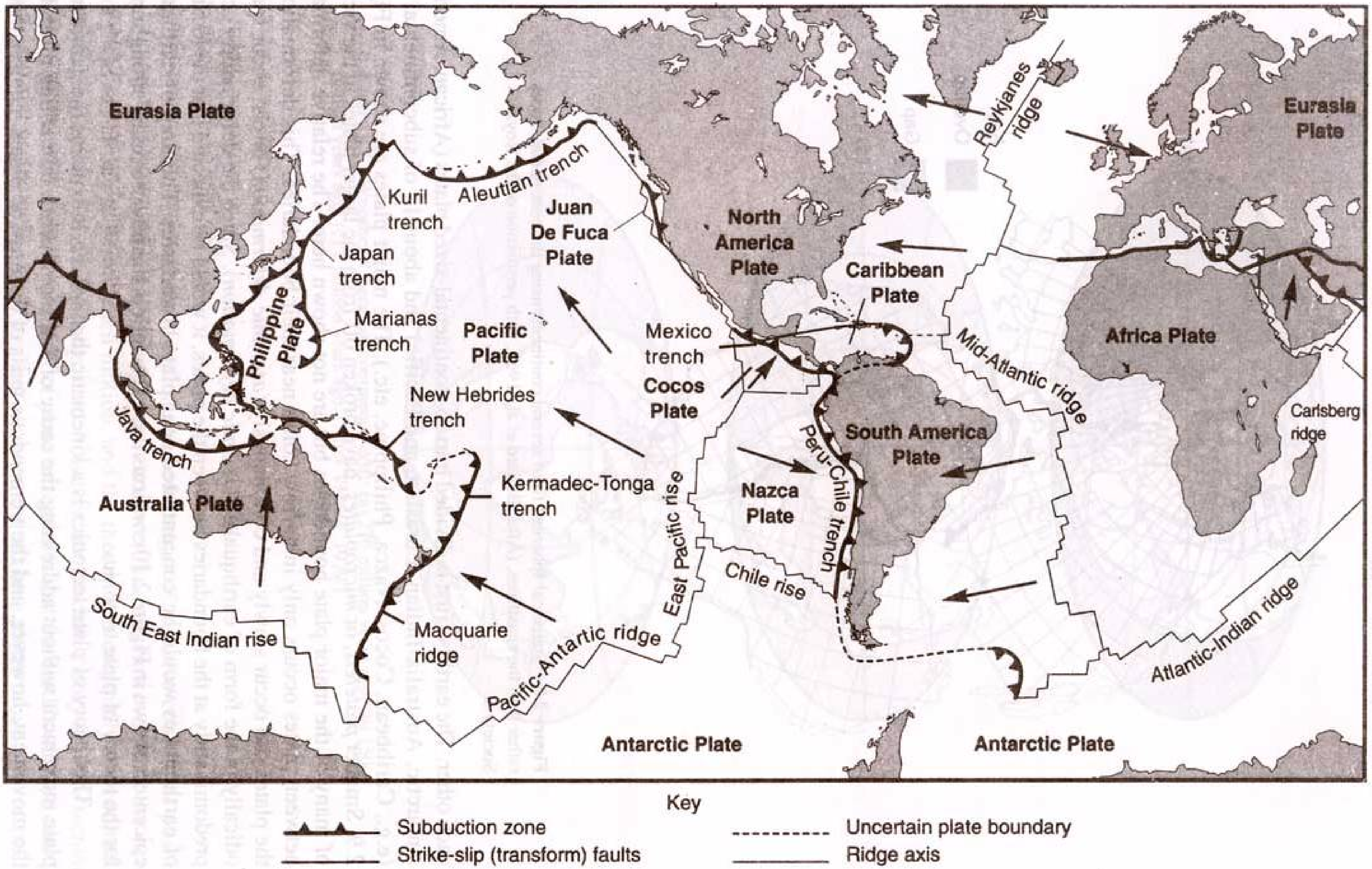
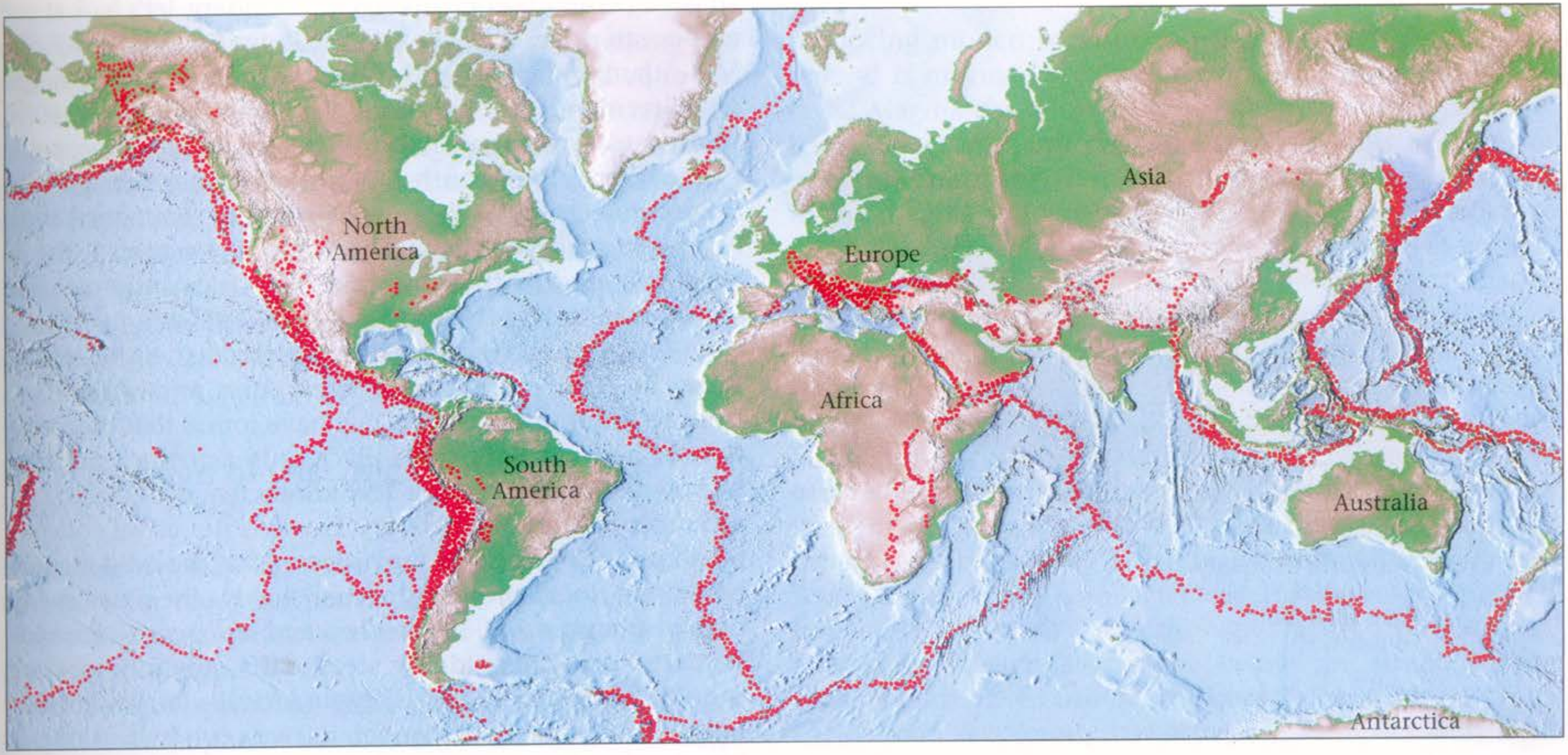


Figure 2.9 The major tectonic plates, mid-oceanic ridges, trenches, and transform faults of the earth. Arrows indicate directions of plate movement. (After Fowler, 1990.)

FIGURE 4.5 The locations of most earthquakes fall in distinct bands. These earthquake belts define the positions of the plate boundaries.



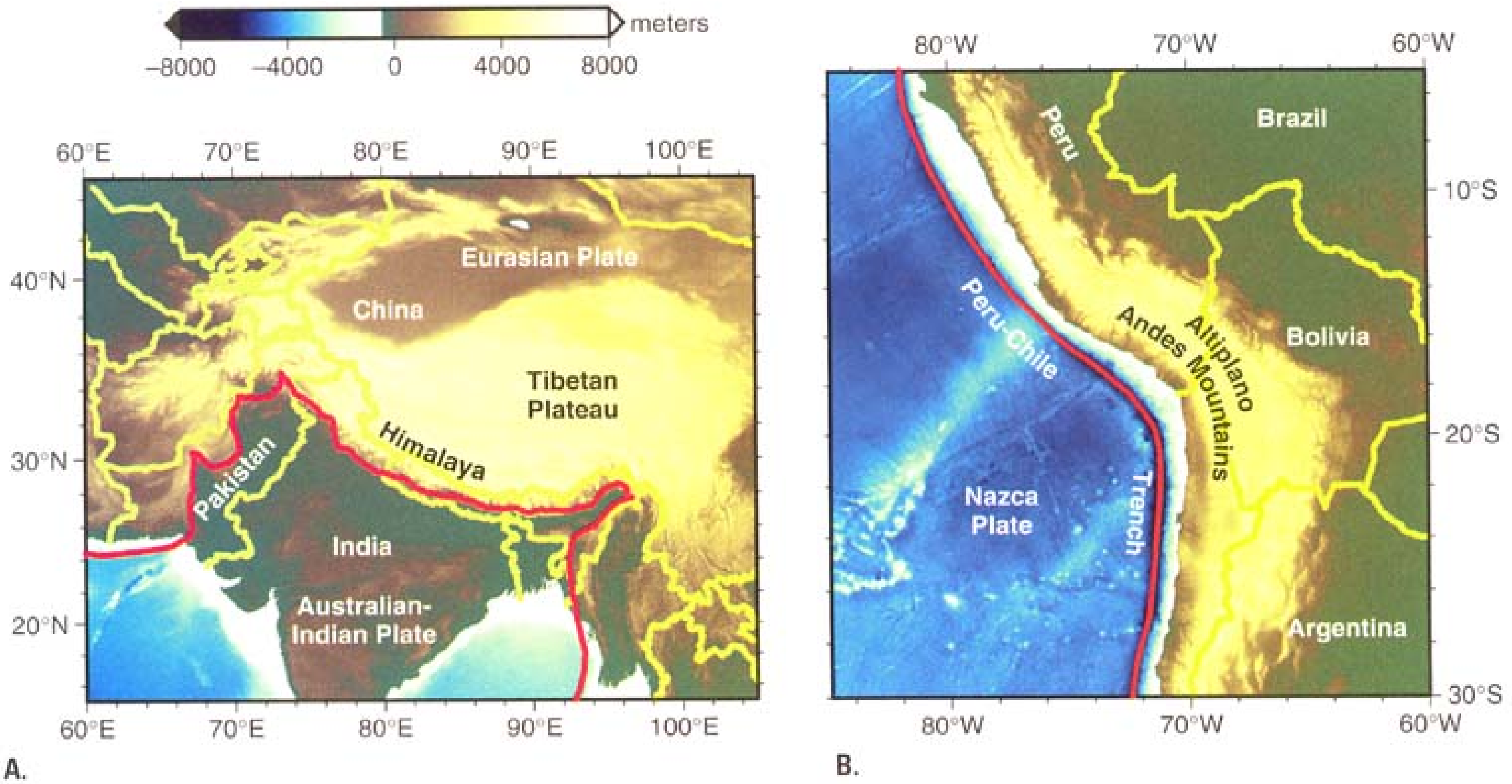


Figure 12.3 Continental Plateaus Along Convergent Plate Boundaries Color-coded elevation maps of (A) the Tibetan Plateau, formed along the collision between the Australian–Indian Plate and the Eurasian Plate; and (B) the Altiplano ("high fl
face" in Spanish), formed along the subduction boundary between the Nazca Plate and the South American Plate.

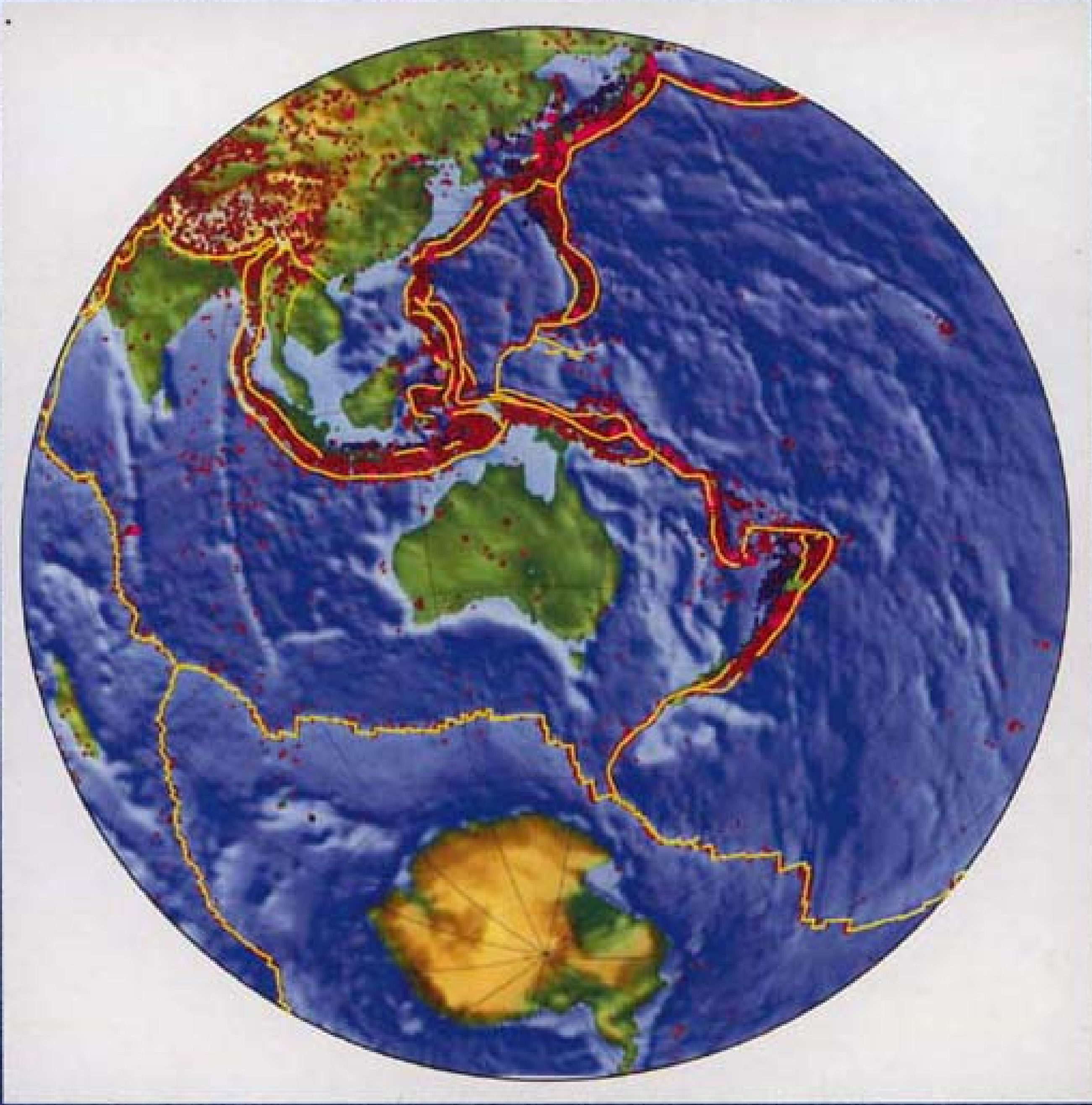
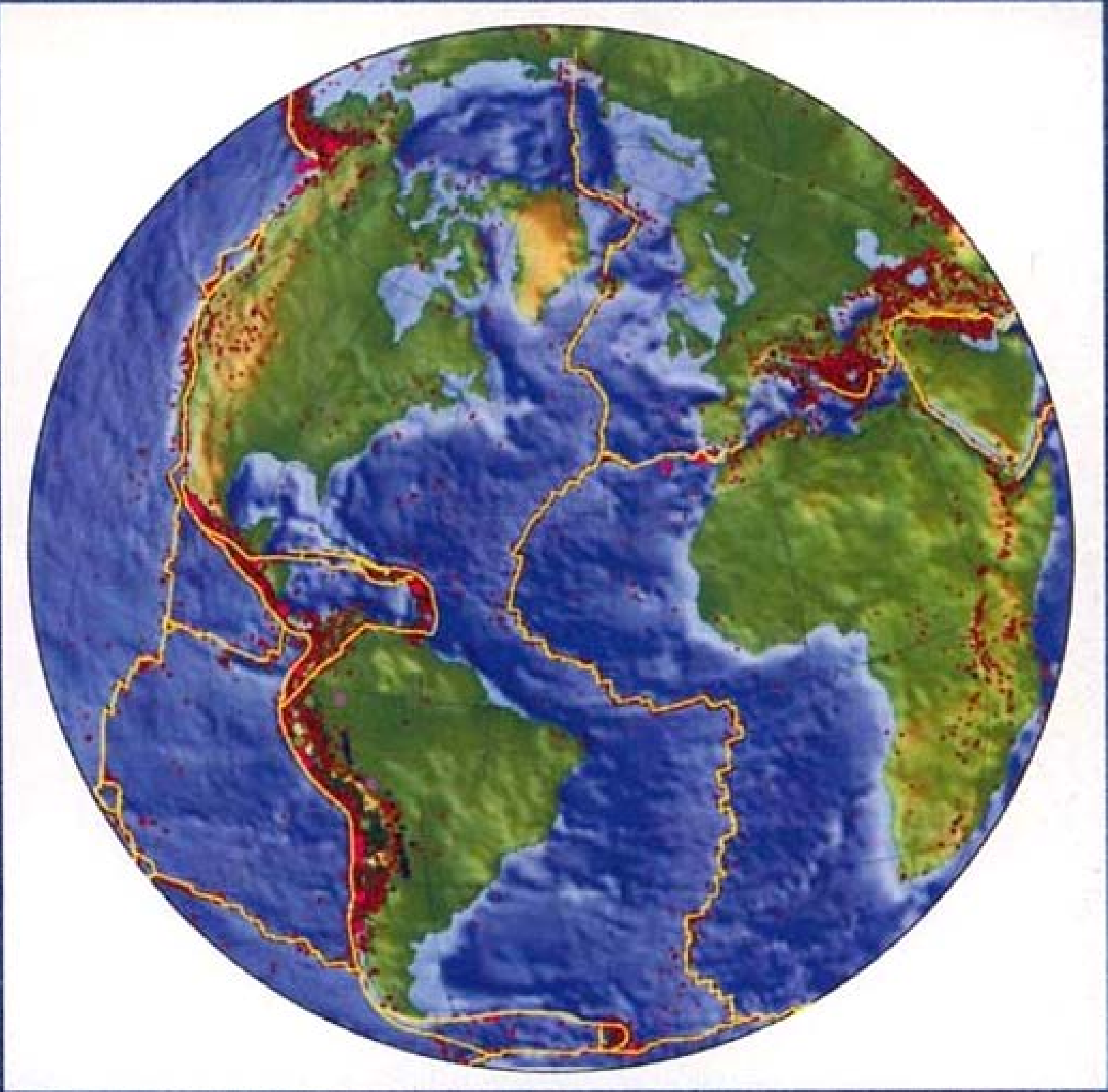
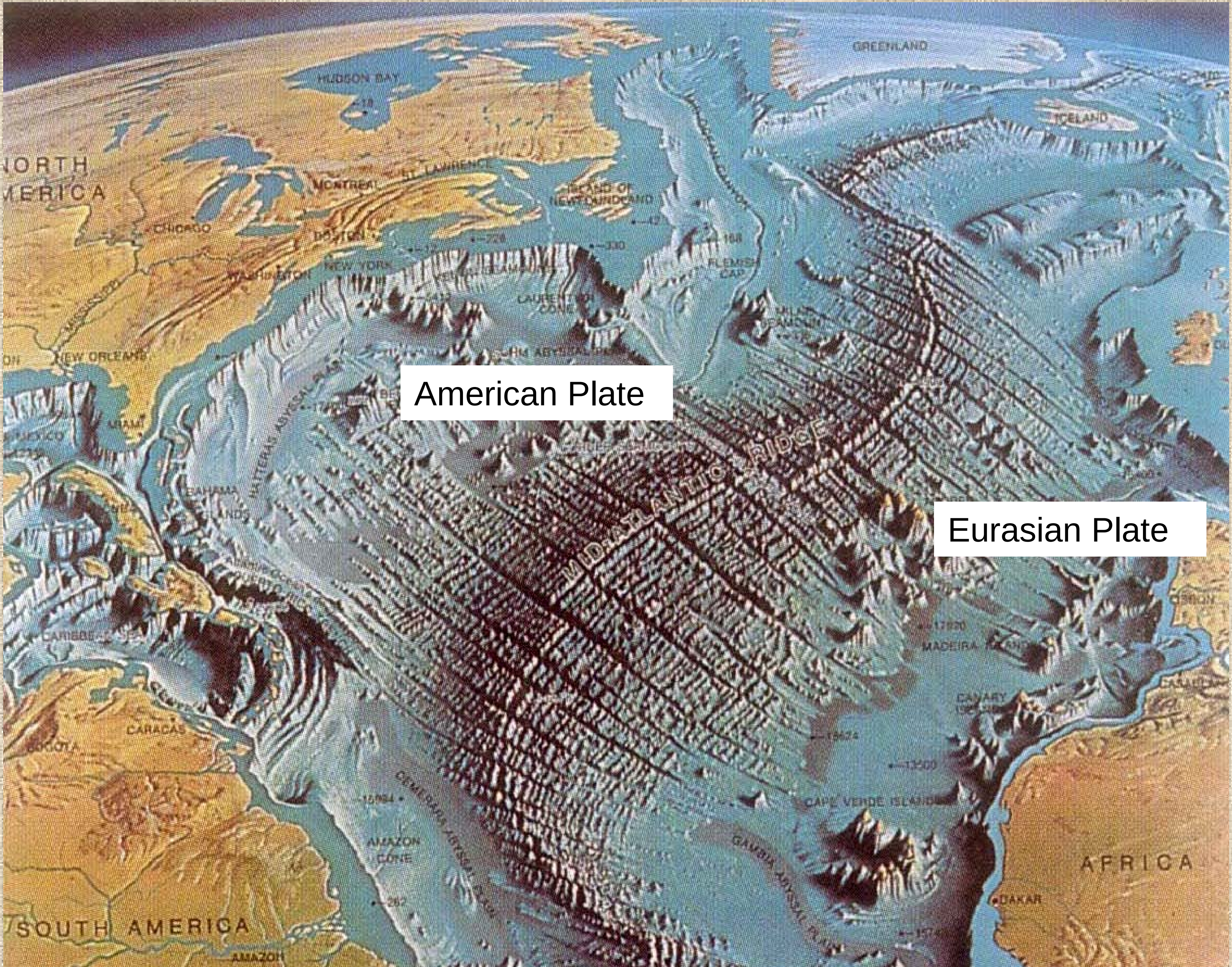


PLATE 10
Seismicity of the Earth, 1964 to 1995 (magnitudes greater than 5.1), with tectonic plate boundaries superimposed. The large circles are major earthquakes with a magnitude over 6.4. This Pacific projection is centered on the Indo-Australia plate. [Courtesy of International Association of Seismology and the Earth's Interior.]

PLATE 11
Projection of the Atlantic hemisphere showing the America and Africa plates, and the mid-Atlantic seismically active ridge. The seismicity and plate boundaries are similar to those in Plate 10. [Courtesy of International Association of Seismology and the Earth's Interior.]

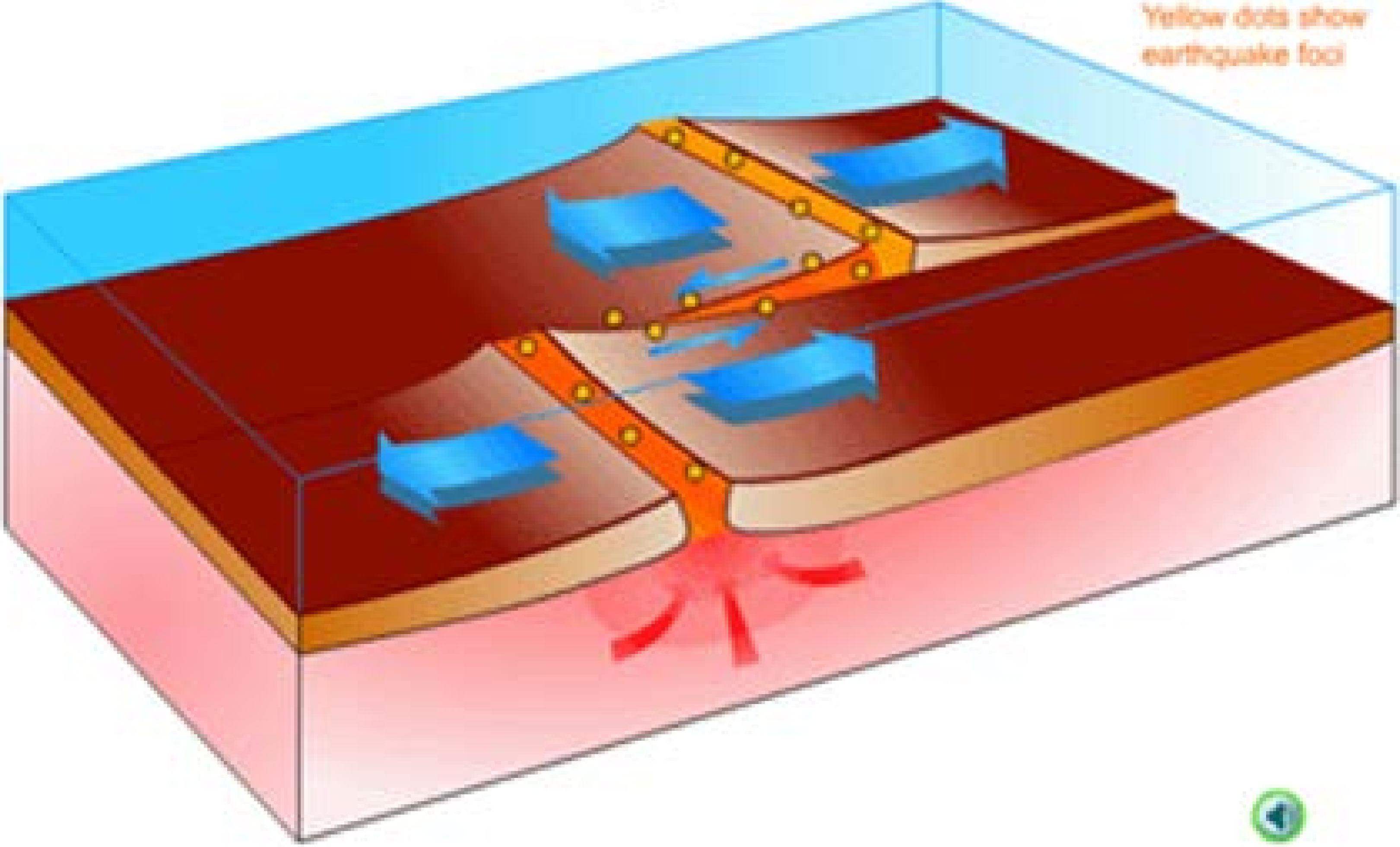




American Plate

Eurasian Plate

Transform fault at mid-ocean ridge



Yellow dots show earthquake foci

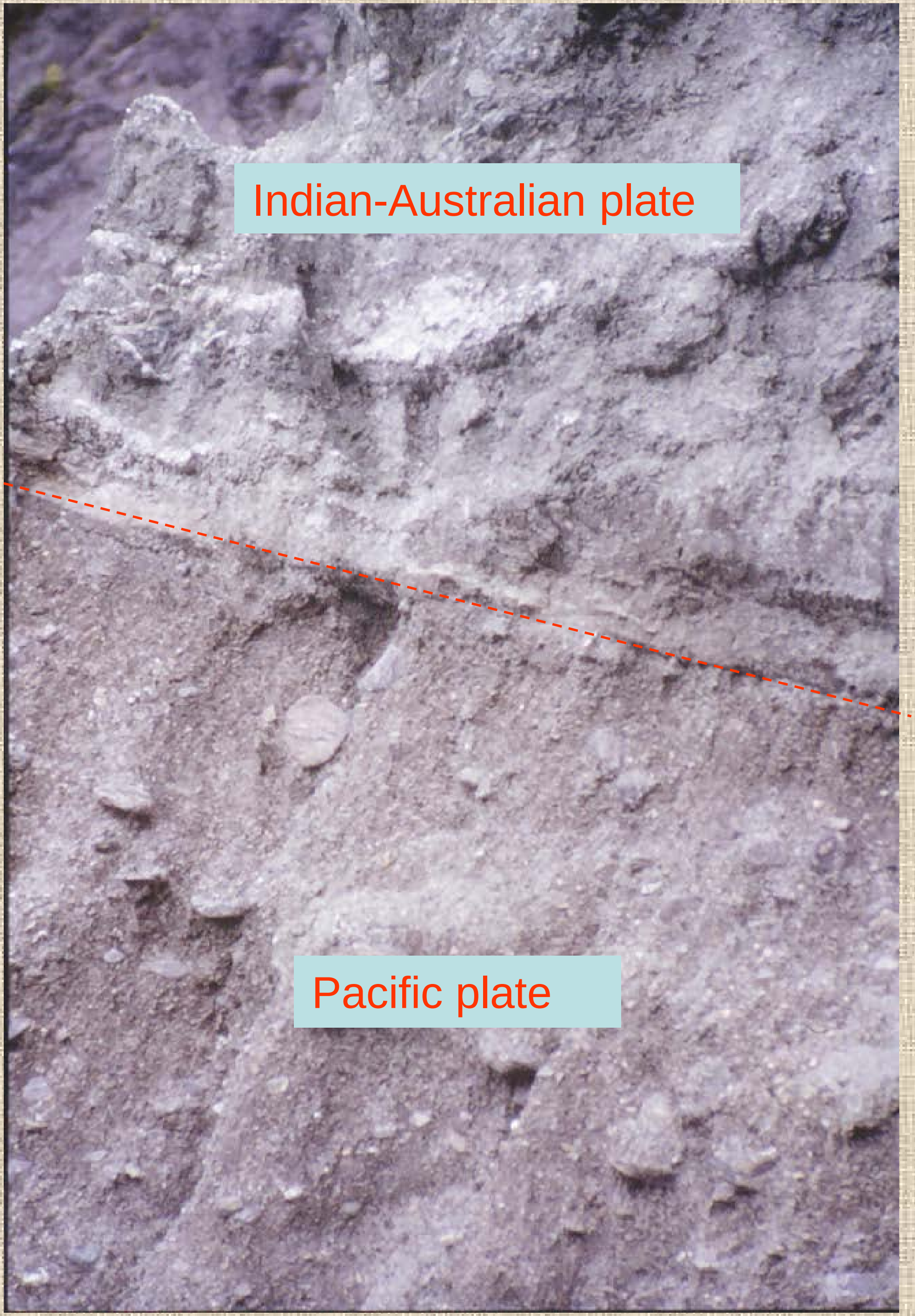
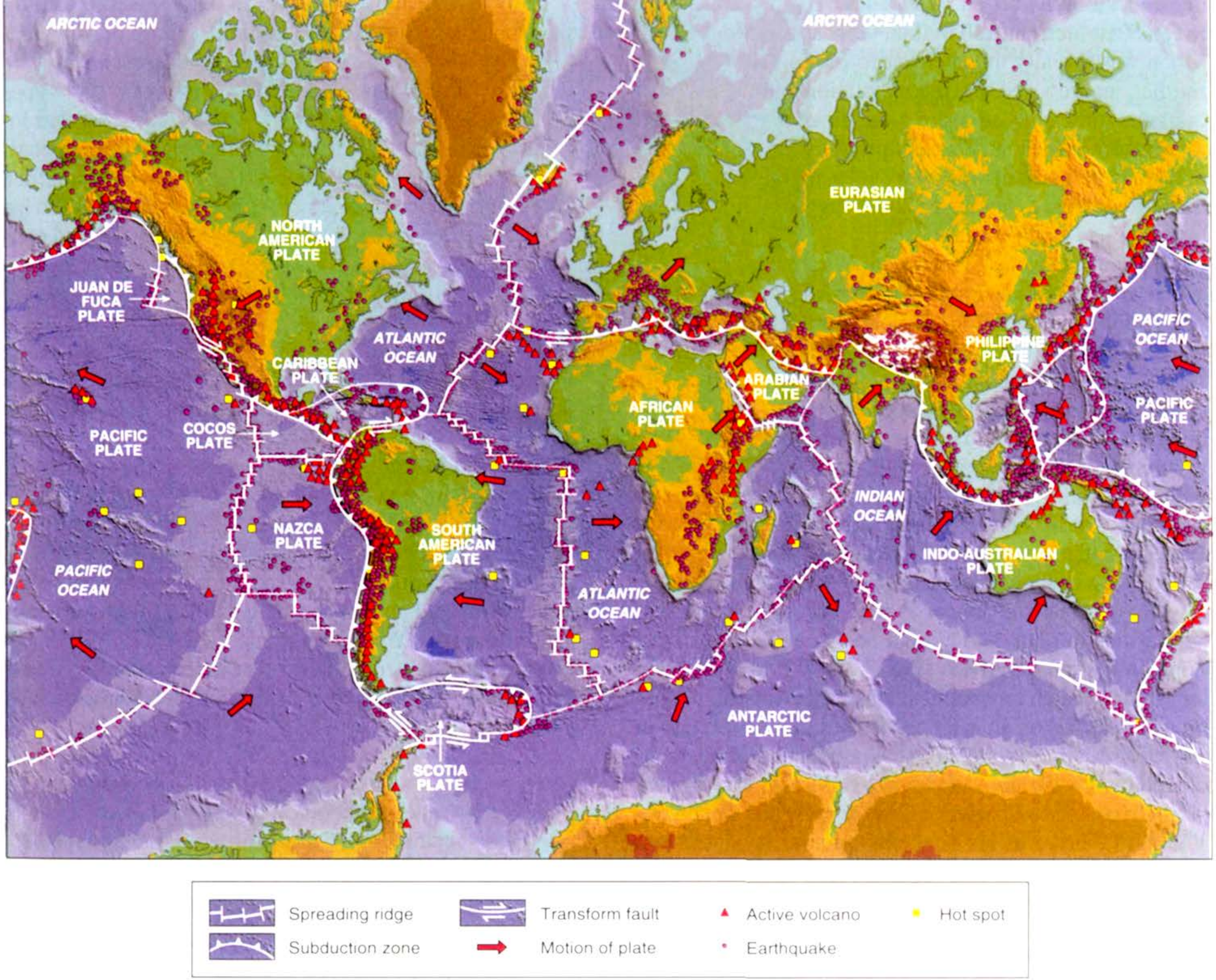


Photo taken by Upreti. An outcrop of the very sharp plate boundary in New Zealand



■ **FIGURE 7.1b** The same map as Fig. 7.1a showing hot spots, active volcanoes, and areas of abundant seismic activity. (Submarine volcanoes are not shown here.)

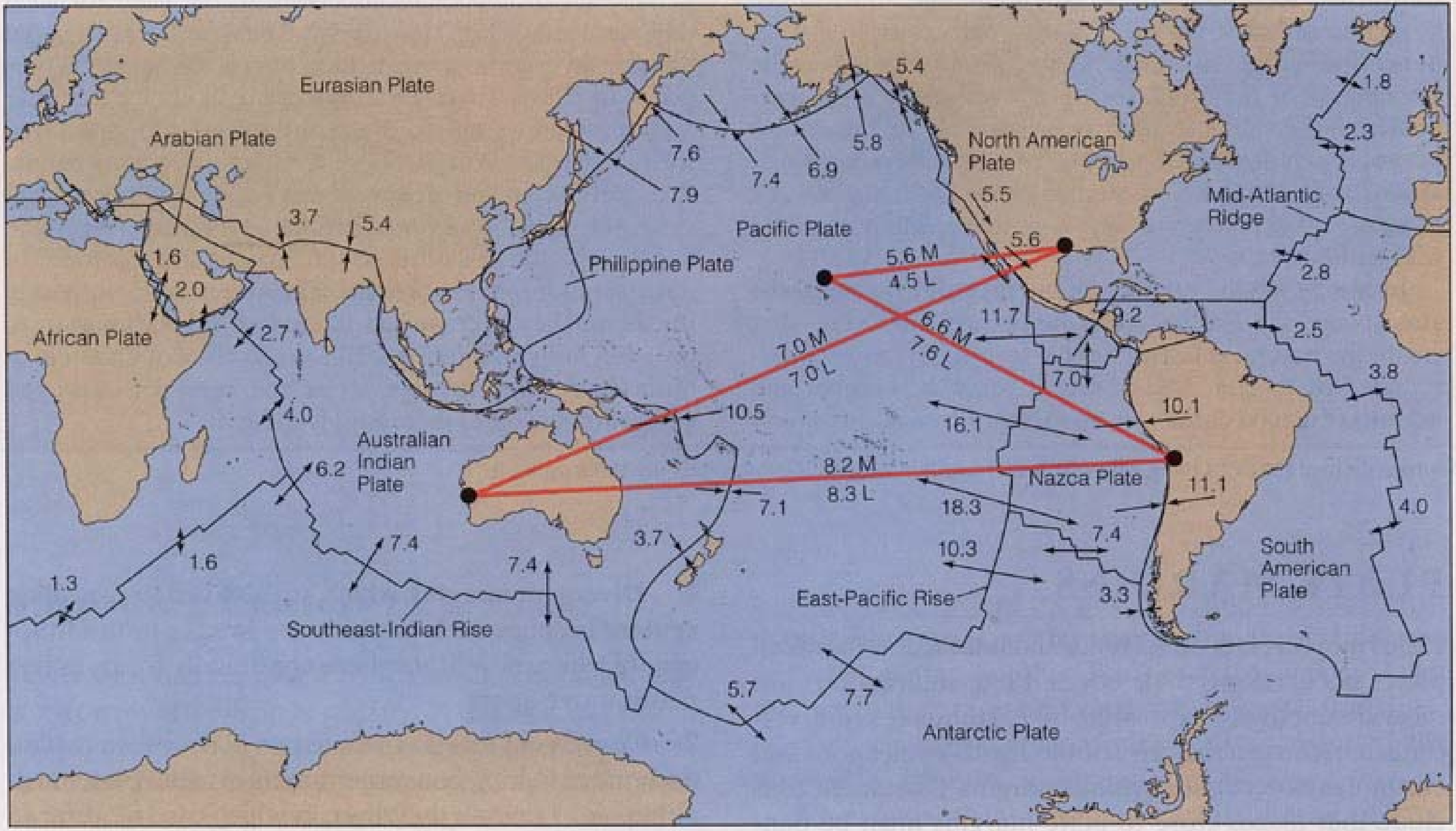


Figure 2.6 The Speed of Plates Present-day plate speeds in centimeters per year, determined in two ways. Numbers along the midocean ridges are average speeds indicated by magnetic measurements. A speed of 16.1 cm, as shown for the East Pacific Rise, means that the distance between a point on the Nazca Plate and a point on the Pacific Plate increases, on average, by 16.1 cm each year in the direction of the arrows. The long red lines connect stations used to determine plate speeds by means of laser ranging (L) techniques. The measured speeds between stations are very close to average speeds estimated from magnetic measurements (M).

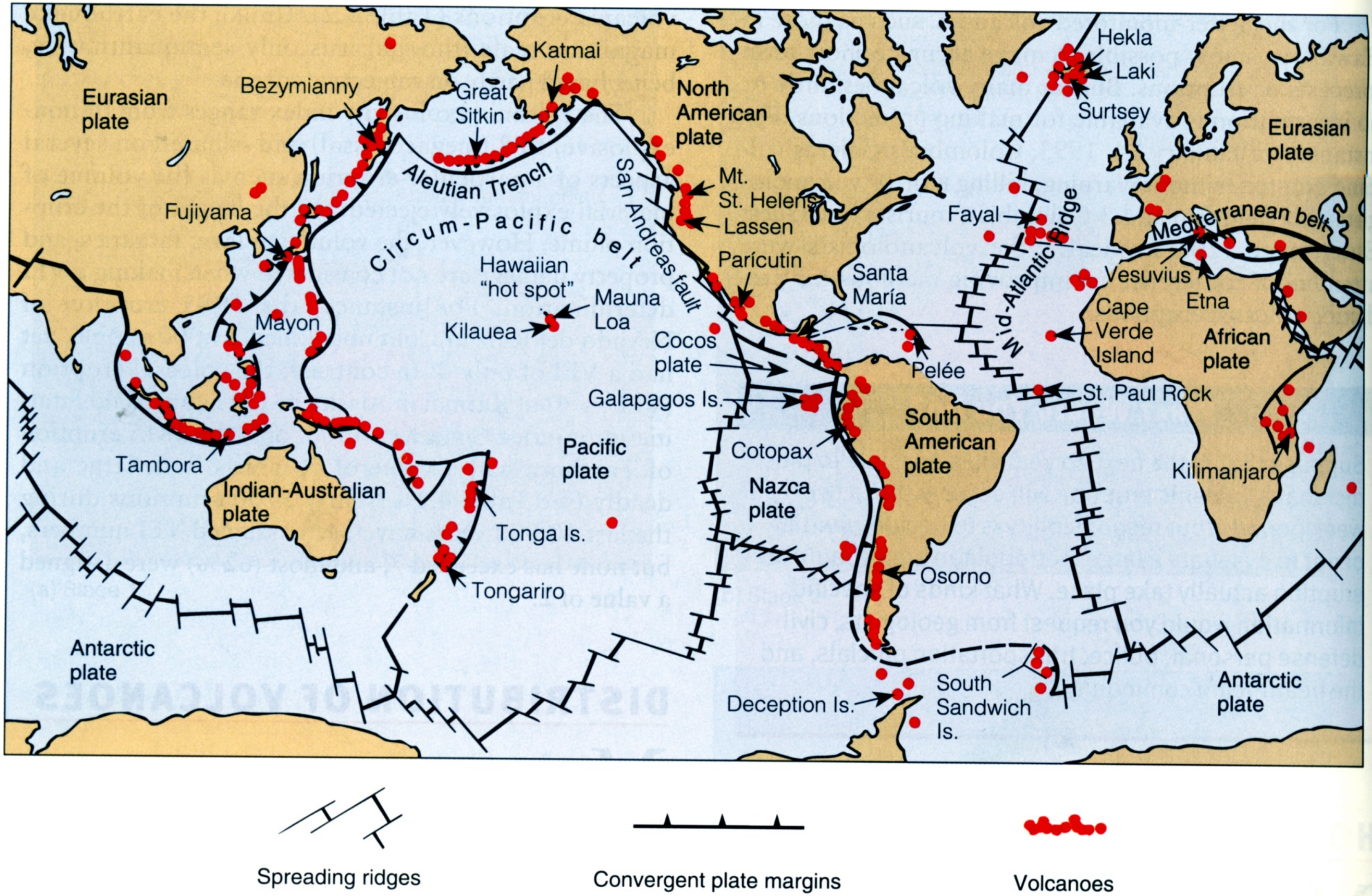


Figure 4.20

Most volcanoes are at or near plate boundaries. Two major volcano belts are recognized: The circum-Pacific belt contains about 60% of all active volcanoes, about 20% are in the Mediterranean belt, and most of the rest are located along mid-oceanic ridges.

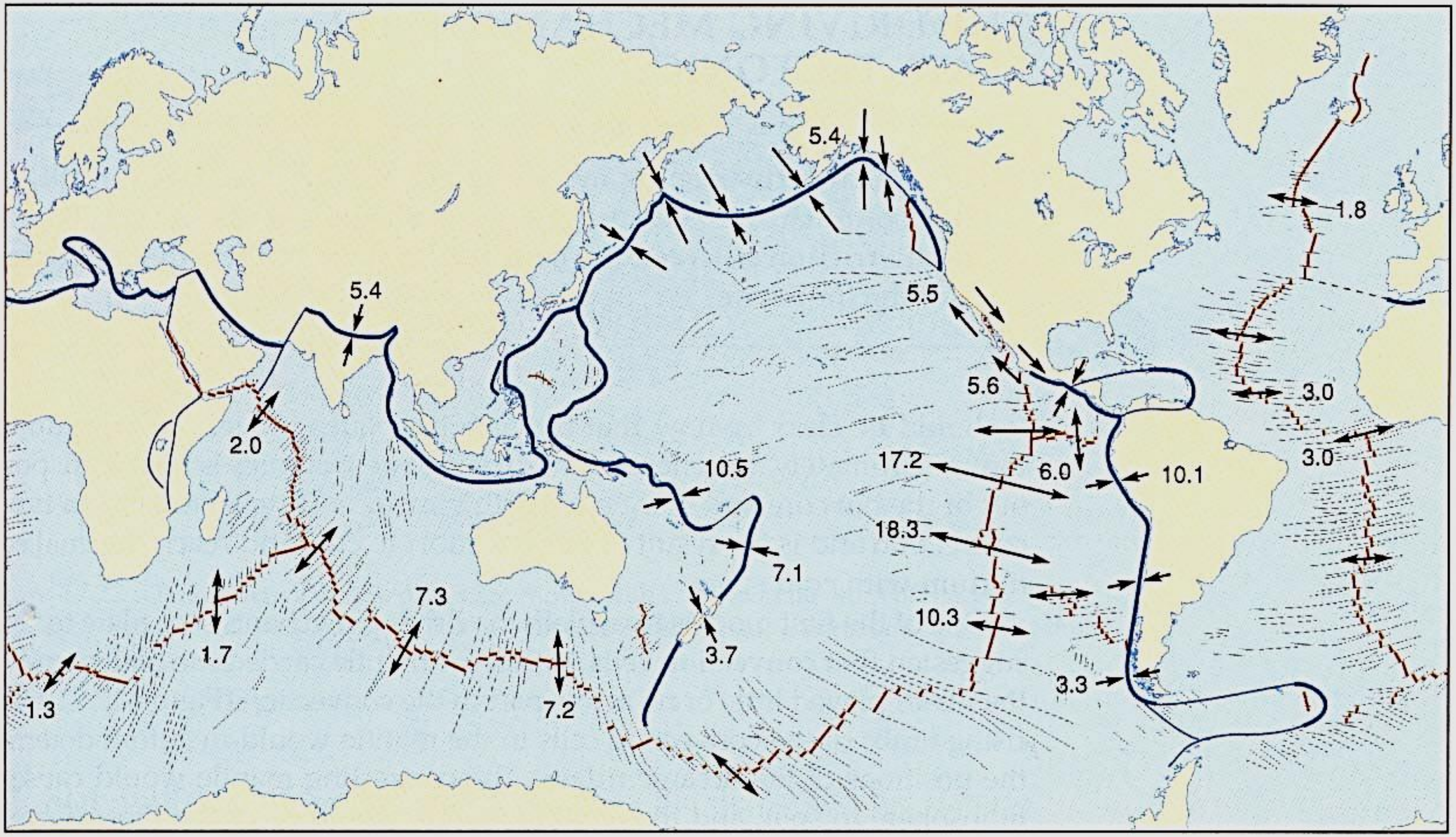
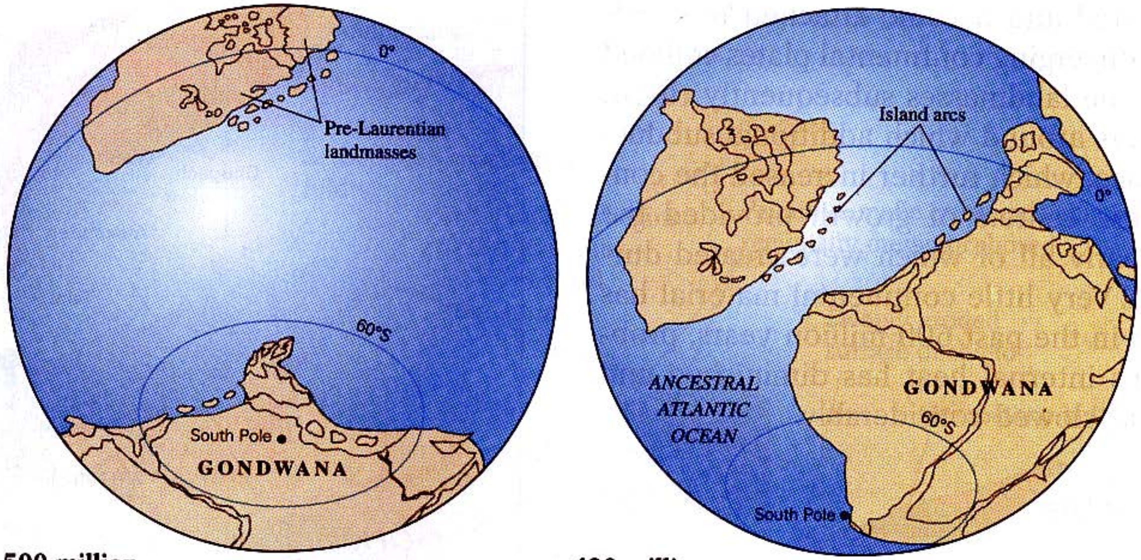
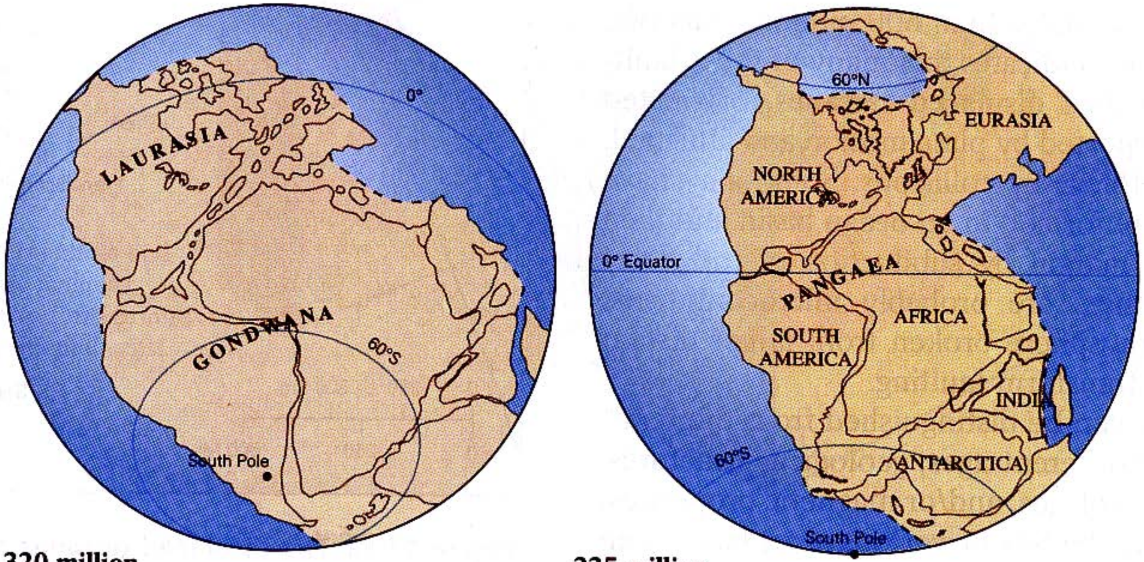


Figure 17.20 Relative velocities and directions of plate movement show how the major plates are currently interacting. The lengths of the arrows are proportional to the velocity of plate movement; the numbers represent velocity in centimeters per year.



500 million years ago

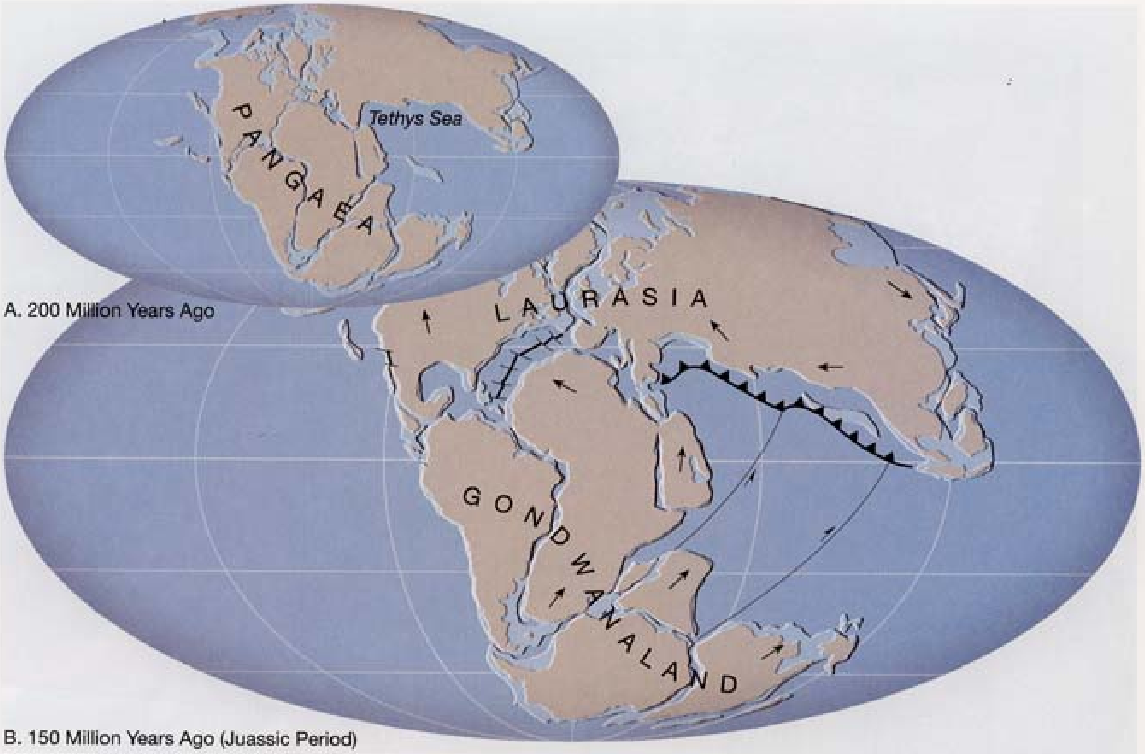
420 million years ago



320 million years ago

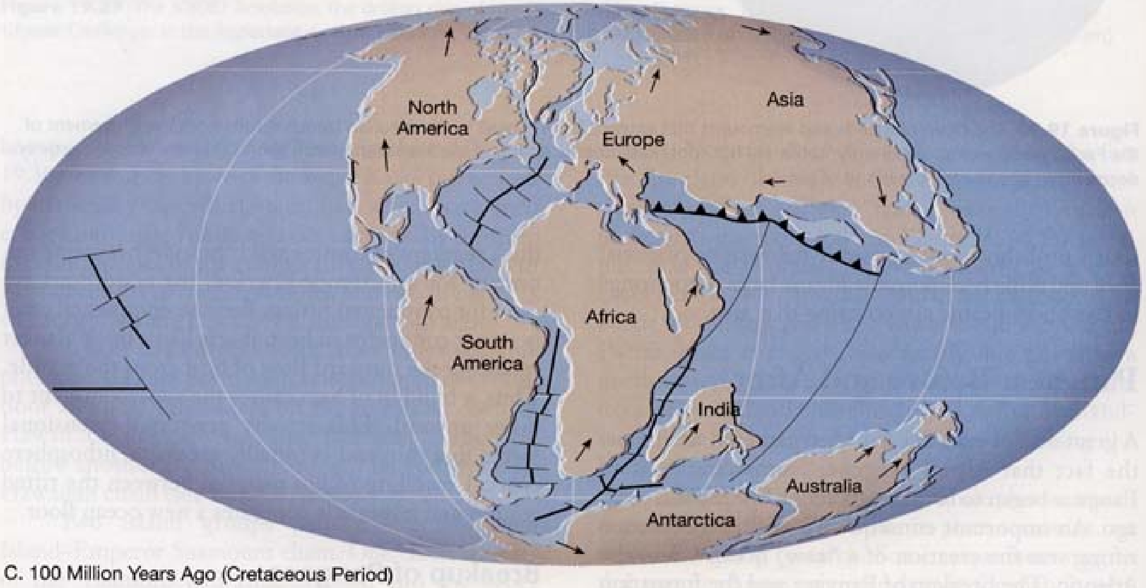
225 million years ago

Figure 11-20 The origin of the supercontinent Pangaea.



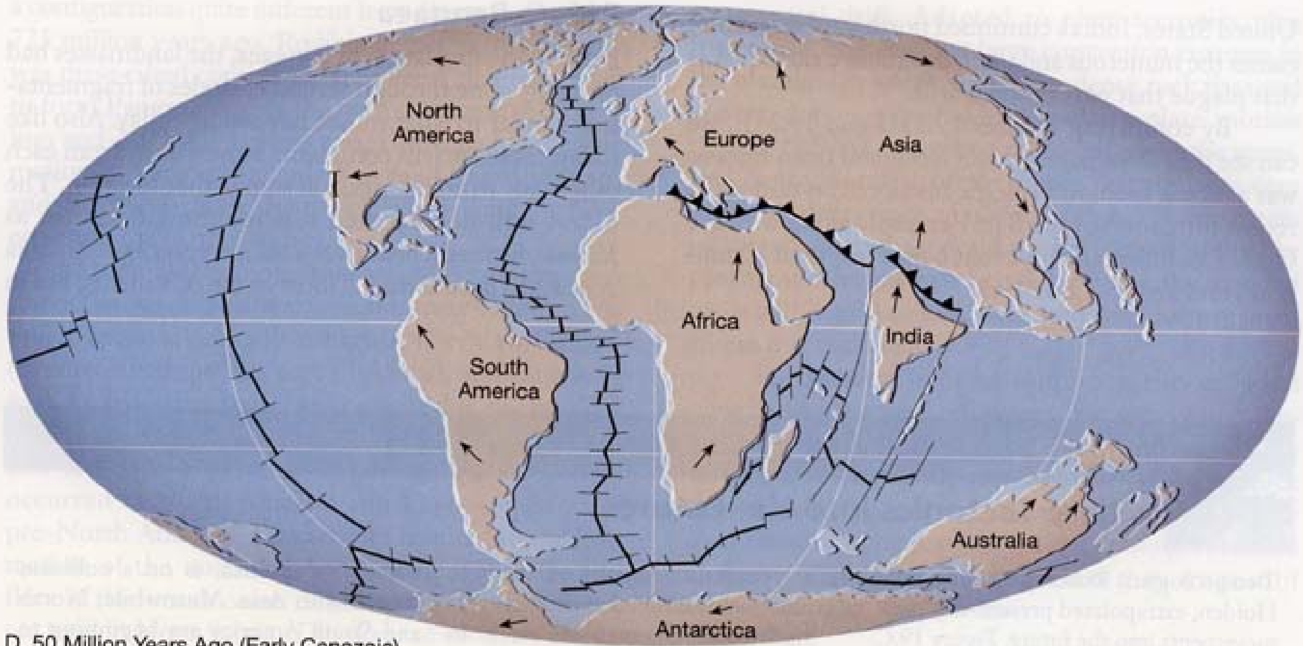
A. 200 Million Years Ago

B. 150 Million Years Ago (Juassic Period)

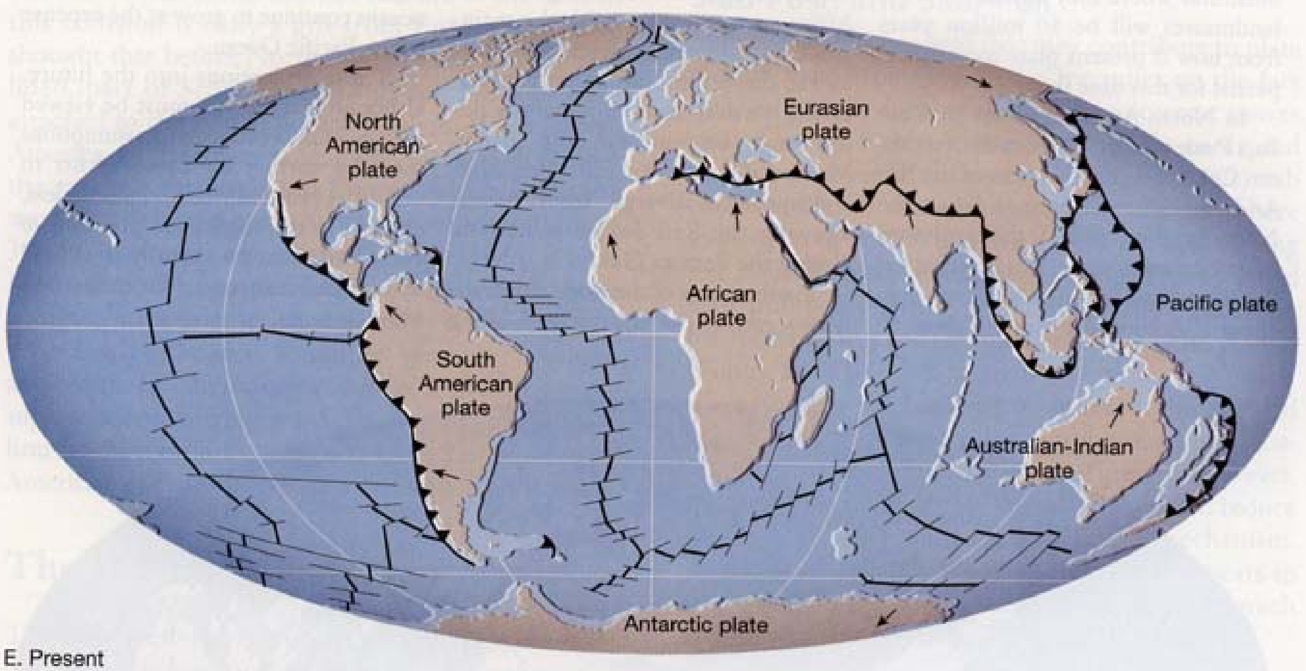


C. 100 Million Years Ago (Cretaceous Period)

Figure 19.31 Several views of the breakup of Pangaea over a period of 200 million years.



D. 50 Million Years Ago (Early Cenozoic)



E. Present

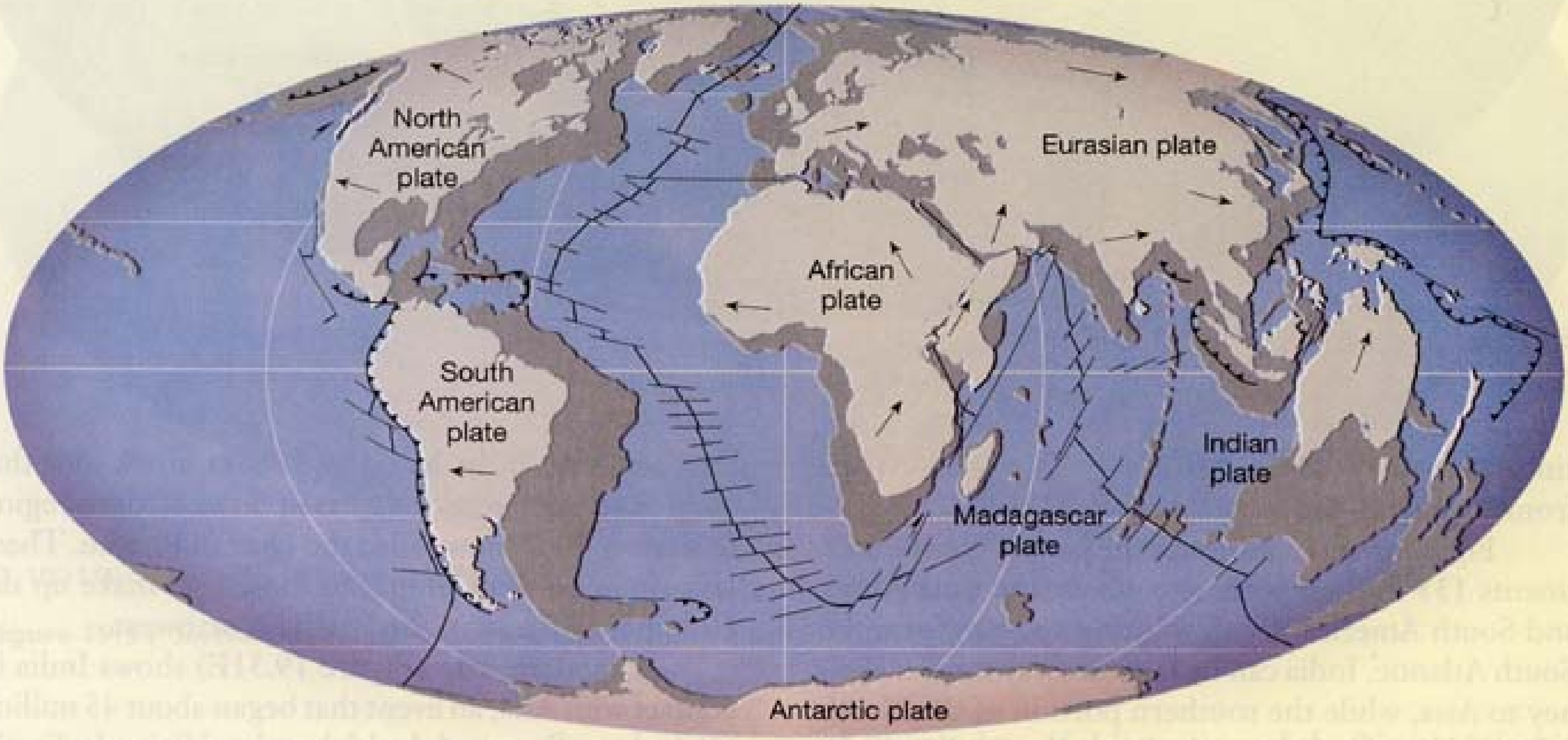


Figure 19.C The world as it may look 50 million years from now. (From "The Breakup of Pangaea," Robert S. Dietz and John C. Holden. Copyright 1970 by Scientific American, Inc. All rights reserved.)

Plate Boundaries

Three kinds of plate boundaries are recognized and define three fundamental kinds of deformation and geologic activity:

1. Divergent Plate Boundaries:
Zones of tension, where plates split and spread apart

2. Convergent Plate Boundaries:
Zones where plates collide and (*Subduction Zones)* one plate moves down into the mantle

3. Transform Fault Boundaries:
Zones of hearing, where plates slide past each other without diverging or converging

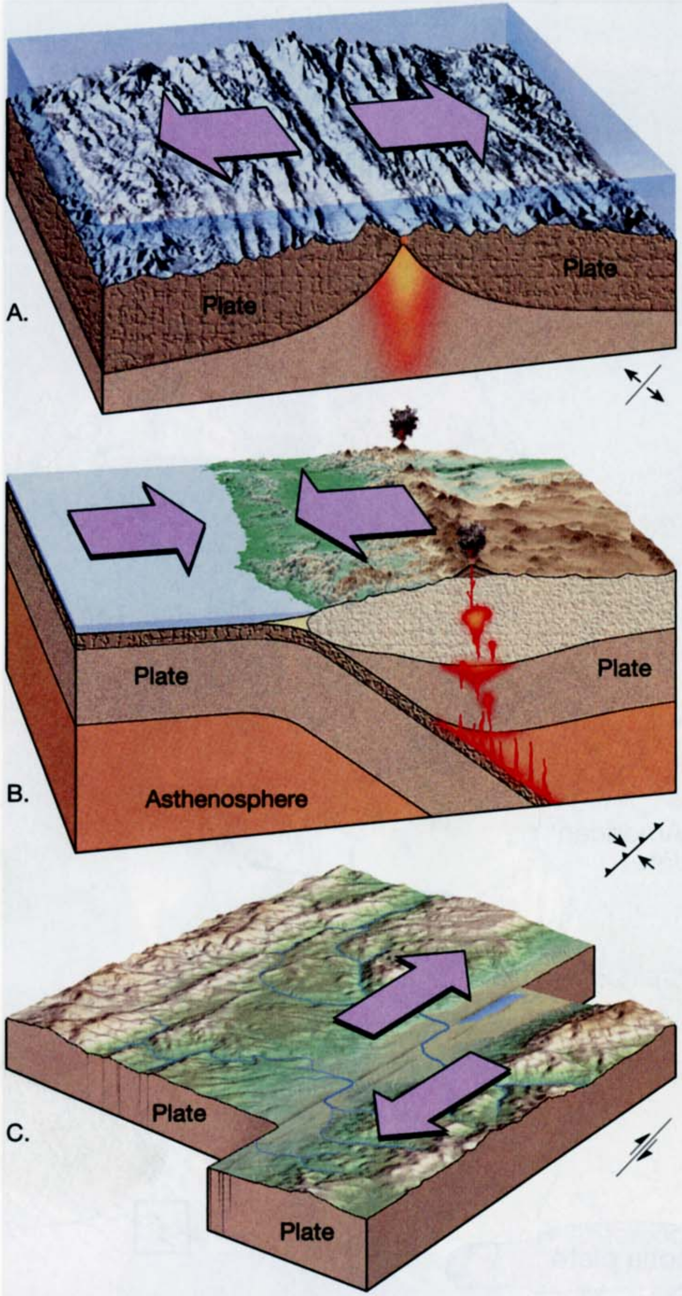
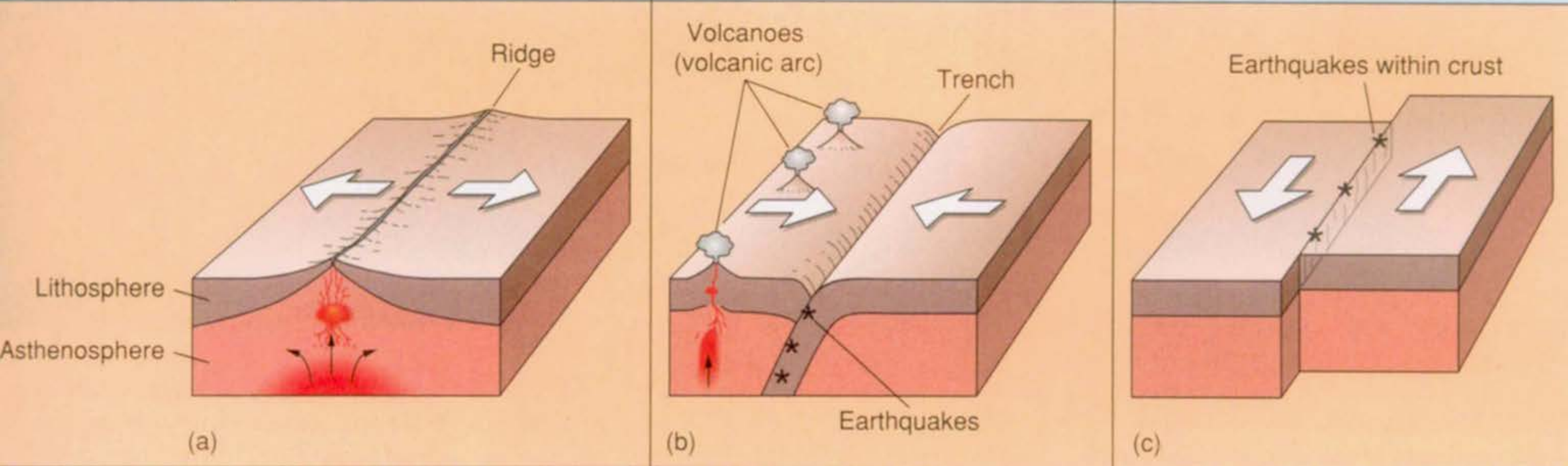
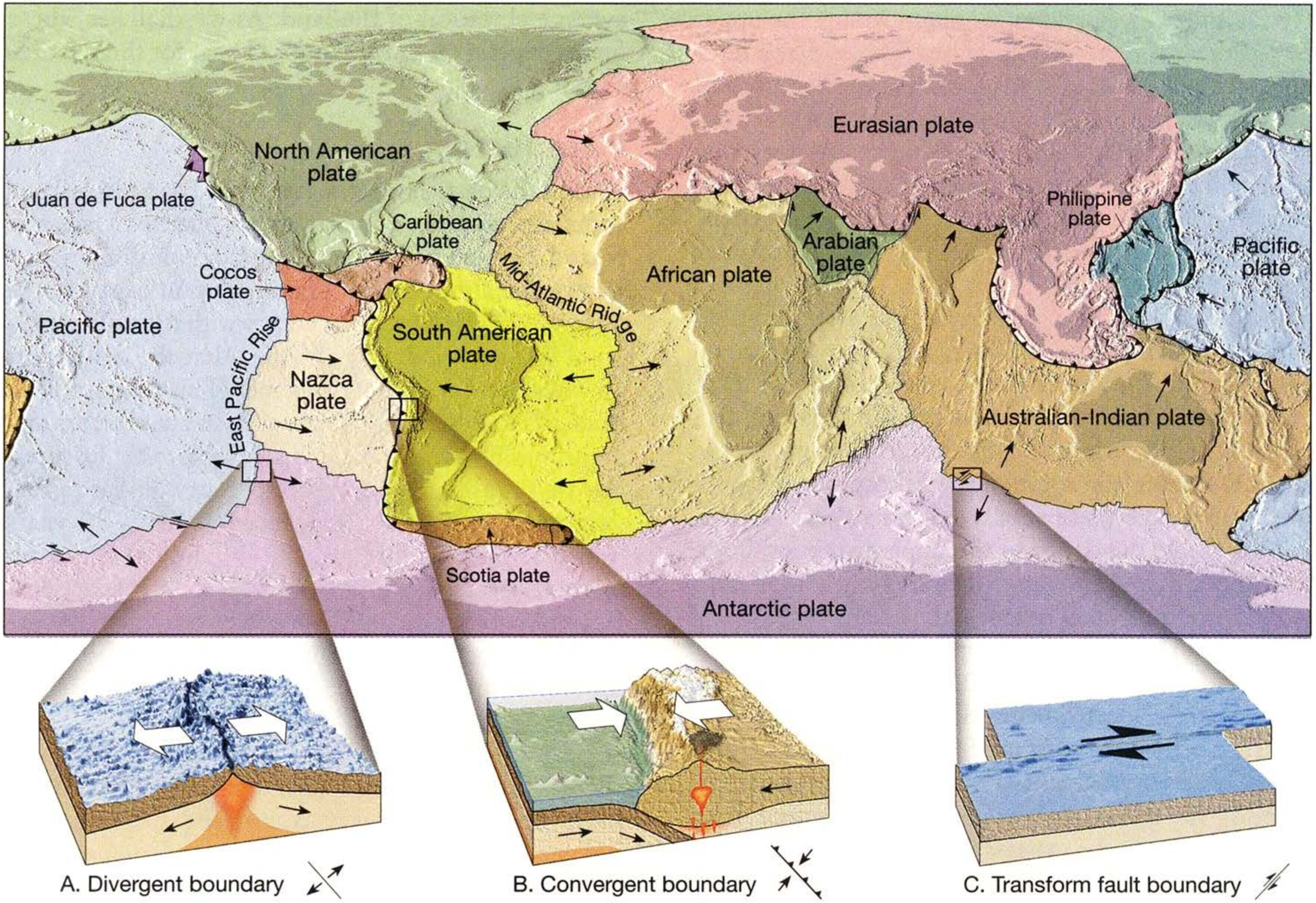


Figure 19.18 Schematic representation of plate boundaries showing the relative motion of plates. **A.** Divergent boundary. **B.** Convergent boundary. **C.** Transform fault boundary.

Type of Margin	Divergent	Convergent	Transform
Motion	Spreading	Subduction	Lateral sliding
Effect	Constructive (oceanic lithosphere created)	Destructive (oceanic lithosphere destroyed)	Conservative (lithosphere neither created or destroyed)
Topography	Ridge/Rift	Trench	No major effect
Volcanic activity?	Yes	Yes	No





A. Divergent boundary

B. Convergent boundary

C. Transform fault boundary

Figure 1.16 Mosaic of rigid plates that constitute Earth's outer shell. (After W. B. Hamilton, U.S. Geological Survey)

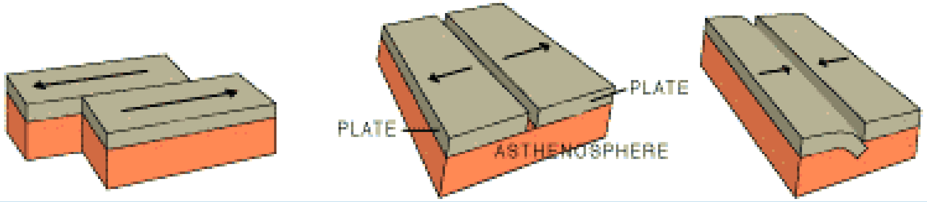
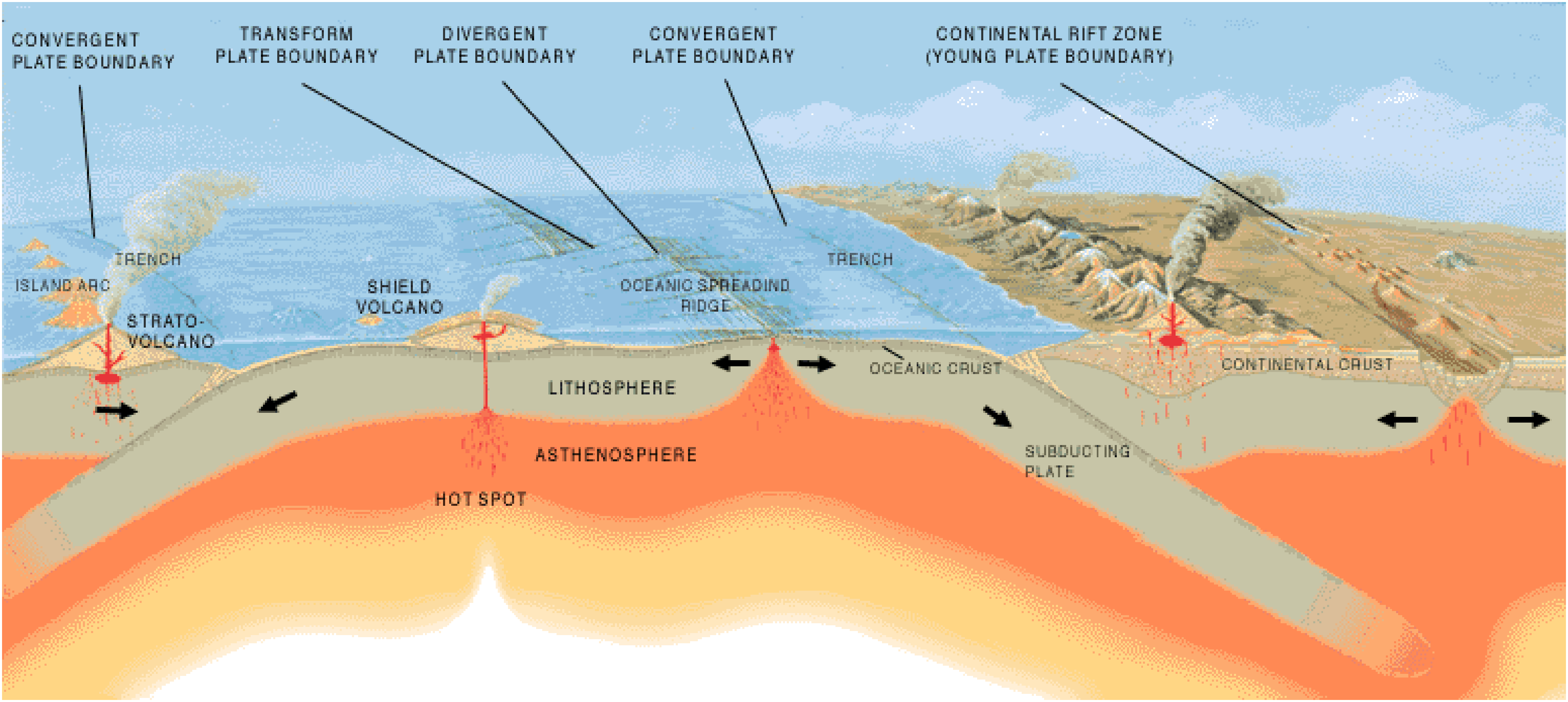
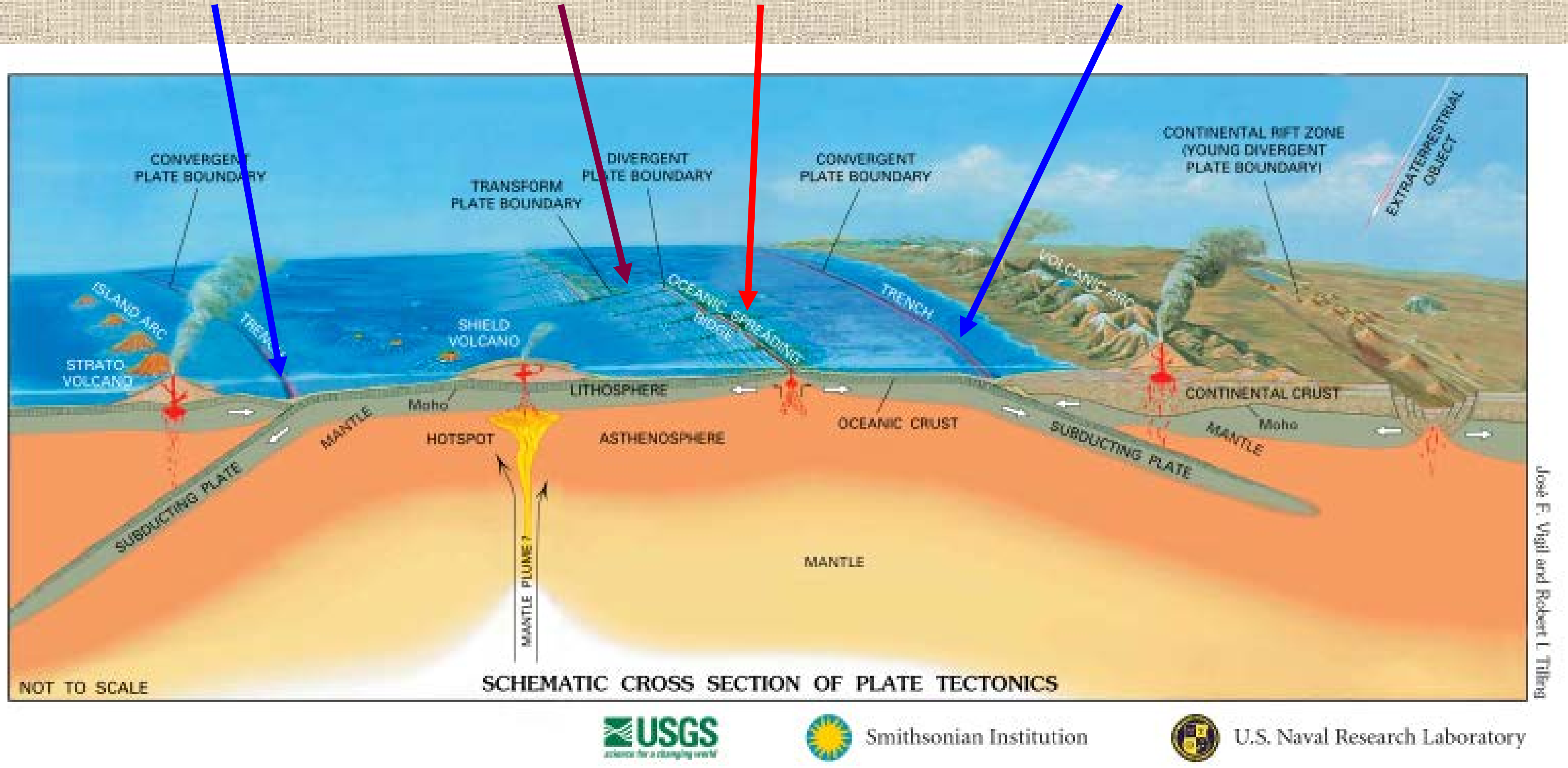


PLATE
PLATE
ASTHENOSPHERE


CONVERGENT PLATE BOUNDARY
TRANSFORM PLATE BOUNDARY
DIVERGENT PLATE BOUNDARY
CONVERGENT PLATE BOUNDARY
CONTINENTAL RIFT ZONE (YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-VOLCANO
SHIELD VOLCANO
OCEANIC SPREADIND RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE
HOT SPOT
SUBDUCTING PLATE

SCHEMATIC CROSS SECTION OF PLATE TECTONICS

convergent transform divergent convergent **boundaries**



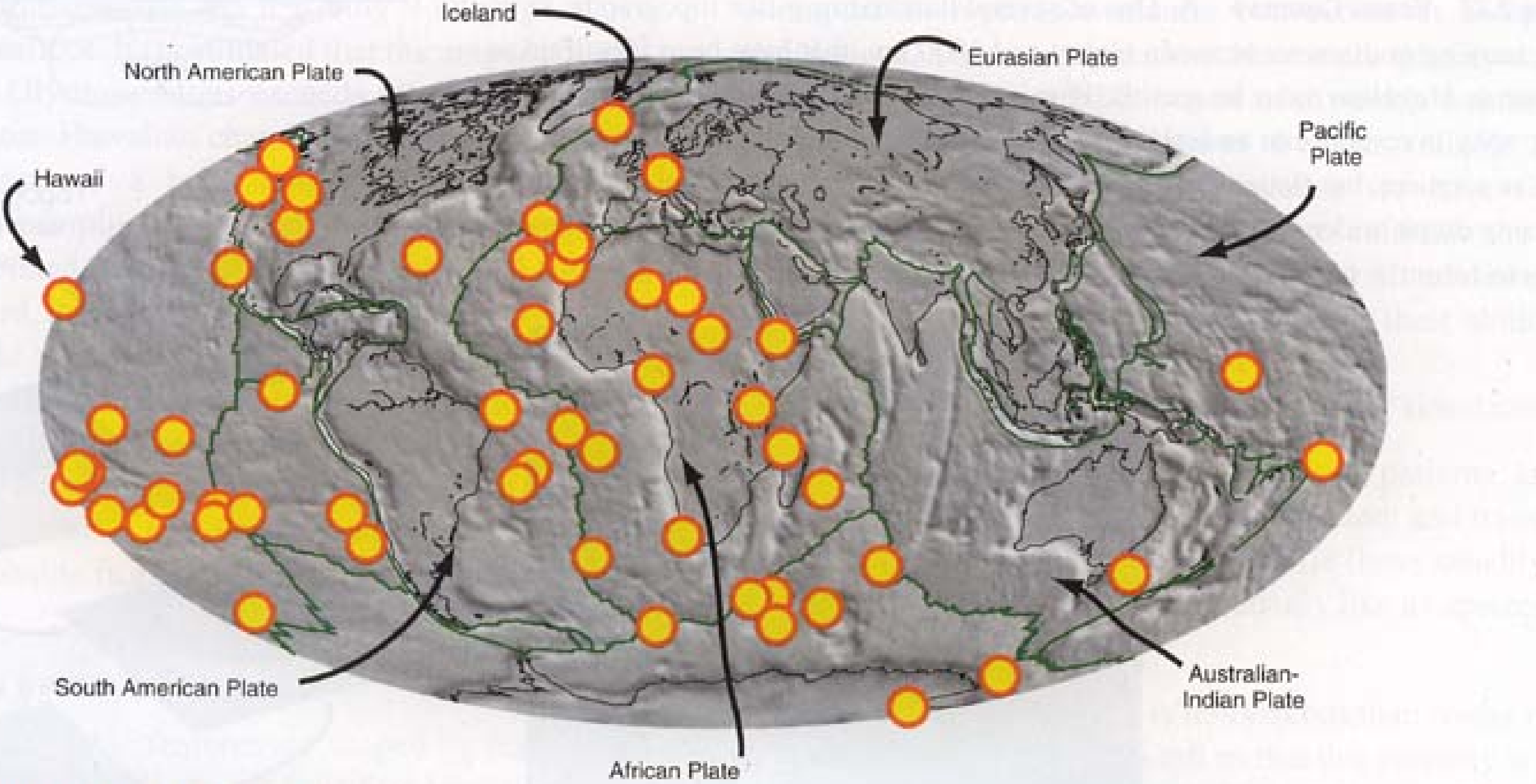


Figure 2.22 Volcanism and Hot Spots Most volcanism on Earth occurs underwater at the midocean ridges. Most volcanoes above sea level are associated with subduction zones. In addition, hot spot volcanism associated with rising mantle plumes (yellow circles) has been identified at several locations. Some hot spots, such as under Iceland, are associated with plate boundaries. Other hot spots, such as Hawaii, lie within plate interiors.

CONTINENT ↔ AL RIFTING

G. DAVIS
CUG/B
5/27/2013

Views of the Earth, Copyright © 2006 by Christoph Hormann http://earth.imagico.de/

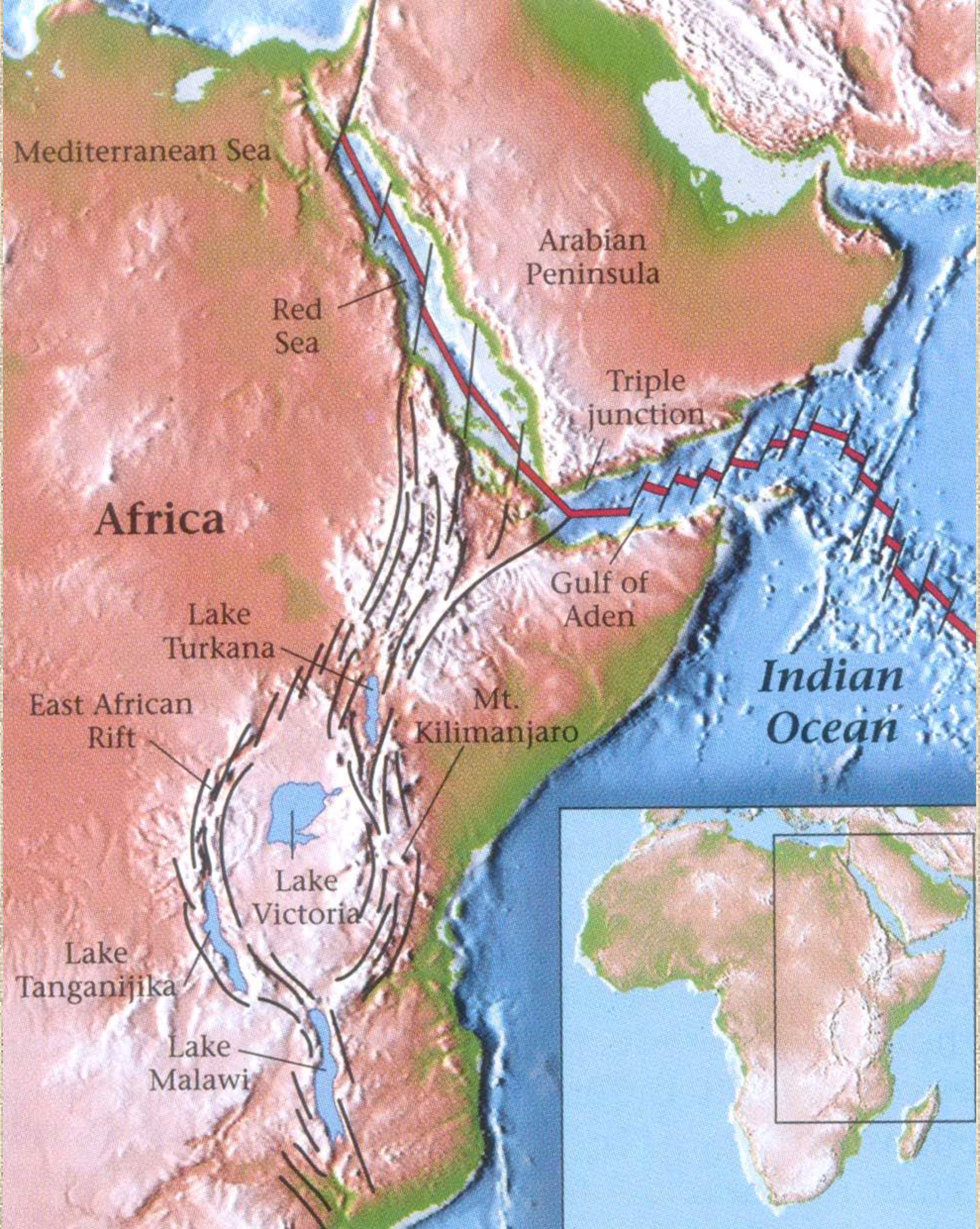

Mediterranean Sea
Arabian Peninsula
Red Sea
Triple junction
Africa
Gulf of Aden
Lake Turkana
Indian Ocean
East African Rift
Mt. Kilimanjaro
Lake Victoria
Lake Tanganijika
Lake Malawi

Figure 1: Colored Digital Elevation Model showing tectonic plate boundaries, outlines of the elevation highs demonstrating the thermal bulges and large lakes of East Africa. Click Image to Enlarge. The basemap is a Space Shuttle radar topography image by NASA.

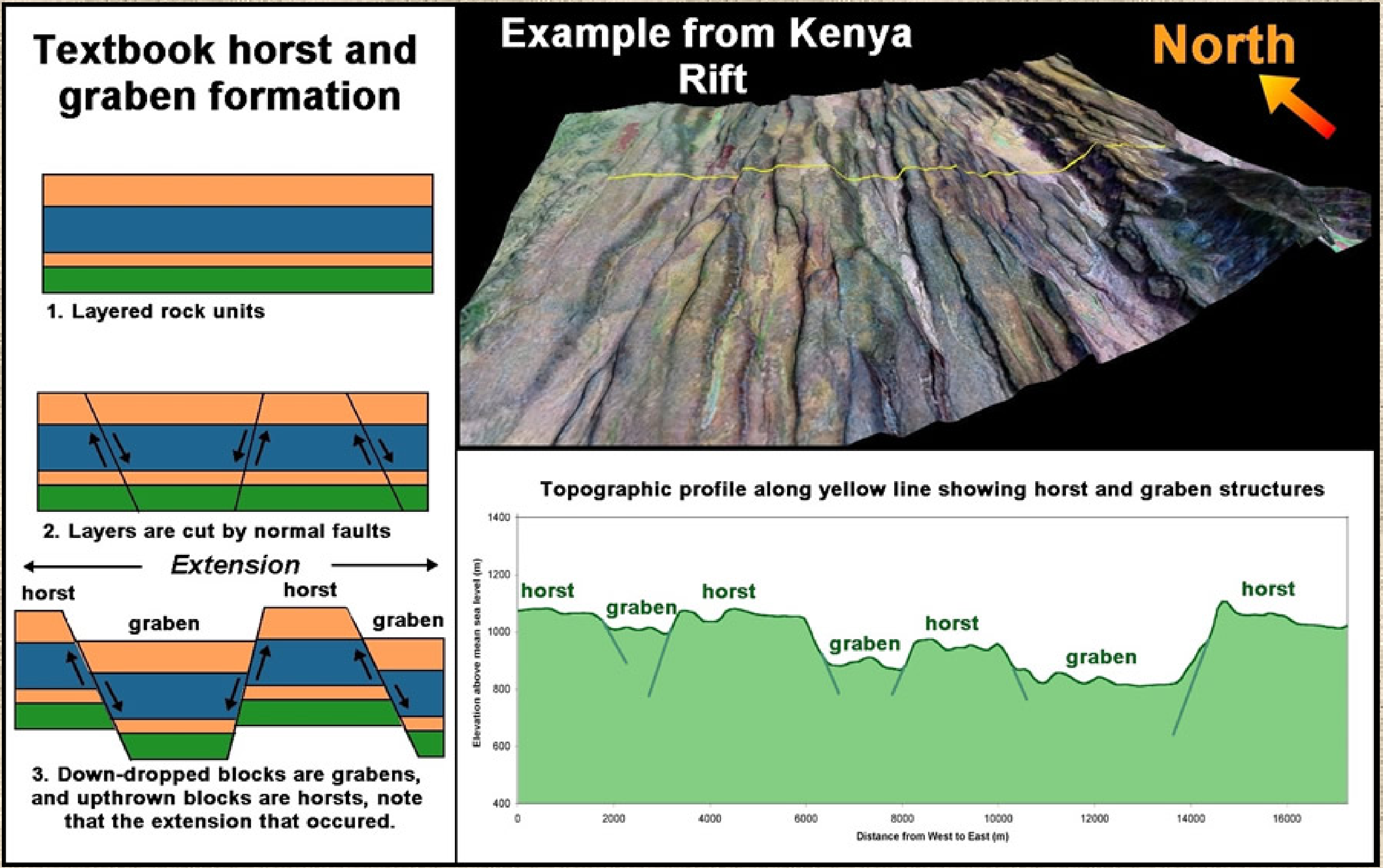


Figure 3: "Textbook" horst and graben formation (left) compared with actual rift terrain (upper right) and topography (lower right). Notice how the width taken up by the trapezoidal areas undergoing normal faulting and horst and graben formation increases from top to bottom in the left panel. Rifts are considered extensional features (continental plates are pulling apart) and so often display this type of structure.

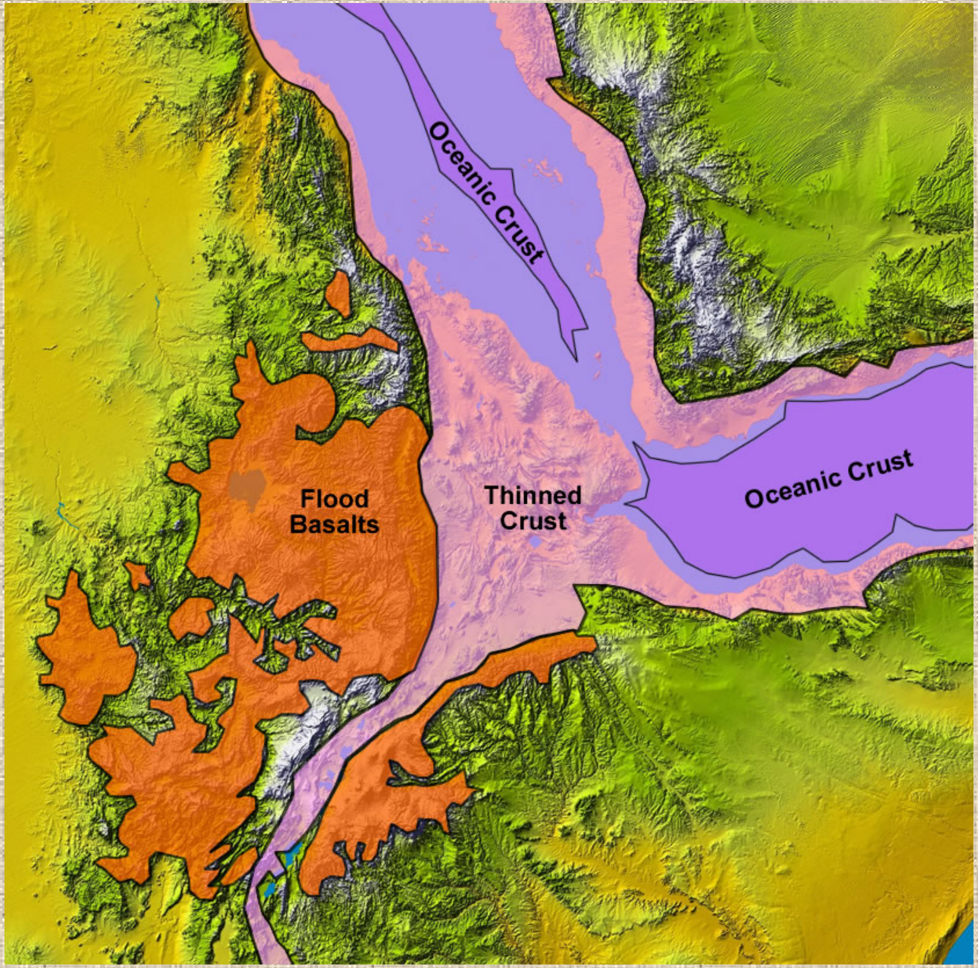
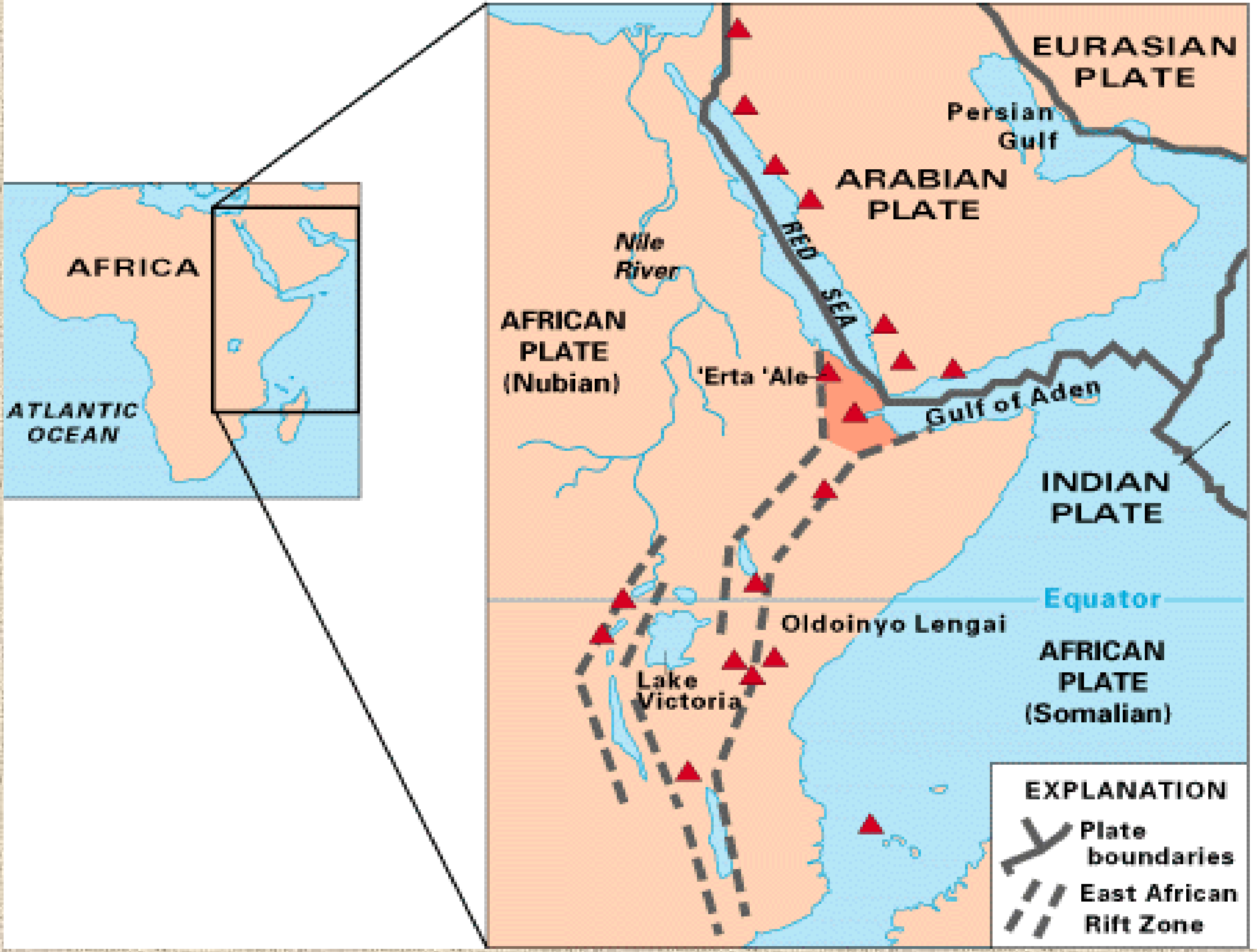


Figure 4: Triple Junction in the Afar region of Ethiopia. Image shows areas of stretched and oceanic crust as well as areas of exposed flood basalts that preceded rifting. Areas unshaded or covered by flood basalts represent normal continental crust. As the crust is pulled apart you end up with thinned crust with a complex mixture of continental and volcanic rock. Eventually the crust thins to the point where oceanic-type basalts are erupted which is the signal that new ocean crust is being formed. This can be seen in the Gulf of Aden as well as a small sliver within the Red Sea. The original extent of the flood basalts would have been greater, but large areas have been buried within the rift valley by other volcanic eruptions and sediments. Click Image to Enlarge


AFRICA
ATLANTIC OCEAN
EURASIAN PLATE
Persian Gulf
ARABIAN PLATE
RED SEA
Nile River
AFRICAN PLATE (Nubian)
'Erta 'Ale
Gulf of Aden
INDIAN PLATE
Equator
Oldoinyo Lengai
AFRICAN PLATE (Somalian)
Lake Victoria
EXPLANATION
Plate boundaries
East African Rift Zone

This image shows several fault scarps that are progressively farther away. Essentially we are looking at the edges of several horst blocks from within a graben that contains Lake Baringo. Image © Alex Guth. Click Image to Enlarge

This was taken at the Njorowa Gorge in Hell's Gate National Park. The gorge was carved by water, and is quite spectacular in many regards, but here we have an igneous dike cutting through the wall of the canyon, with Dr. Wood and one of our guides for scale. Image © Alex Guth.

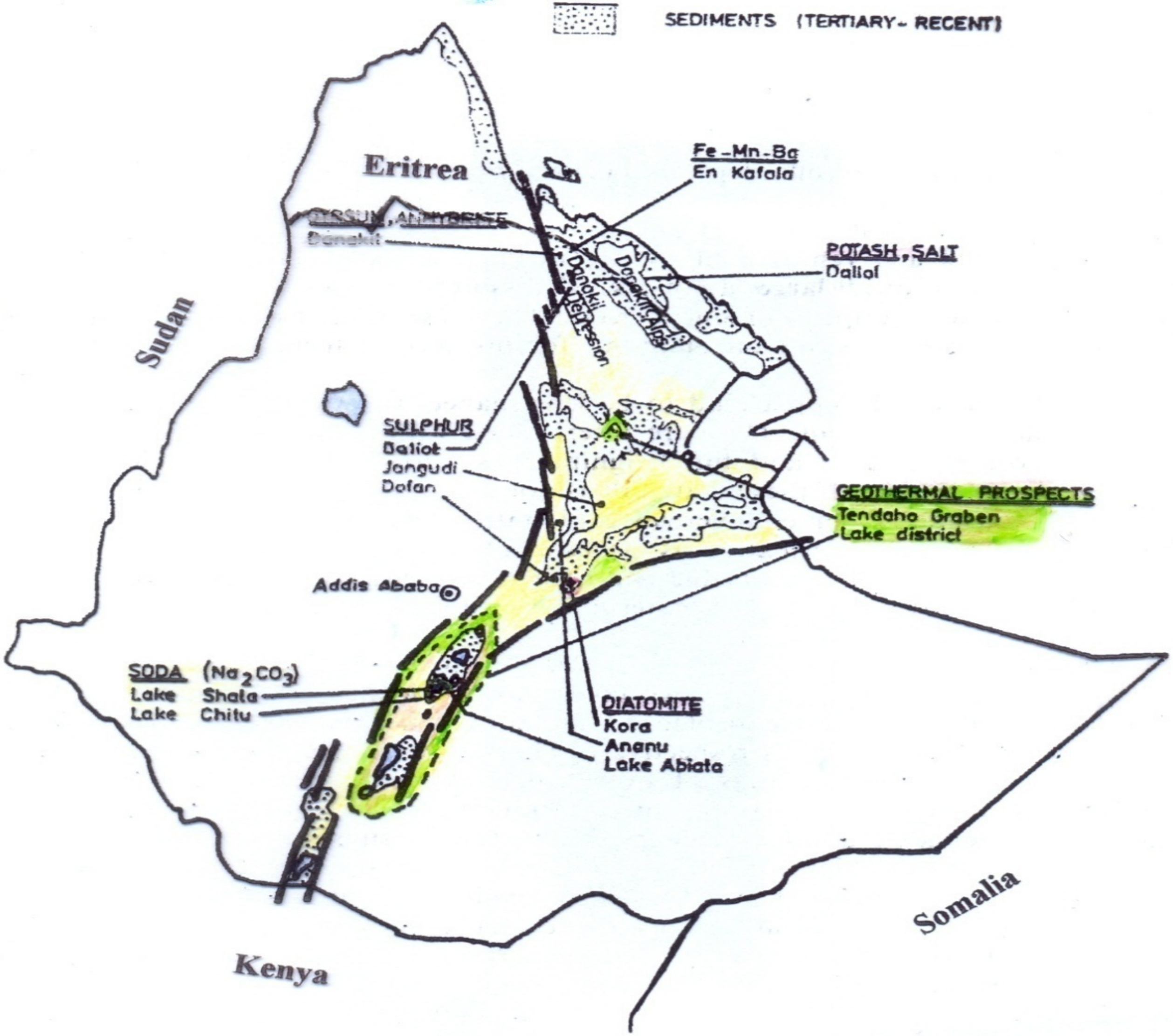
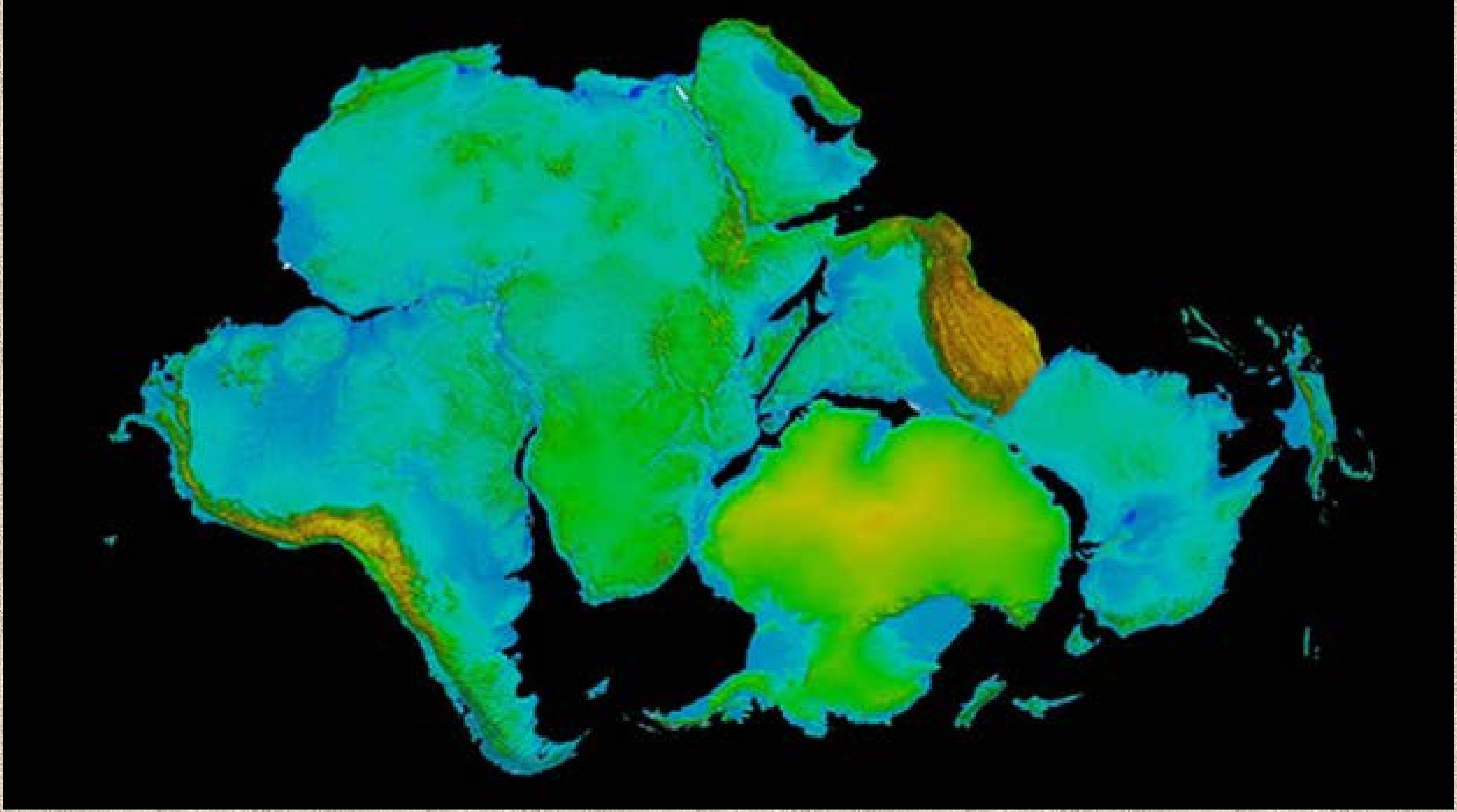


Figure 10 — Economic deposits in the Ethiopian Rift Valley.

Thank you


CHINA
RUSSIA
GREENLAND
UNITED STATES
MEXICO
BRAZIL
ALGERIA
LIBYA
EGYPT
NIGER
CHAD
SUDAN
SAUDI ARABIA
CONGO
INDIA
ANTARCTICA
AUSTRALIA



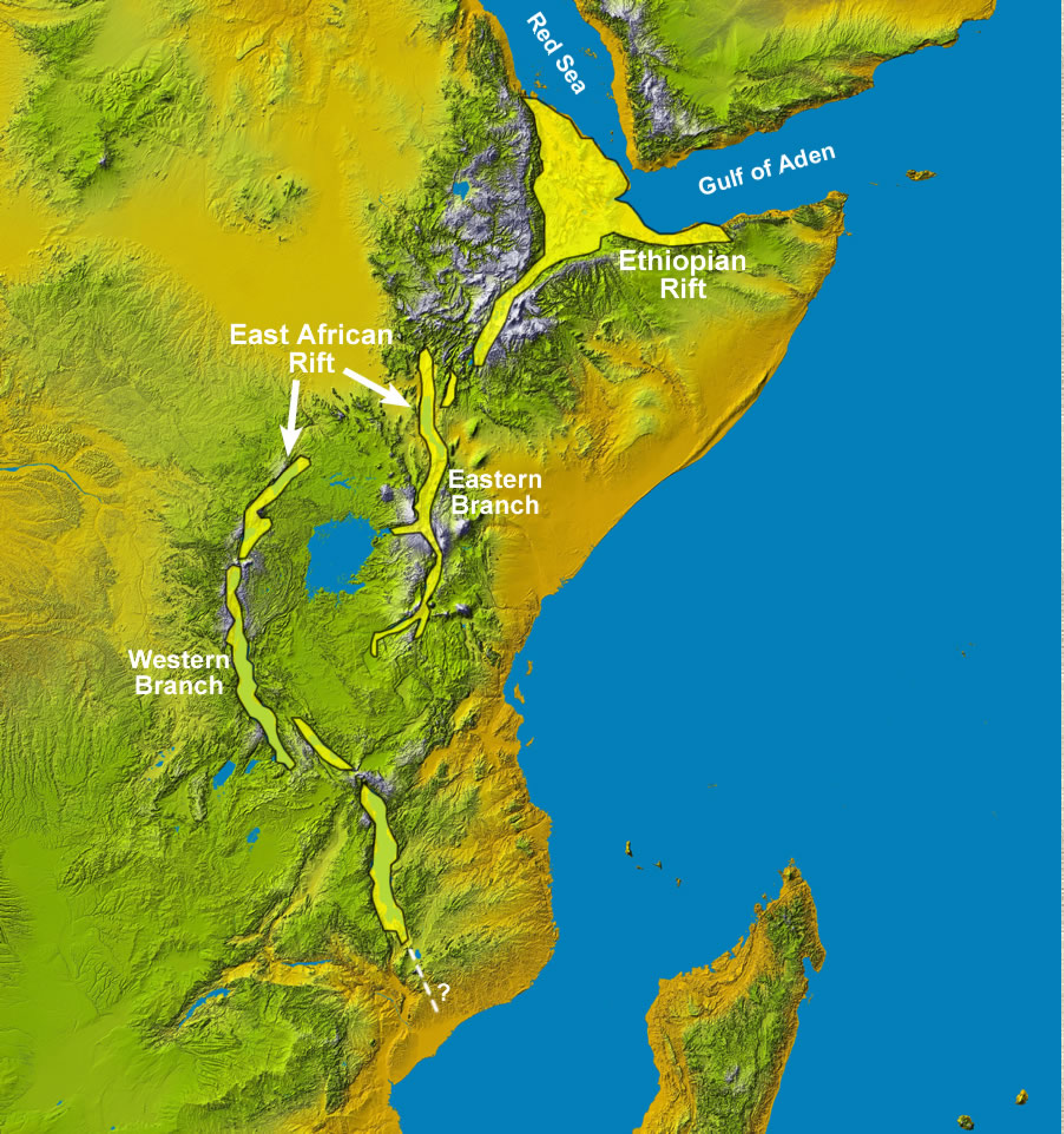


Figure 2: Rift segment names for the East African Rift System. Smaller segments are sometimes given their own names, and the names given to the main rift segments change depending on the source. Click Image to Enlarge. The basemap is a Space Shuttle radar topography image by NASA.

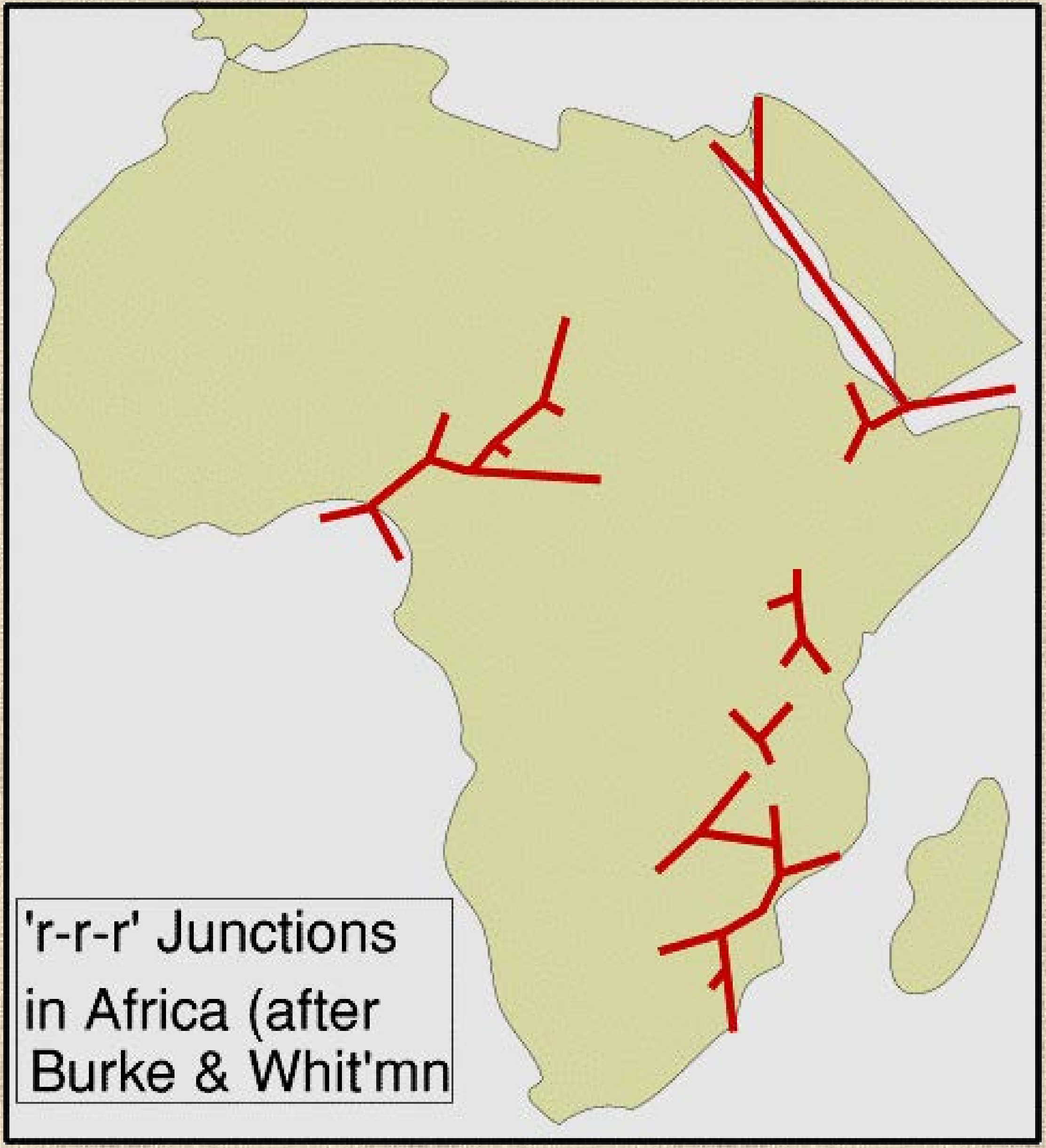


Fig. 3. The continent of Africa is thought to have been split by a series of rift valleys in various states of development. Those in East Africa are still in thick crust. Those in West Africa are associated with thick oil-bearing sediments. In the Red Sea area the rifting has gone so far as to form a narrow ocean. In the south-east Madagascar has been completely separated from Africa by rifting.

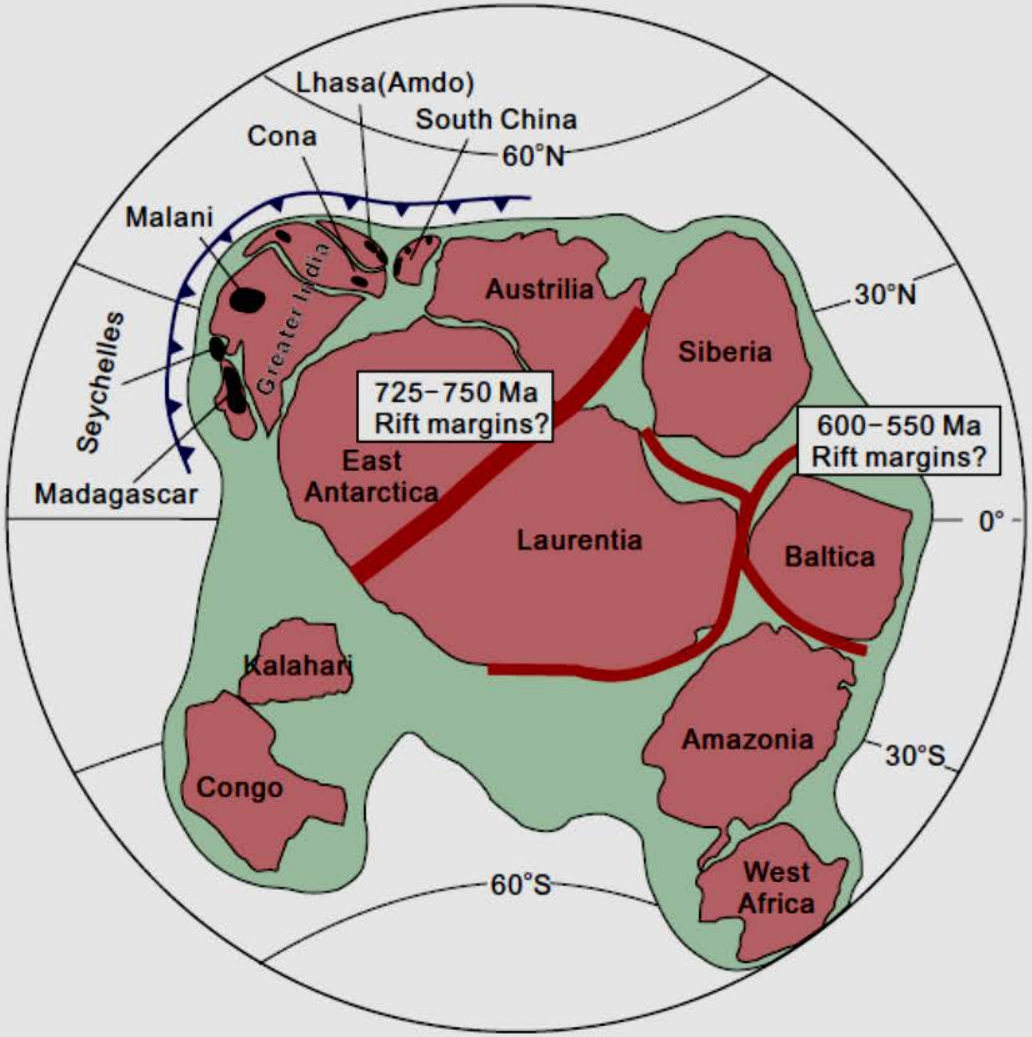


Fig. 10. A reconstruction of the Rodinia supercontinent at approximately 750 Ma (modified after Torsvik et al., 1996; Meert and Torsvik, 2003; Zhou et al., 2006; Rino et al., 2008; Bybee et al., 2010; Pradhan et al., 2010; Dong et al., 2011), showing the distribution of late Mesoproterozoic–early Neoproterozoic convergence plate margin and the positions of lithologies with an Andean-arc affinity (labeled in black).