GEOTECTONICS

What is Plate Tectonics

- The Earth’s crust and upper mantle are broken into sections called plates
- Plates move around on top of the mantle like rafts

PLATE TECTONICS:

Pieces of a Jig-saw puzzle of both continent and ocean often reinforced by geological and bio-geographical considerations.

In accordance to sea floor spreading from oceanic ridges the Continents move aside

If one ocean grows the adjacent ocean should shrink but it is not the case in some plate.

This is due to subduction at the plate collision site.

Tectonic Plate Boundary Types:

Extensional

Compressional

Transform (sliding) or Undefined

What is the Lithosphere?

- The crust and part of the upper mantle = lithosphere
  - –100 km thick
  - –Less dense than the material below it so it “floats”

What is the Asthenoshere?

- The plastic layer below the lithosphere = asthenosphere
- The plates of the lithosphere float on the asthenosphere

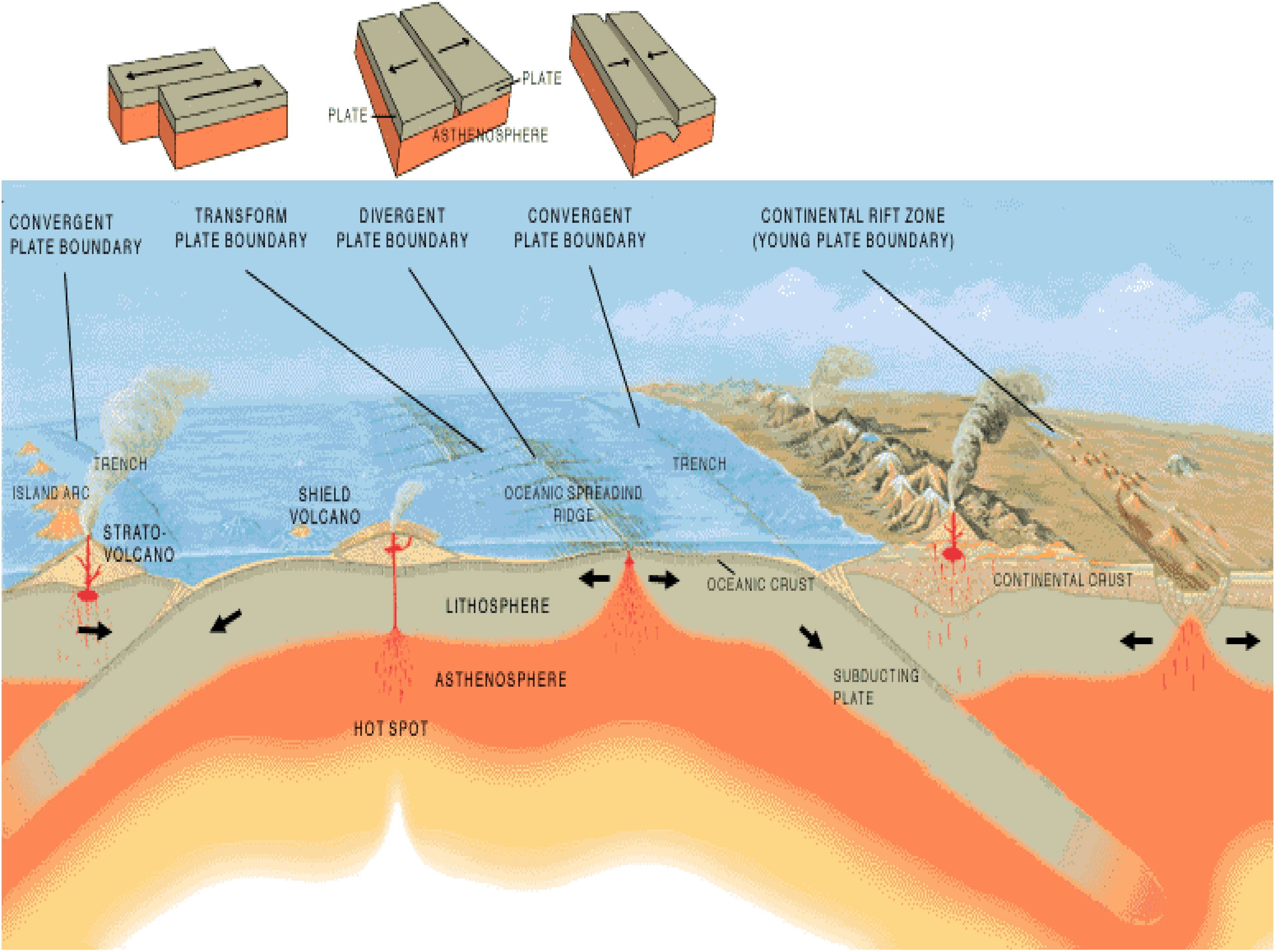


PLATE
PLATE
ASTHENOSPHERE
CONVERGENT PLATE BOUNDARY
TRANSFORM PLATE BOUNDARY
DIVERGENT PLATE BOUNDARY
CONVERGENT PLATE BOUNDARY
CONTINENTAL RIFT ZONE (YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-VOLCANO
SHIELD VOLCANO
OCEANIC SPREADING RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE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

2 Types of Plates

- Ocean plates - plates below the oceans
- Continental plates - plates below the continents

Plate Boundaries

Divergent Boundaries

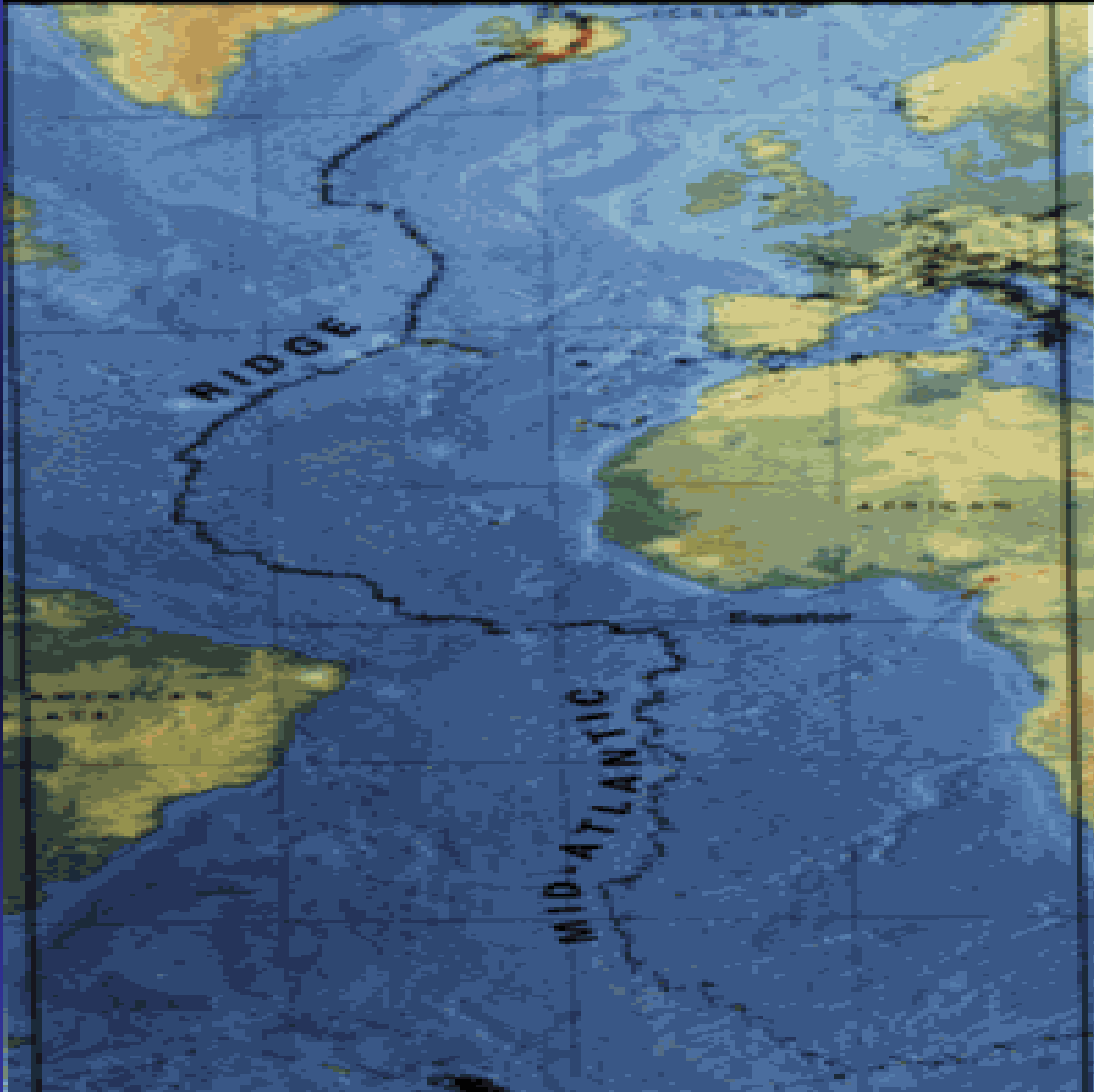
- Boundary between two plates that are moving apart or rifting

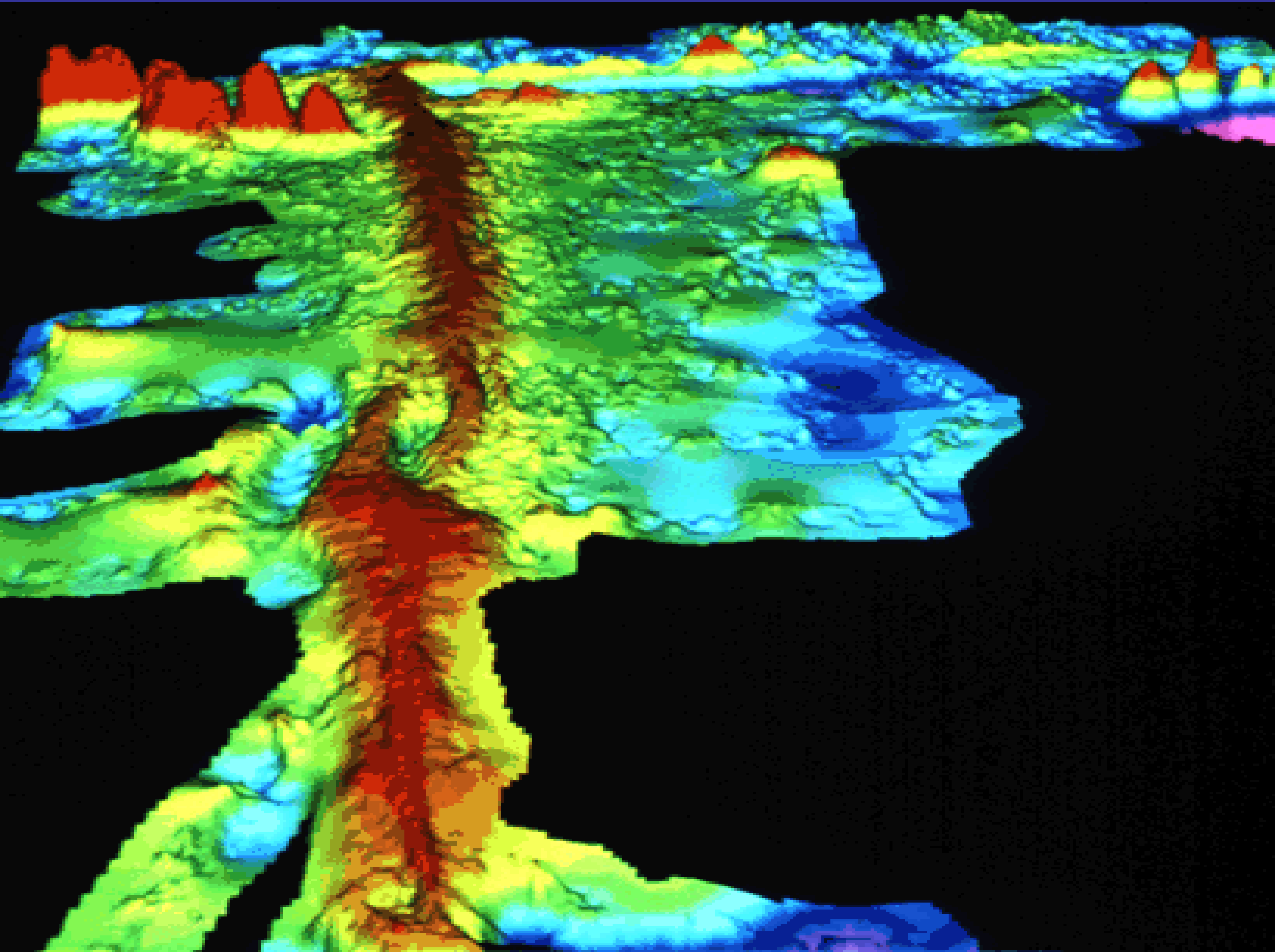
← →

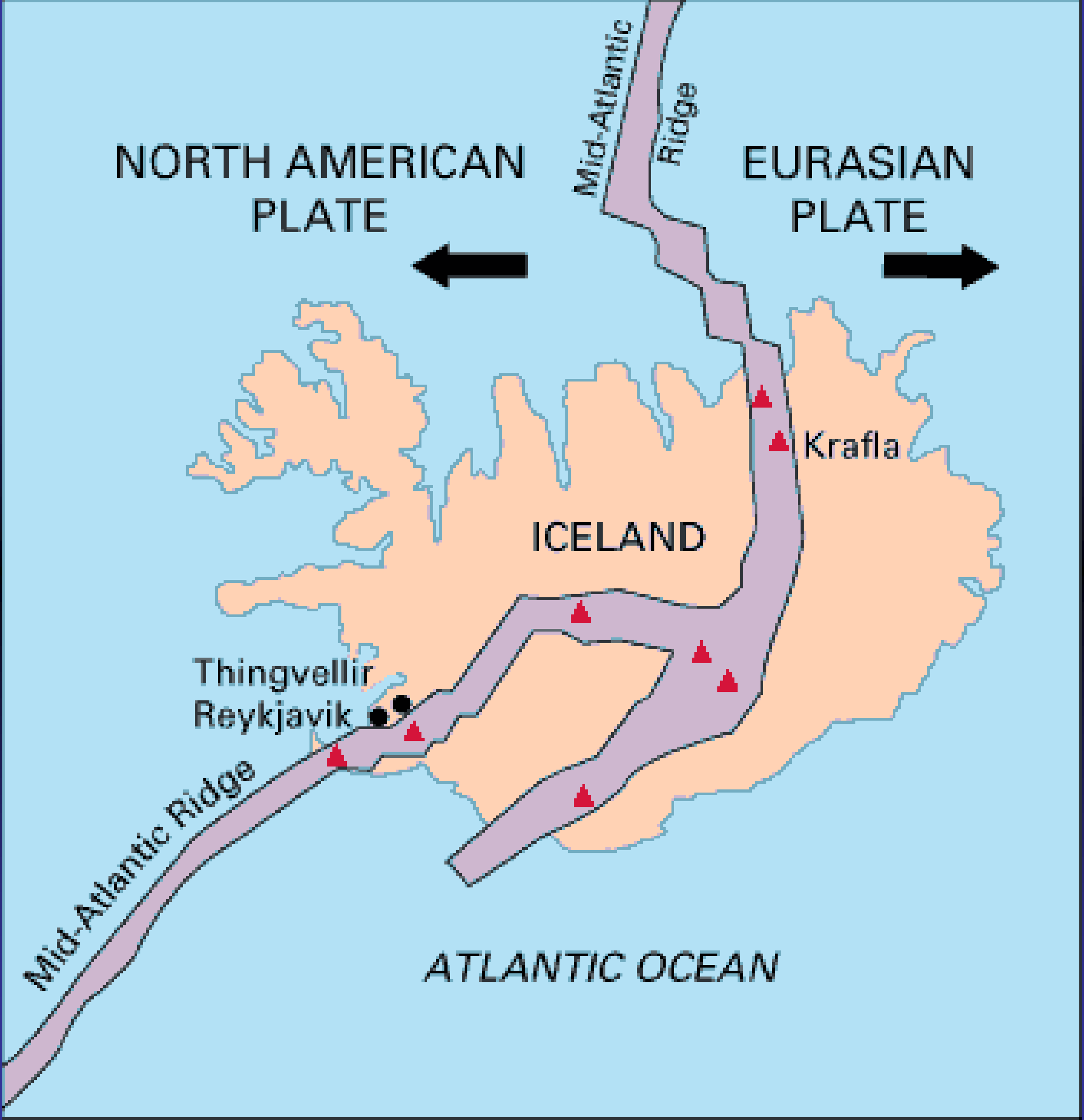
- RIFTING causes SEAFLOOR SPREADING

Features of Divergent Boundaries

- Mid-ocean ridges
- rift valleys
- fissure volcanoes


RIDGE
MID-ATLANTIC





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

Convergent Boundaries

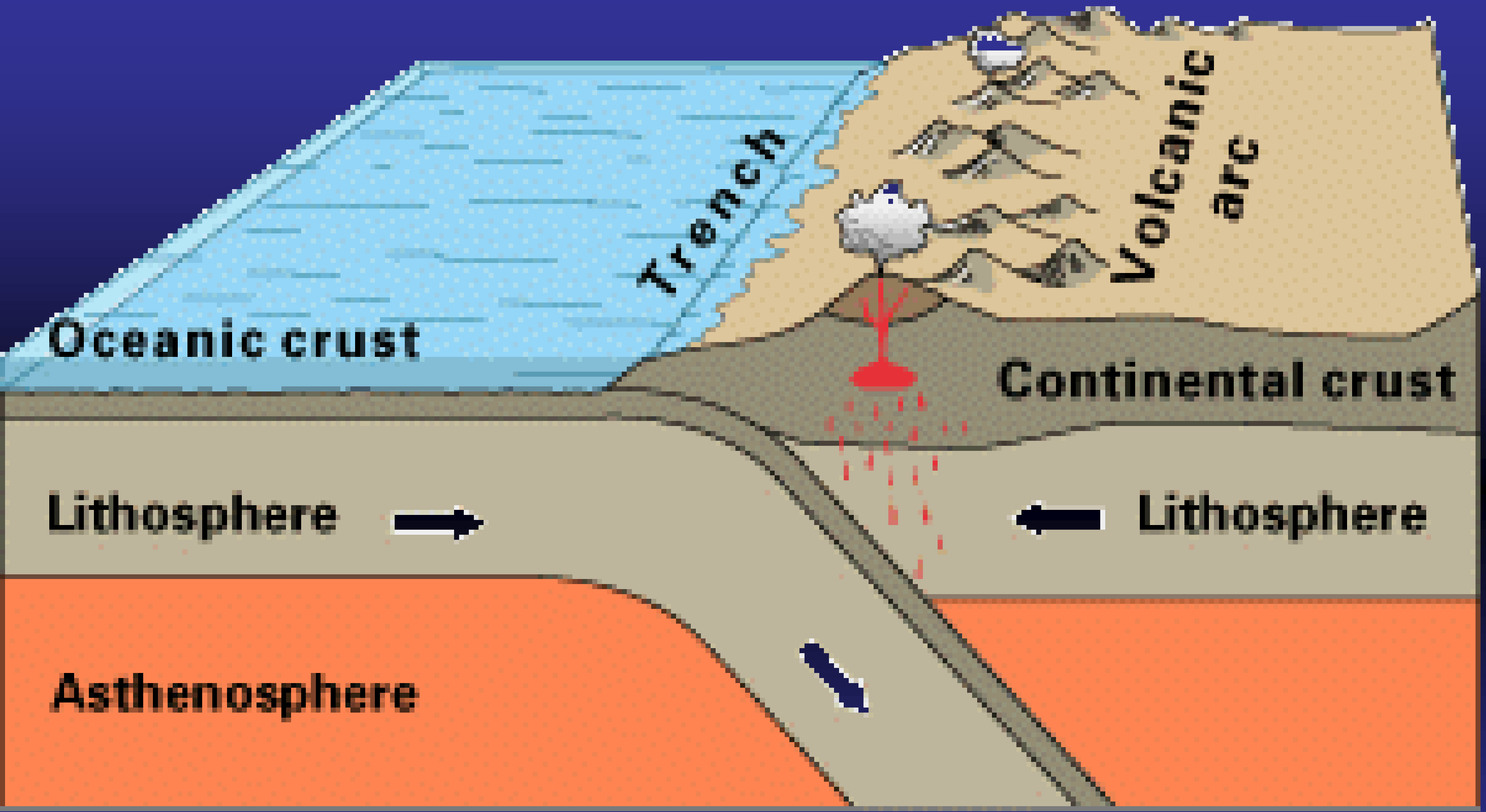
- Boundaries between two plates that are colliding

→ ←

- There are 3 types…

Type 1

- Ocean plate colliding with a less dense continental plate
- Subduction Zone: where the more dense plate slides under less dense the plate
- VOLCANOES occur at subduction zones

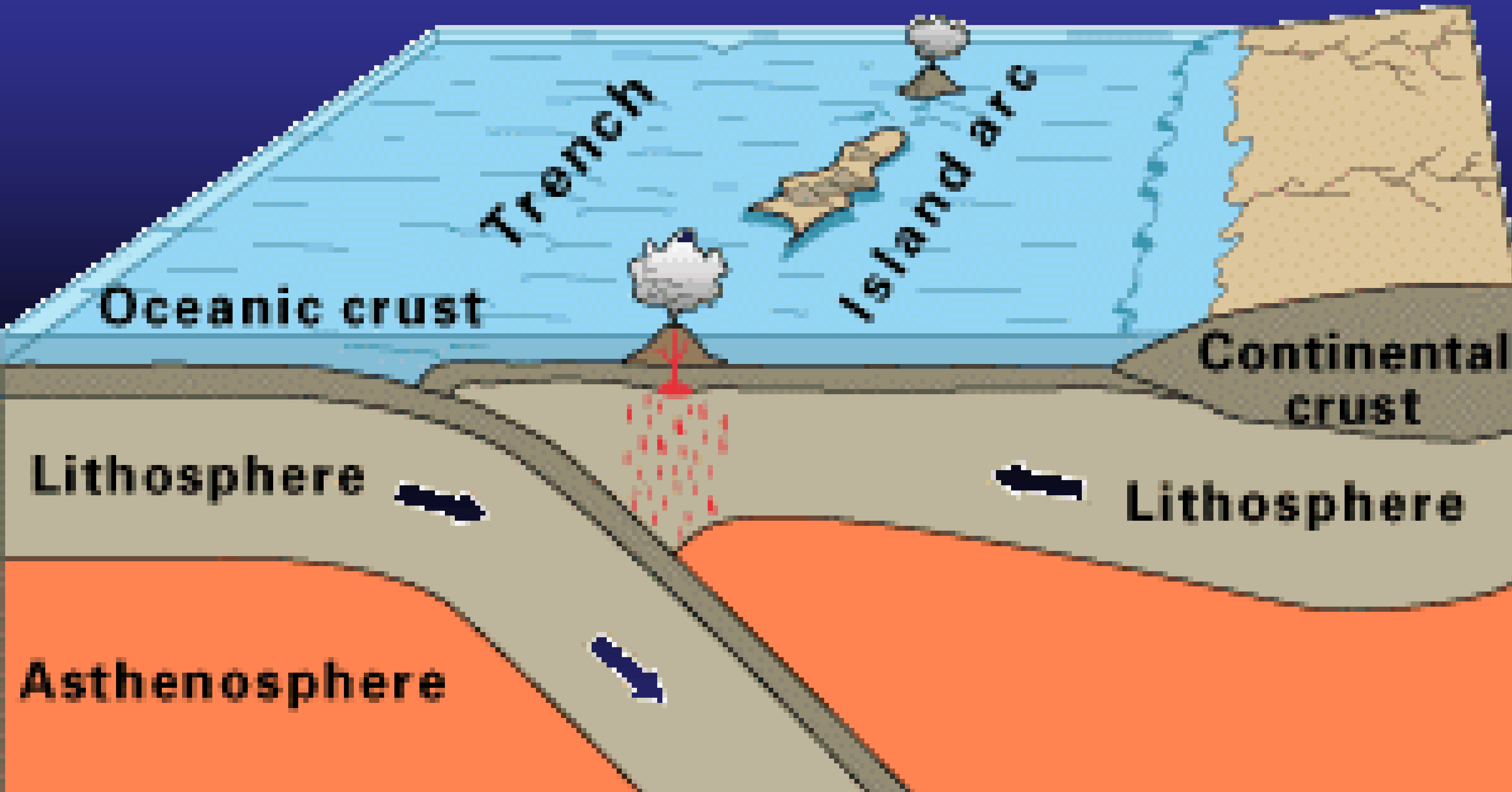


Oceanic-continental convergence

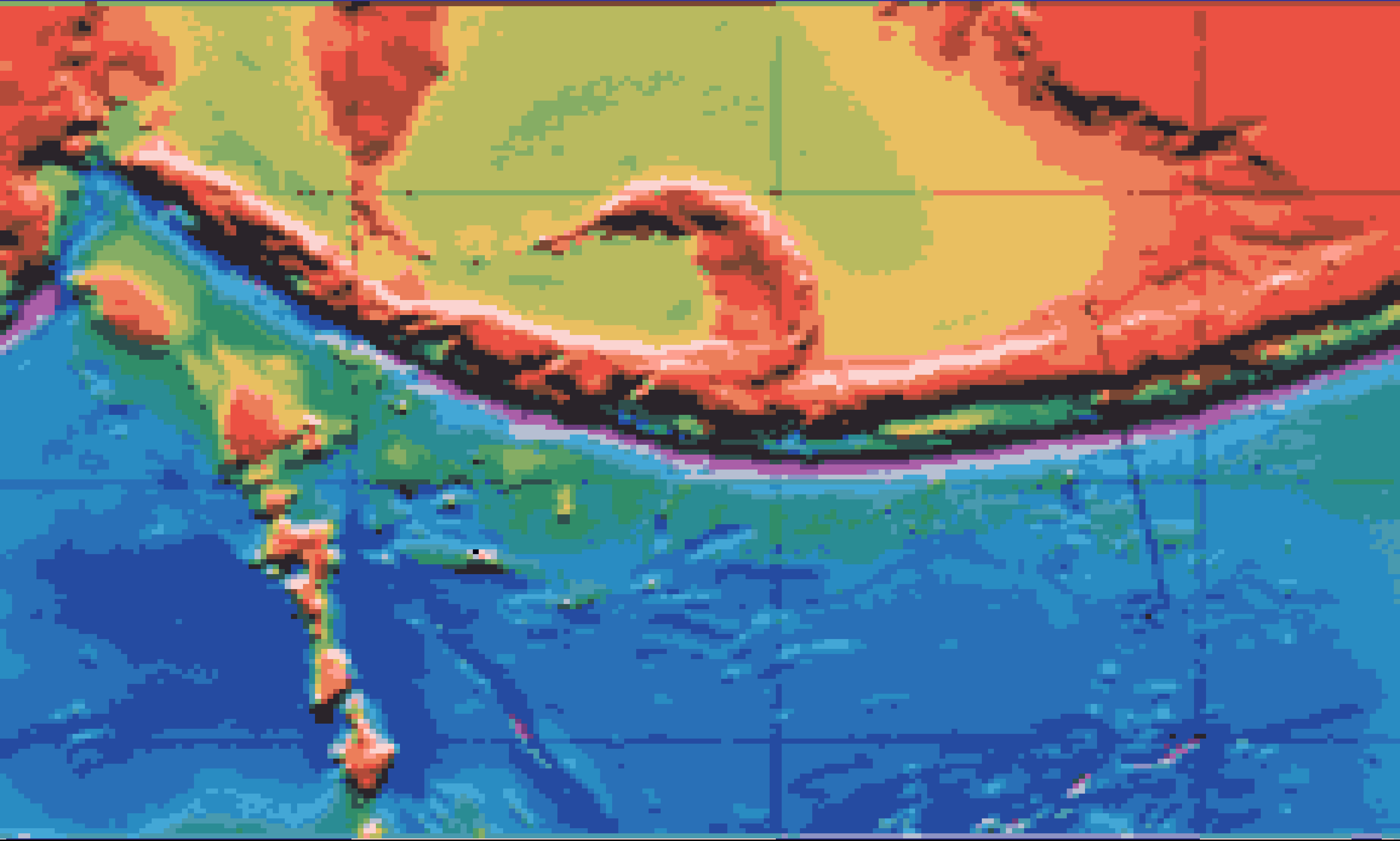
Andes Mountains, South America

Type 2

- Ocean plate colliding with another ocean plate
- The more dense plate slides under less dense the plate creating a subduction zone called a TRENCH



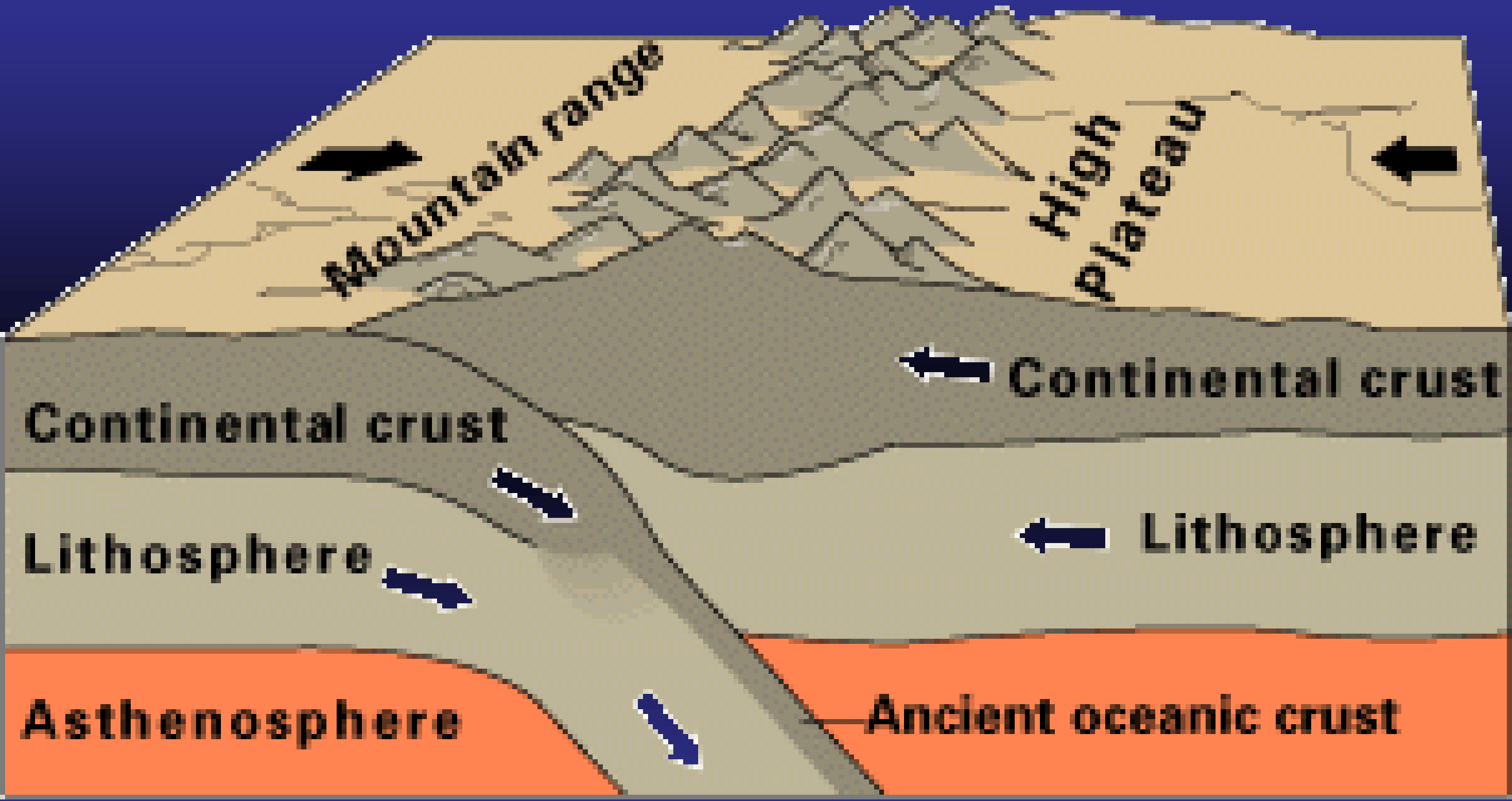
Oceanic-oceanic convergence



Aleutian Islands, Alaska

Type 3

- A continental plate colliding with another continental plate
- Have Collision Zones:
  - –a place where folded and thrust faulted mountains form.

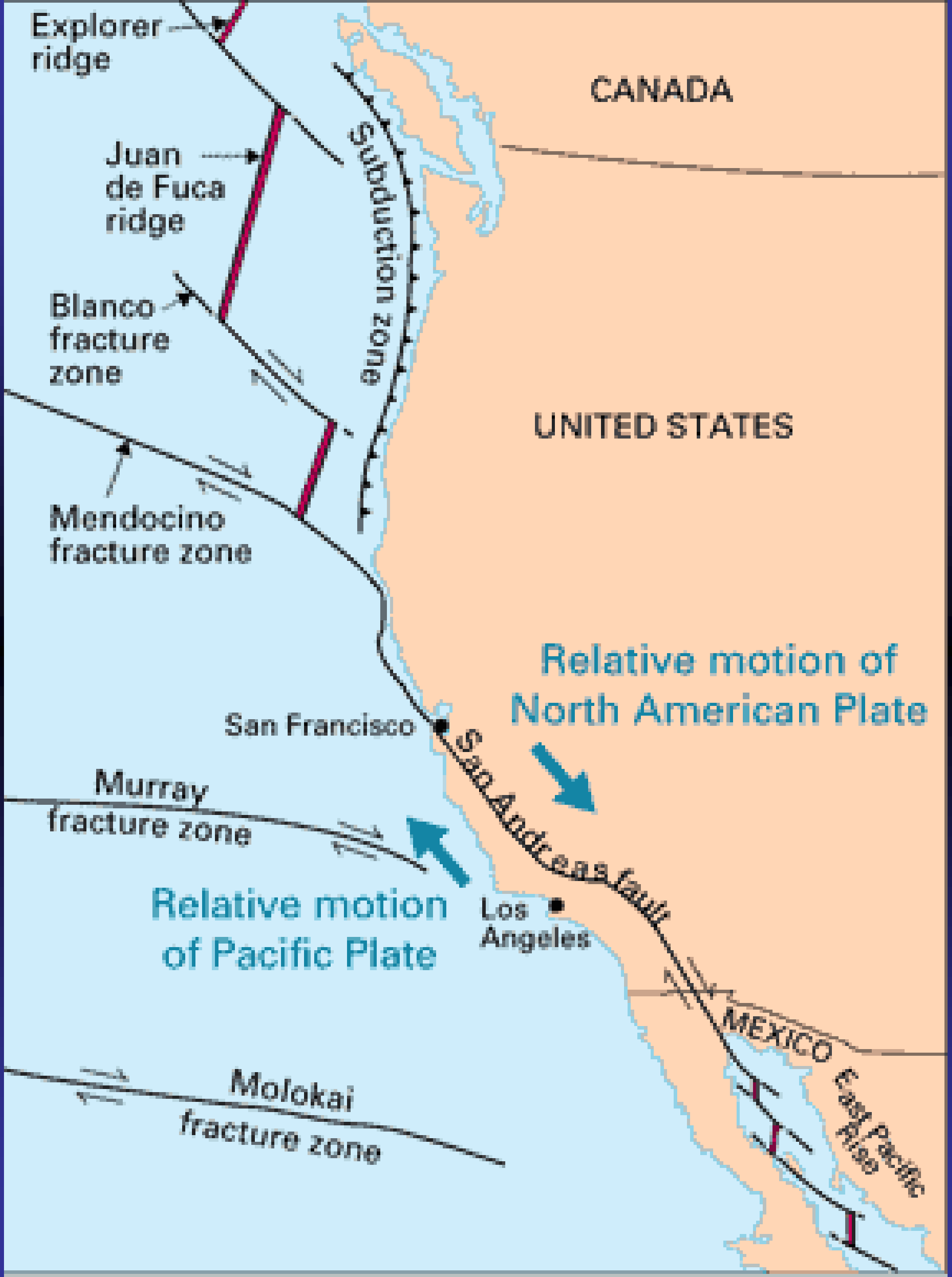


Continental-continental convergence


EURASIAN
PLATE
Tibetan
Plateau
Himalayas
Ganges Plain
Mt. Everest
INDIAN
PLATE
INDIAN OCEAN

Transform Fault Boundaries

- Boundary between two plates that are sliding past each other
- EARTHQUAKES along faults

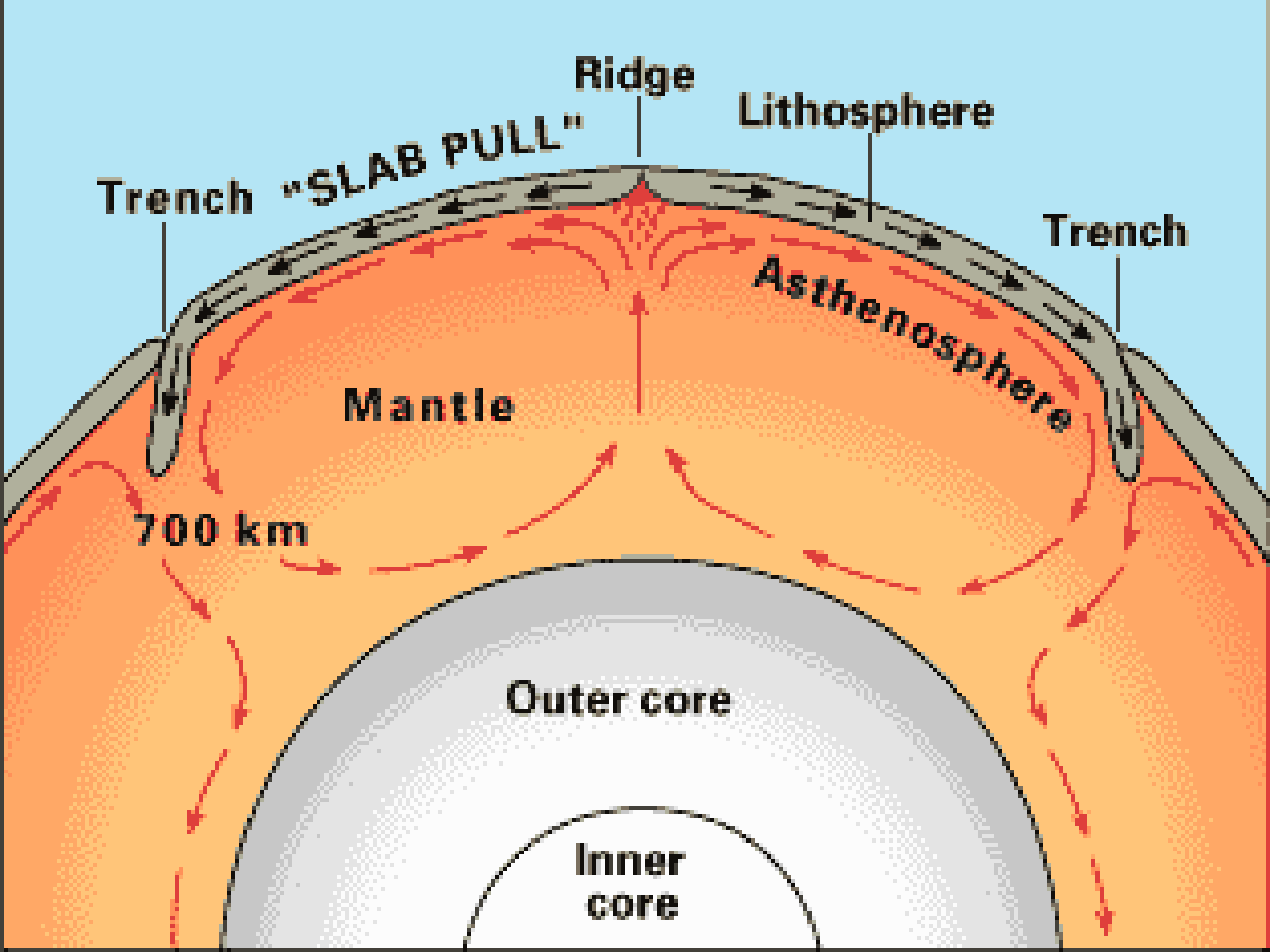

Explorer ridge
CANADA
Juan de Fuca ridge
Subduction zone
Blanco fracture zone
UNITED STATES
Mendocino fracture zone
Relative motion of North American Plate
San Francisco
San Andreas fault
Murray fracture zone
Relative motion of Pacific Plate
Los Angeles
MEXICO
East Pacific Rise
Molokai fracture zone

San Andreas Fault, CA

Causes of Plate Tectonics

Convection Currents

- Hot magma in the Earth moves toward the surface, cools, then sinks again.
- Creates convection currents beneath the plates that cause the plates to move.


Ridge
"SLAB PULL"
Lithosphere
Trench
Trench
Asthenosphere
Mantle
700 km
Outer core
Inner
core

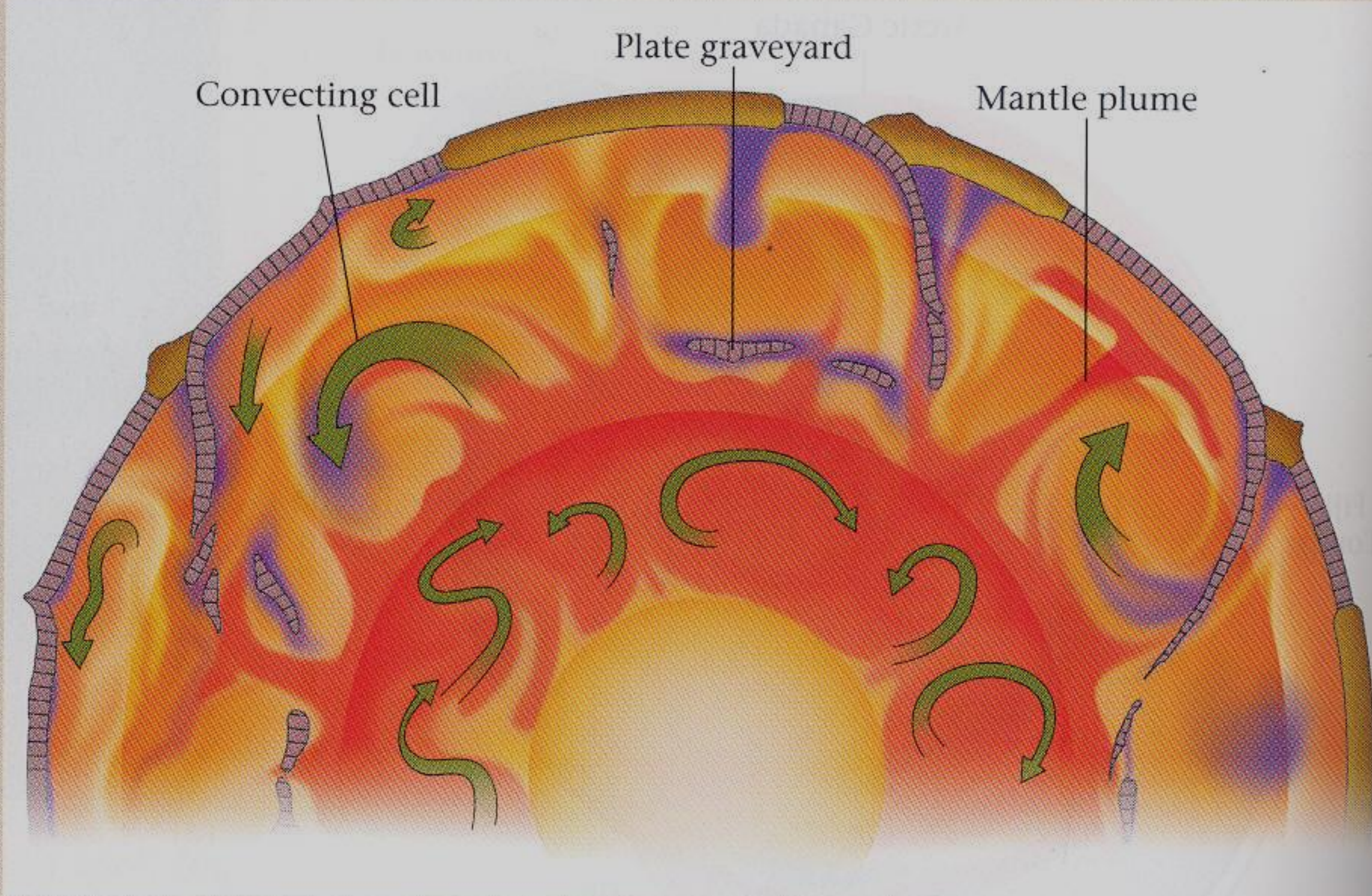


FIGURE C.13 The modern view of a complex and dynamic Earth interior. Note the convecting cells, the mantle plumes, and the subducted-plate graveyards.

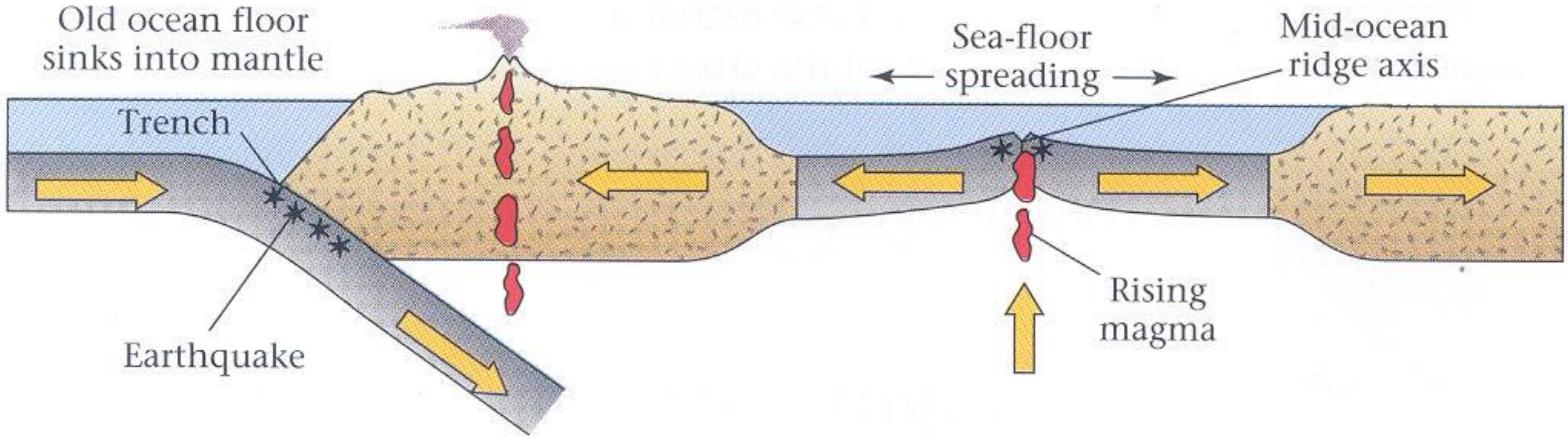


FIGURE 2.21 Harry Hess's basic concept of sea-floor spreading. New sea floor forms at the mid-ocean ridge axis. As a result, the ocean grows wider. Old sea floor sinks into the mantle at a trench. Earthquakes occur at ridges and trenches.

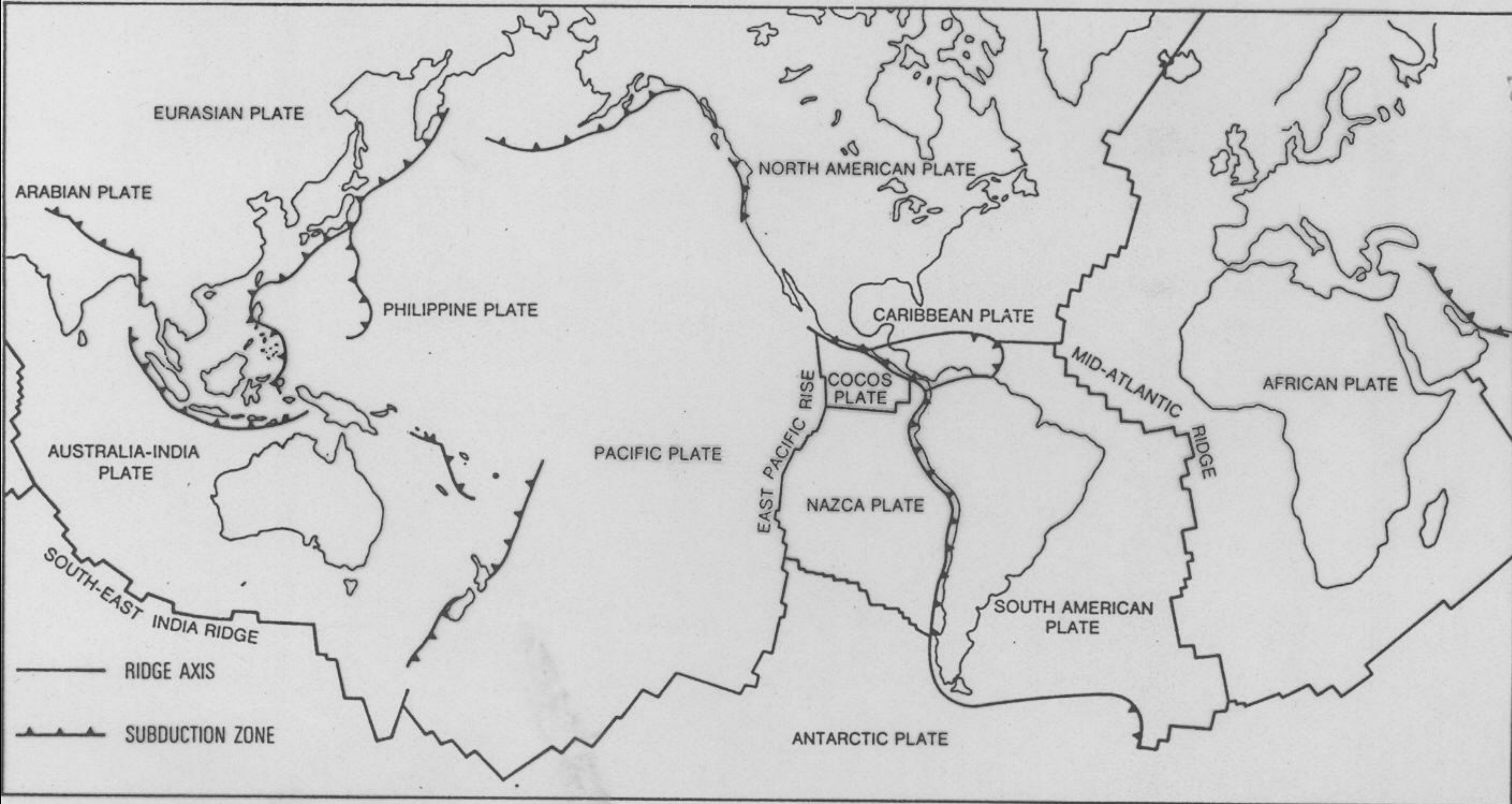
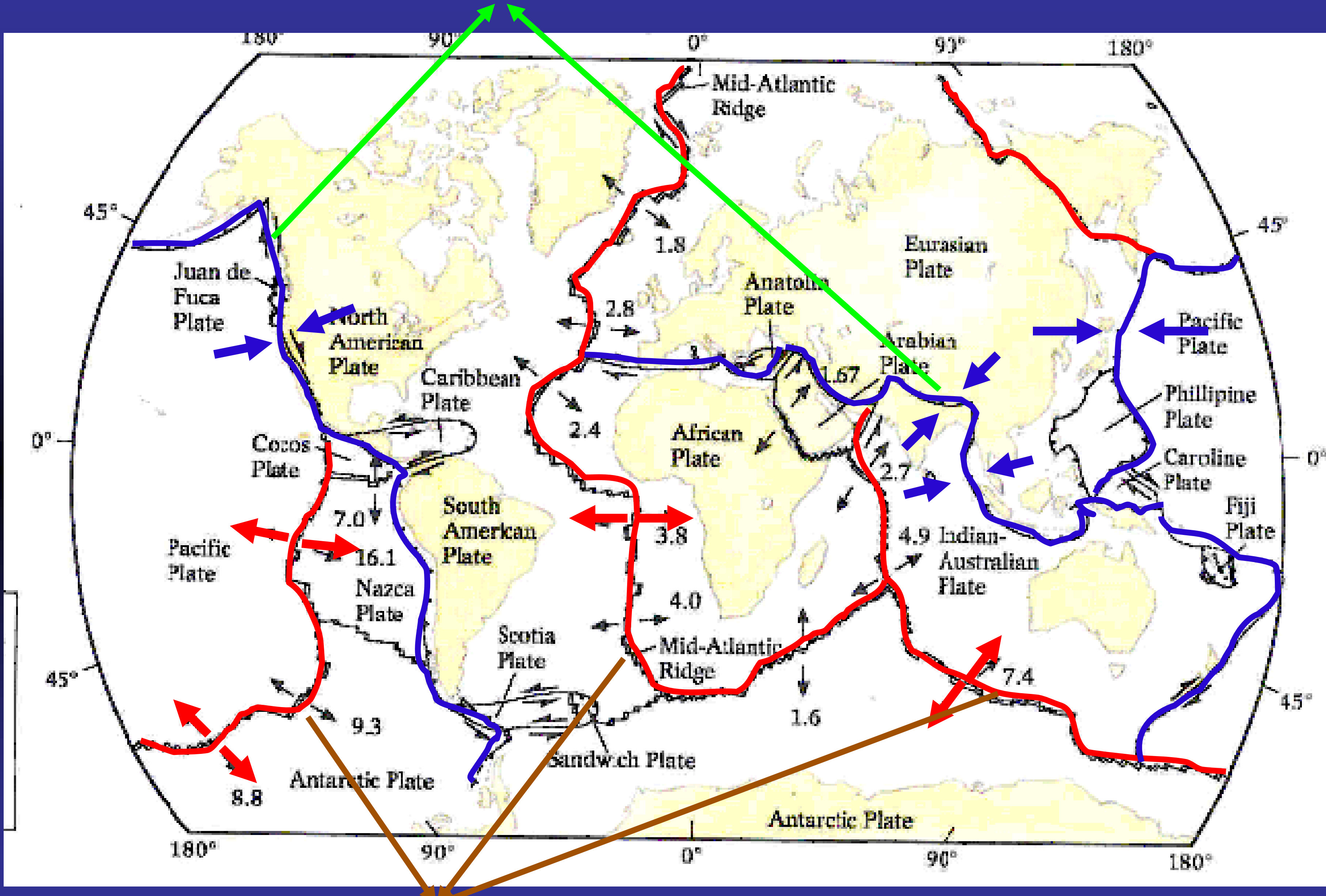


Figure 12.8 The major plates, ridges and subduction zones of plate tectonics

CONVERGENT PLATE BOUNDARIES



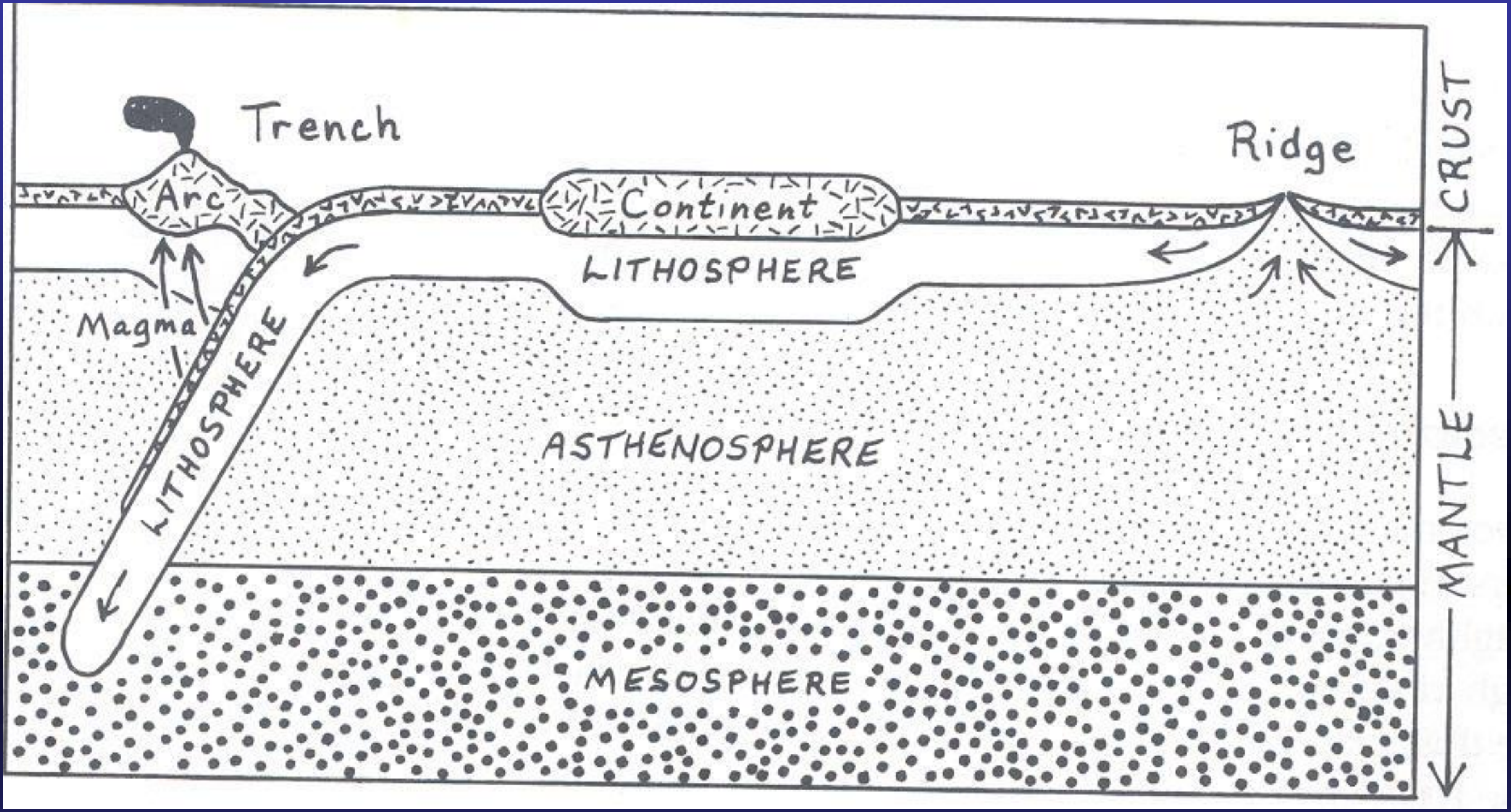
DIVERGENT PLATE BOUNDARIES

Theory of Plate Tectonic:

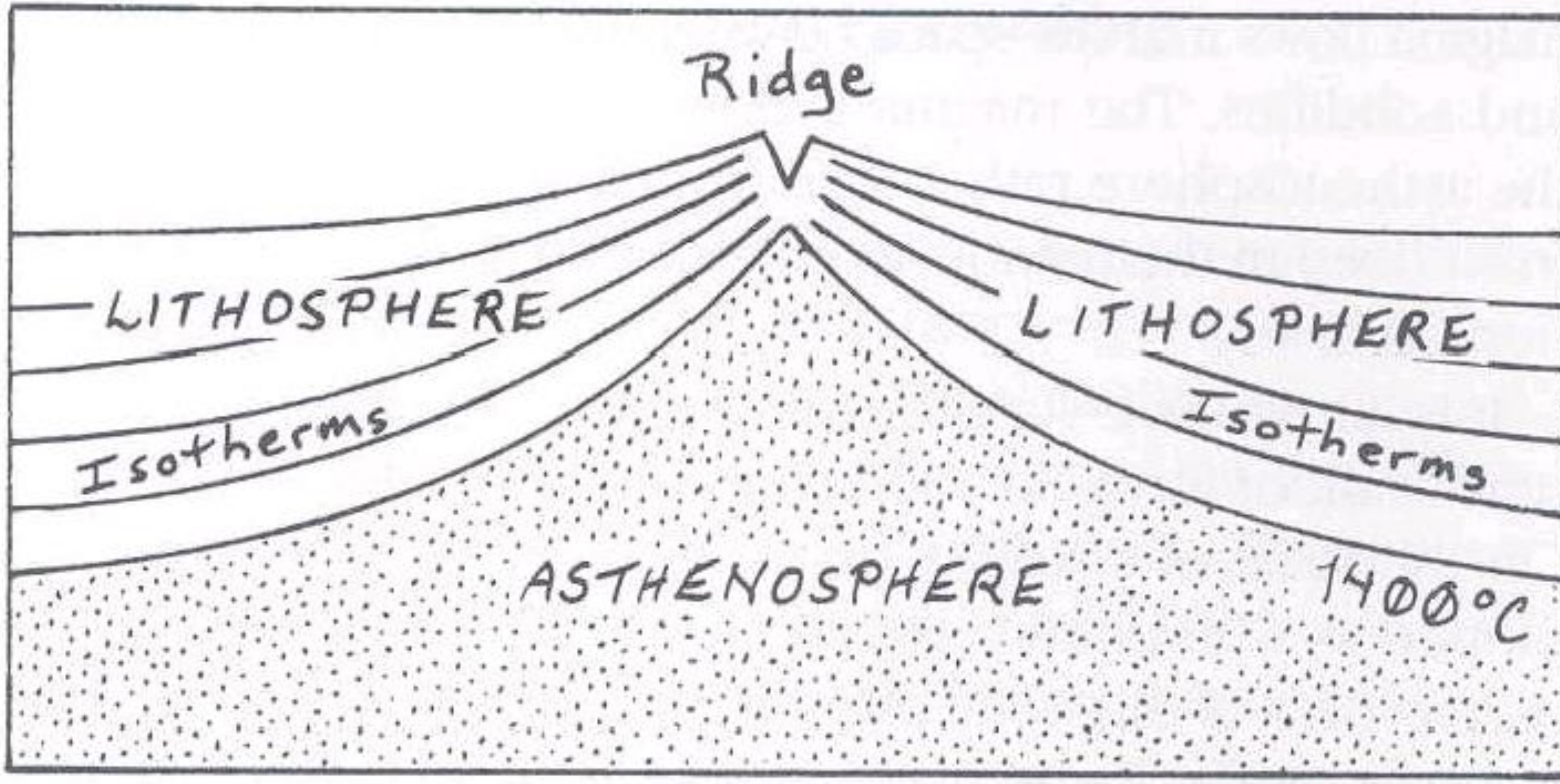
- Largely due to contrast in the deformational properties of two outer layers.
- The stresses exerted along one part of a plate can be transmitted to distant part of the plate
- So the lithosphere plate move over the Asthenosphere
- The surface between lithosphere and Asthenosphere is otherwise is the isothermal line.

Theory of Plate Tectonic: Cont…..

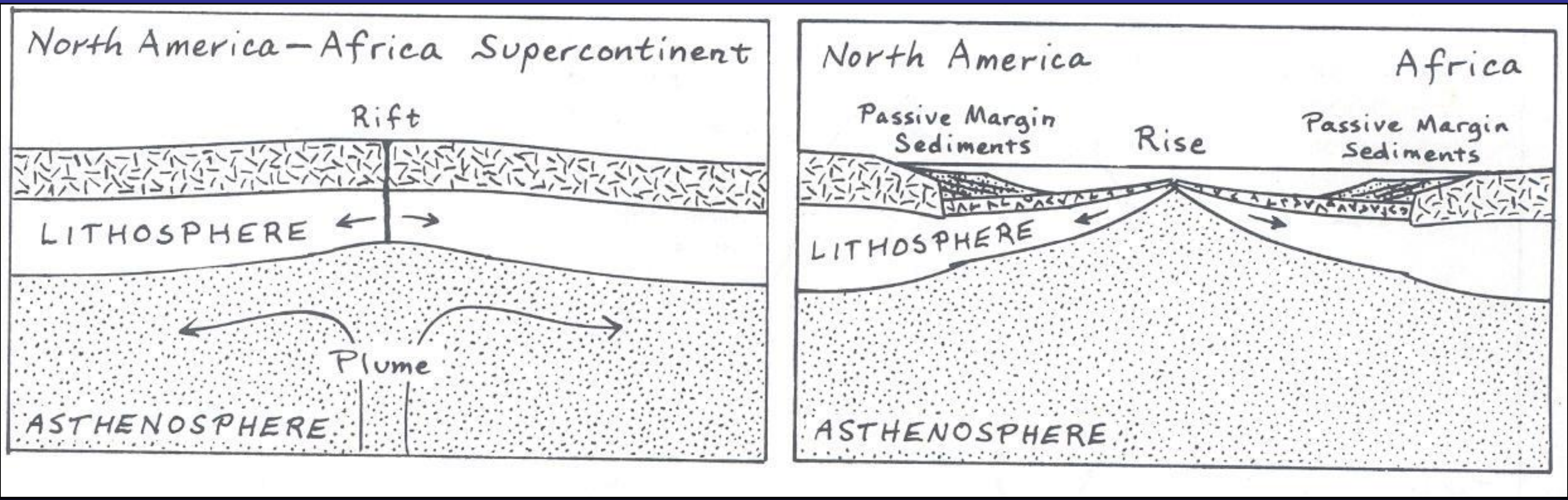
- 80km below the surface the temperature is 1400 C at that temperature mantel rock is in molten stage
- The isothermal line in a static earth will be horizontal
- However when the plate / lithosphere moves it carries its isothermal with it, so it produces downward boundary
- where as in the case of pull apart condition the Asthenosphere moves upward, so the crust thins out



Rigid, cold lithosphere slides over the soft Asthenosphere until it encounters a trench, where it sinks. Plate tectonic cross section : continent does not plow through the lithosphere but rides with it.



Lithosphere thickening and sinking as it cools. Lines are isotherms within the lithosphere



Formation of Atlantic Ocean basin by rifting initiated by a hot mantle plume rising beneath the Africa- North America super continent. As the rift widens, sediments eroded from the continents are deposited upon the trailing edge of the continents.

Plate layering:

Lithosphere:

- Entire crust + upper layer of Mantle
- Highly resistant layer to deformations due to high viscosity or finite strength
- So it is a rigid layer
- about 80km thick

Asthenosphere:

- Soft, easily deformable layer of mantle below the rigid upper layer of mantle and crust (Lithosphere)

Mesosphere:

- Beneath the Asthenosphere
- Less deformable than the Asthenosphere but more deformable than lithosphere

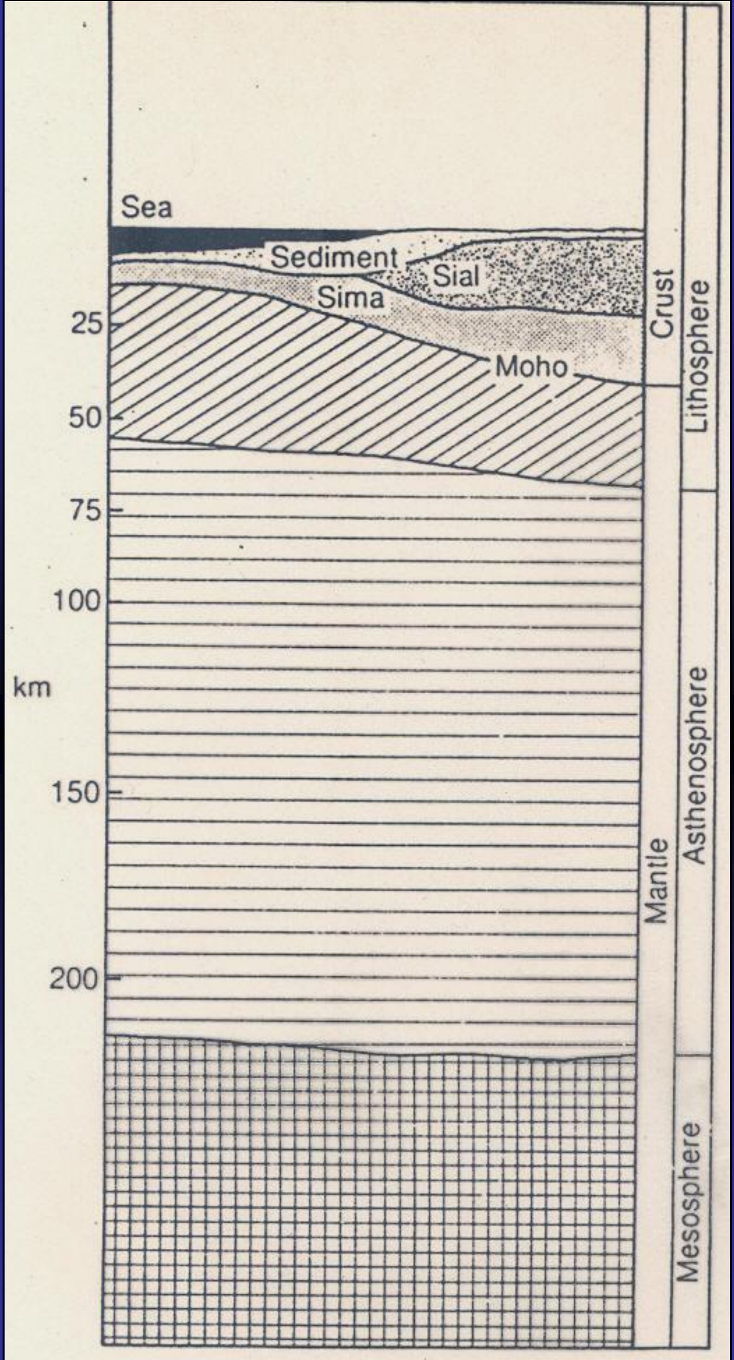


Figure 12.6 Layers in the earth's crust and mantle

CONTINENTS & OCEAN:

Crust

- sial layer - continent area
- Sima layer - Beneath the ocean

Oceanic eruption : Basaltic lava entirely

Continental eruption : All kinds

Basalt
Intermediate
Acid
Fresh magma melt
due to melting &
assimilation

Spreading sites:

— The sites where from the sea floor spreads

— successively the cooled floor acquire magnetism prevailing at that time i.e.,

→ alternatively normal & reverse polarity

— By dating the rocks by potassium / orgon method and measuring distance apart of corresponding sea floor, we can workout the rate of ocean floor spreading.

eg:- 1) Pacific expanded 4.5 cm/ year for ten million years making a total of 45 km

2) 1 - 2 cm / year for North Atlantic

3) 2 - 3 cm/ year for South Atlantic & the Indian Ocean

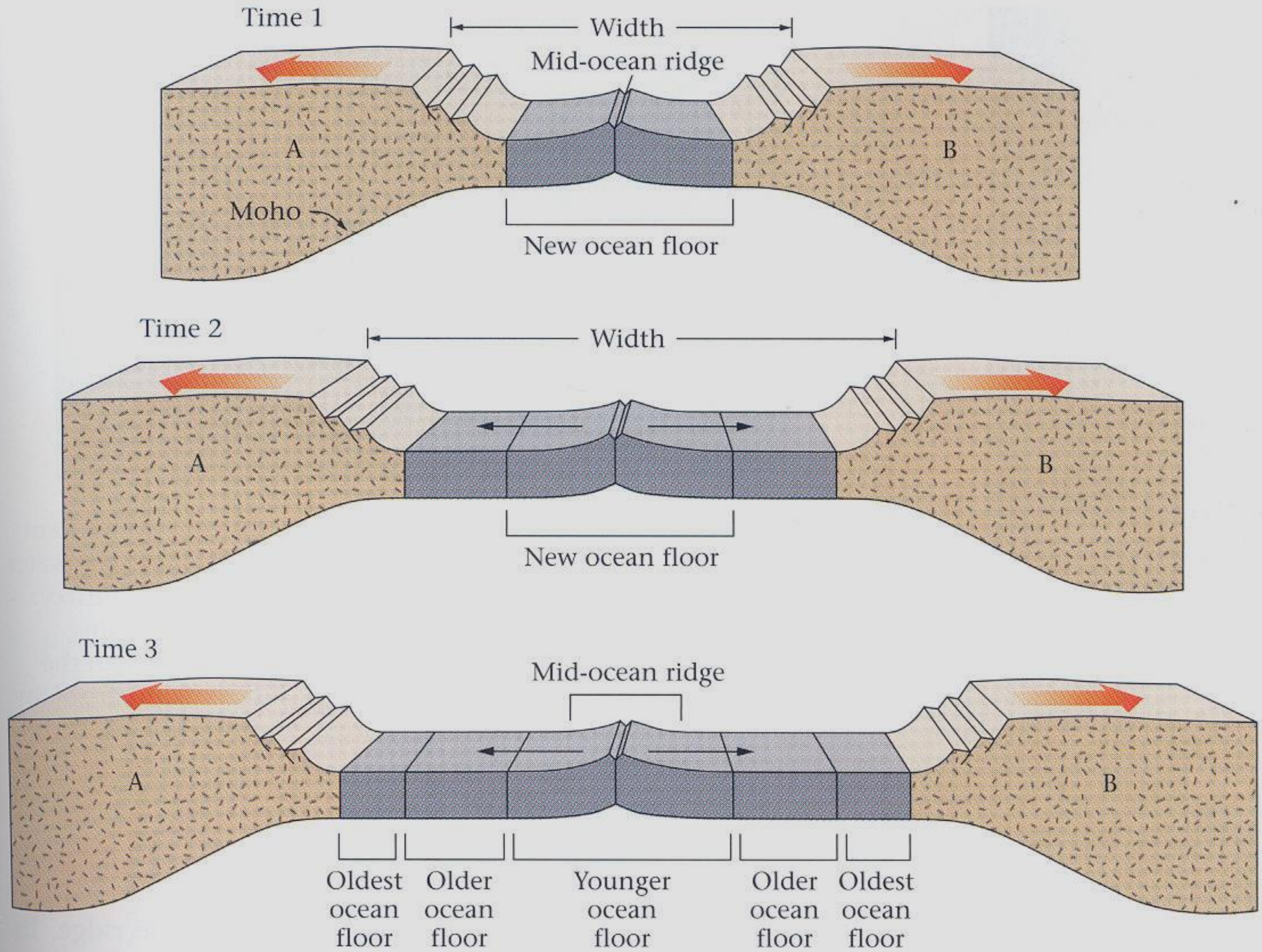


FIGURE 2.33 These sketches depict successive stages in sea-floor spreading along a divergent boundary (mid-ocean ridge); only the crust is shown. The top figure represents an early stage of the process, after the mid-ocean ridge formed but before the ocean grew very wide. With time, as seen in the next two figures, the ocean gets wider and continent A drifts way from continent B. Note that the youngest ocean crust lies closest to the ridge.

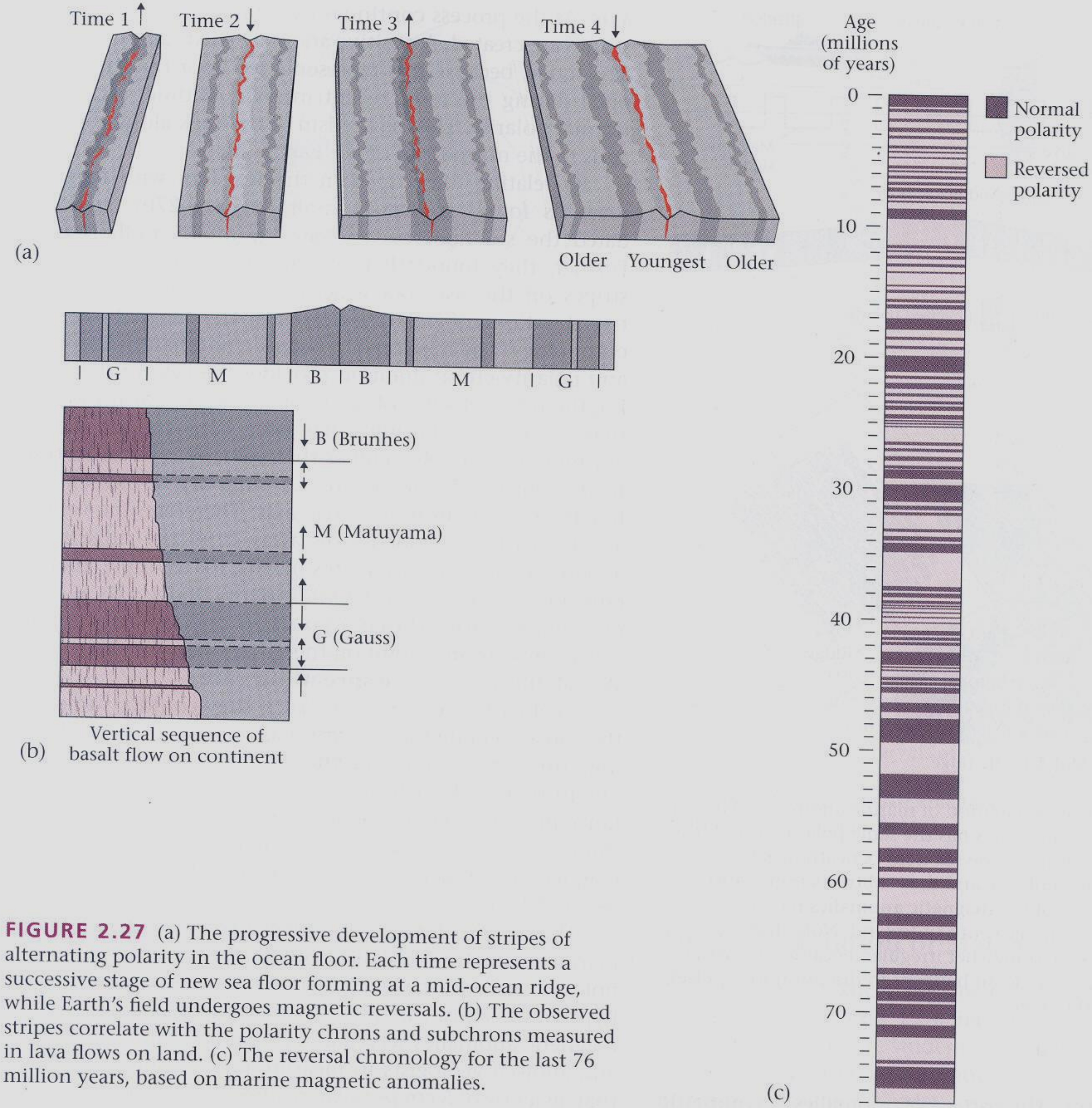


FIGURE 2.27 (a) The progressive development of stripes of alternating polarity in the ocean floor. Each time represents a successive stage of new sea floor forming at a mid-ocean ridge, while Earth's field undergoes magnetic reversals. (b) The observed stripes correlate with the polarity chrons and subchrons measured in lava flows on land. (c) The reversal chronology for the last 76 million years, based on marine magnetic anomalies.

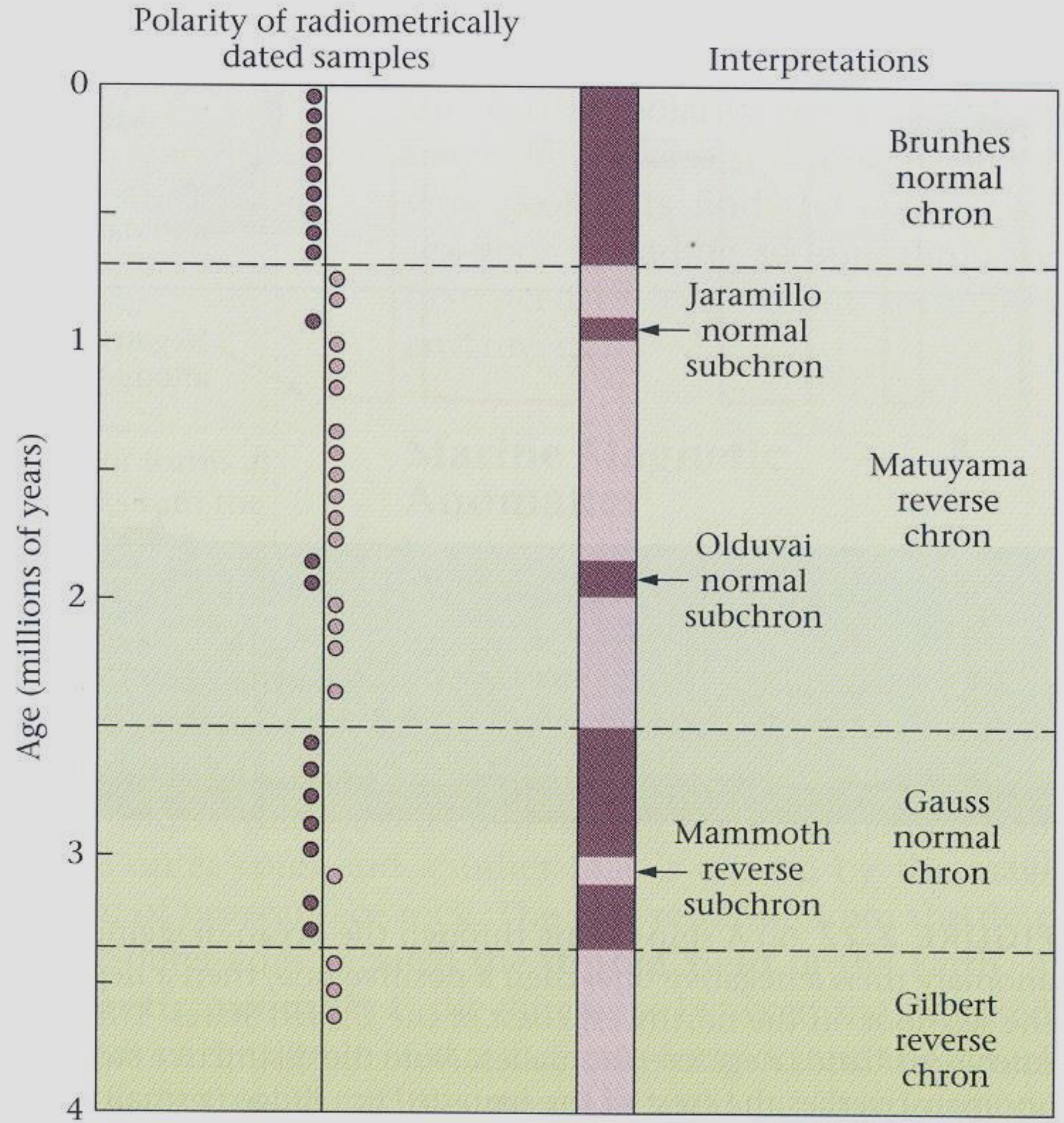


FIGURE 2.25 Radiometric dating of lava flows allows us to determine the age of magnetic reversals during the past 4.5 million years. Major intervals of a given polarity are referred to as polarity chrons, and are named after scientists who contributed to the understanding of Earth's magnetic field. Shorter-duration reversals are called subchrons.

HOT SPOTS:

* Many pacific volcanoes have a linear arrangement
* progressive change in age along the line
* This may have some bearing on ideas of sea floor spreading

→ Each volcano in turn appears to move through a sequence of eruption, erosion, coral growth and subsidence.

But the Island chains are explained as the result of an ocean plate passing over a hotspot fixed in the mantle, which result in periodical eruption.

— the rate of migration of Islands matches with the rate of sea floor spreading

— the direction of the Island chain matches the direction of movement of plates

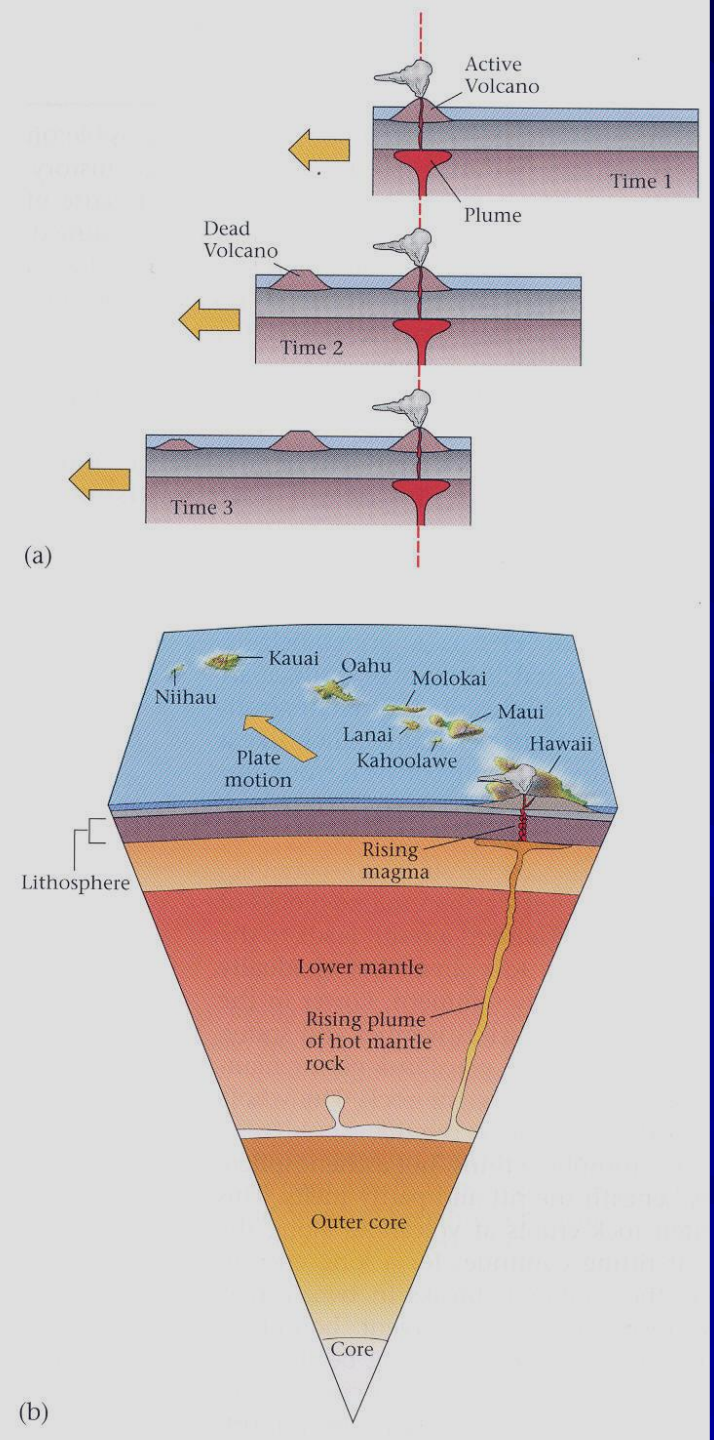


FIGURE 2.48 (a) A mantle plume causes a hot spot to form at the base of a plate, leading to the growth of a volcano on the surface of the plate. As the plate moves, the volcano is carried off the hot spot; it then dies (goes extinct), and a new volcano forms above the hot spot. As the process continues, a chain of extinct volcanoes develops, with the oldest one farthest from the hot spot. The extinct volcanoes gradually sink below sea level and become seamounts. Only the volcano above the hot spot erupts. (b) The plume that forms a hot spot arises from the base of the mantle. Here, we see the plume that underlies the Hawaiian Islands.

COLLISION SITES:

— Andes Type Subduction

— Island Arc Subduction

Andes Type:

— sea floor thrust under continental plate marked by a deep trench just off the continent

— down going slab melts & produce andesite magma & erupted

— further movement marked by a series of earthquakes - Benioff zone

— the continental edge is uplifted to form mountains (The Andes)

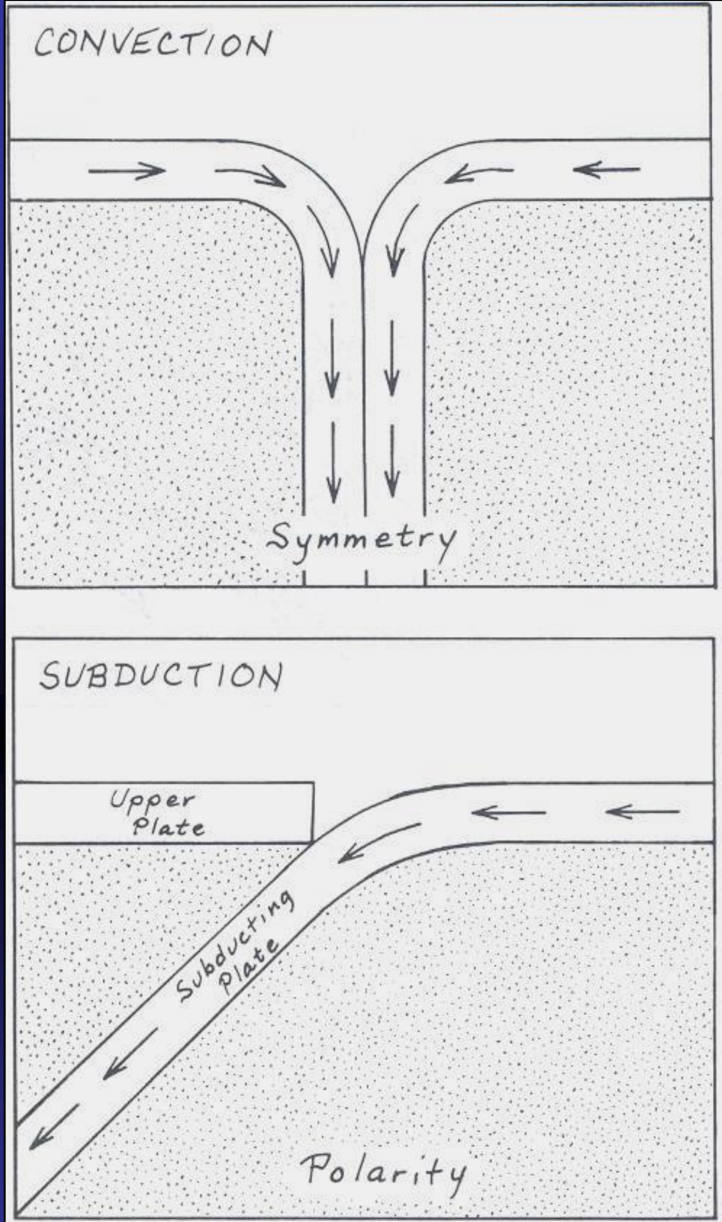
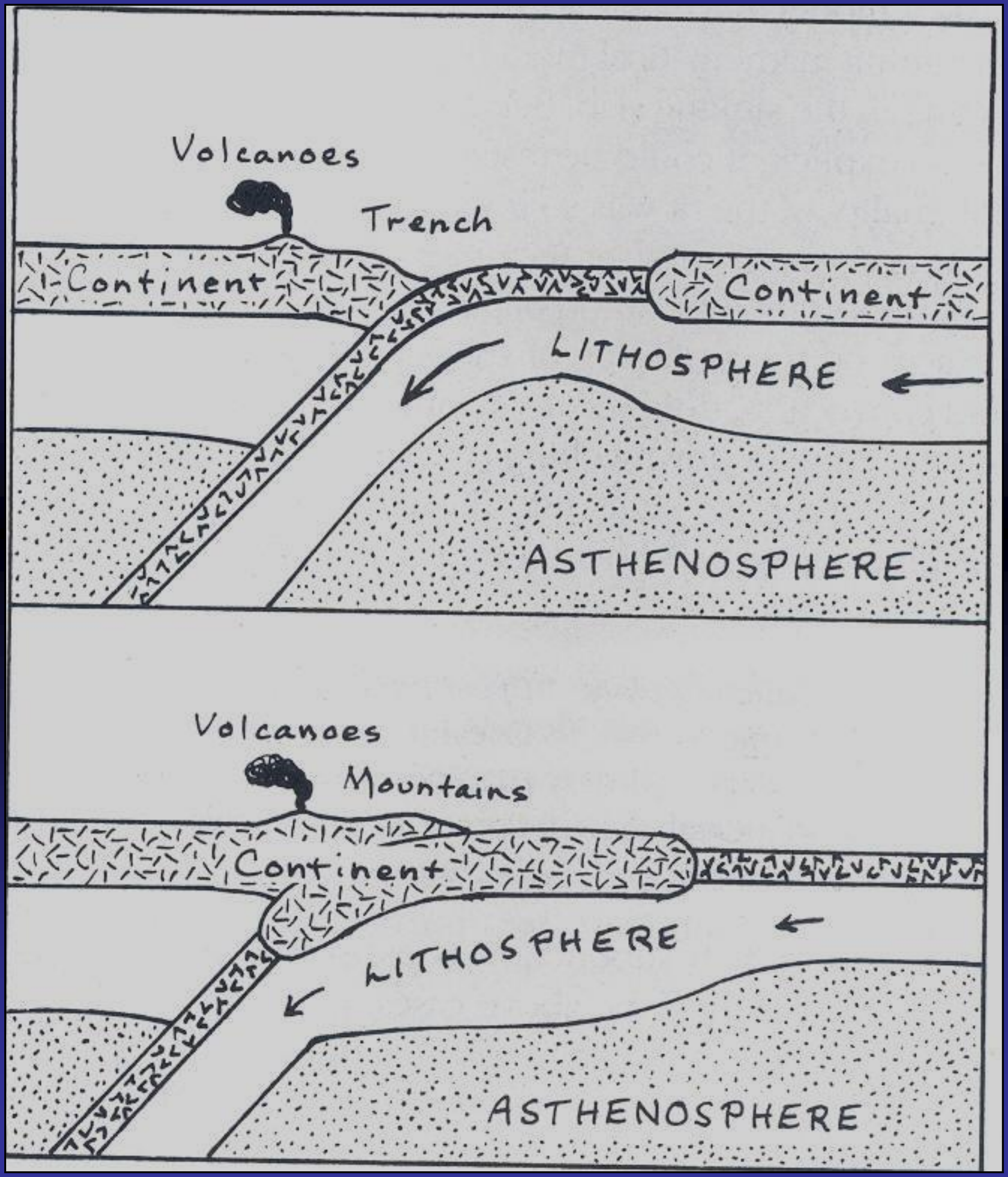
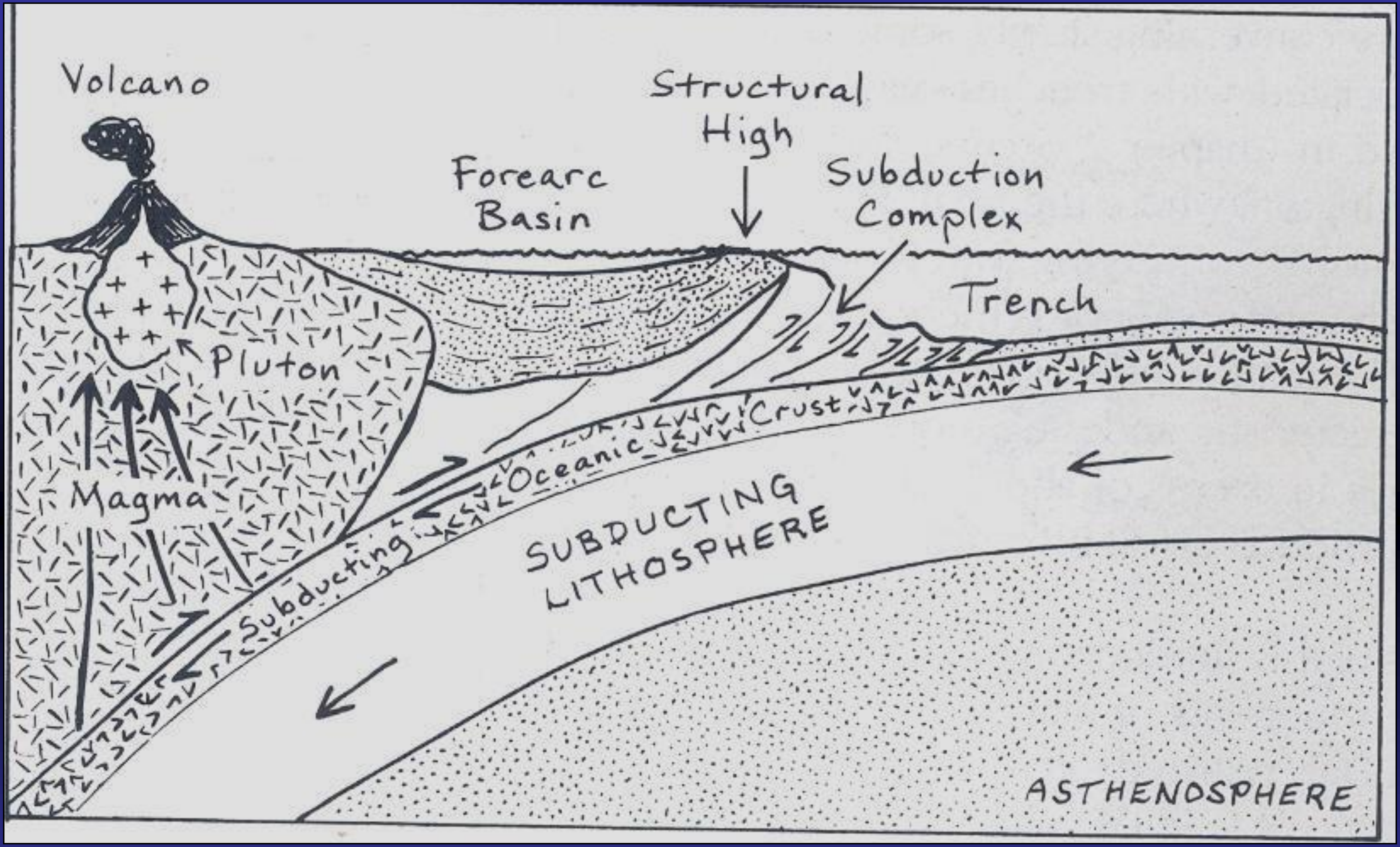


Figure 1-18.
Two theoretical types of convection: symmetrical downwelling and subduction with polarity.

Subduction of Continental plate under continental plate





Geological cross section of the Subduction process

TRIPLE JUNCTIONS & AULACOGENS:

- they are ‘Y’ shaped junctions where three plates comes together, & where the spreading site join
- New plate boundaries are commonly associated with triple junction
- two arms become dominant and third dies out
- the failure arm is - “AULACOGENS”

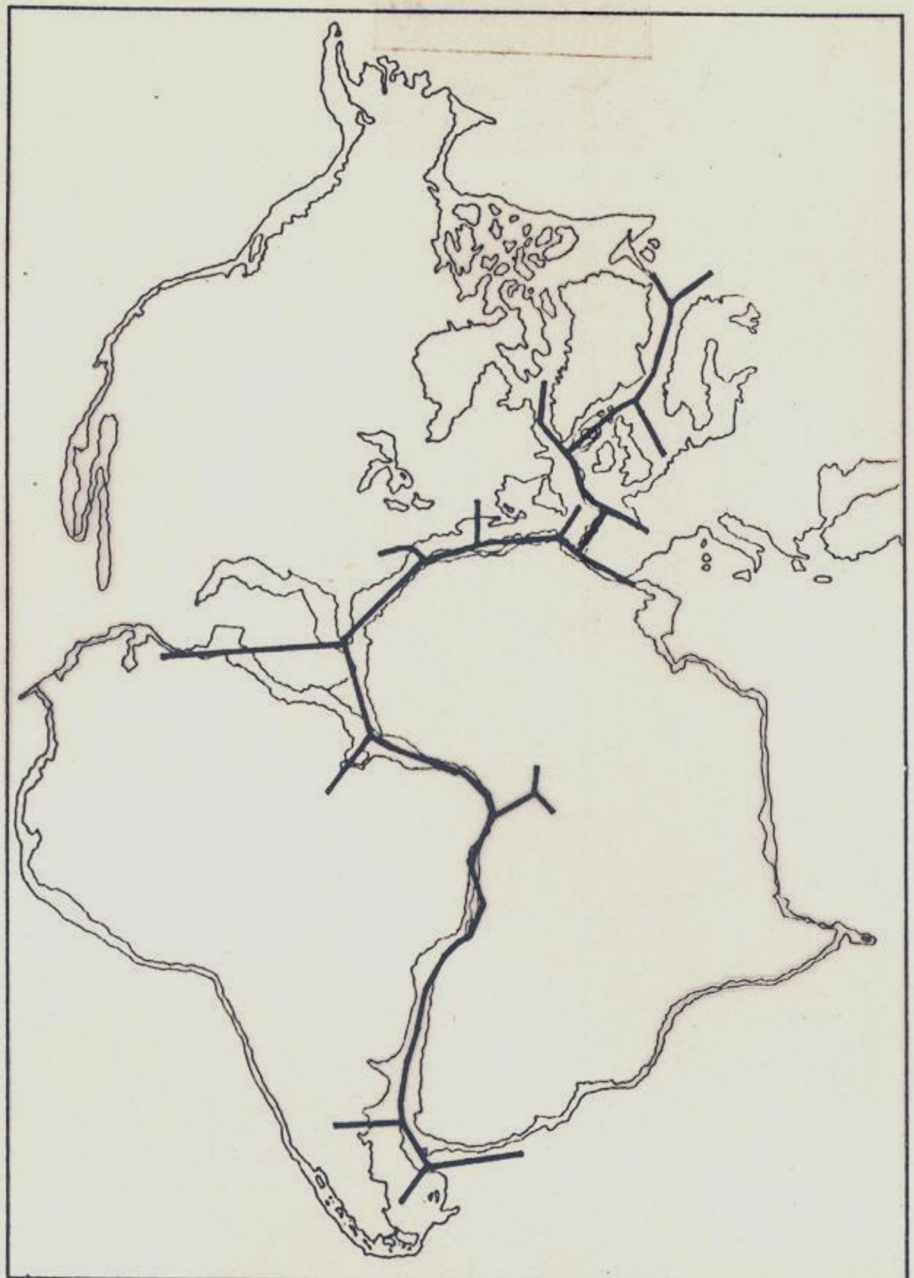


Figure 12.11 Triple junctions around the Atlantic. Most rifts are part of the major separation between America and Europe-Africa, but the failed arms are preserved on the continents as aulacogens

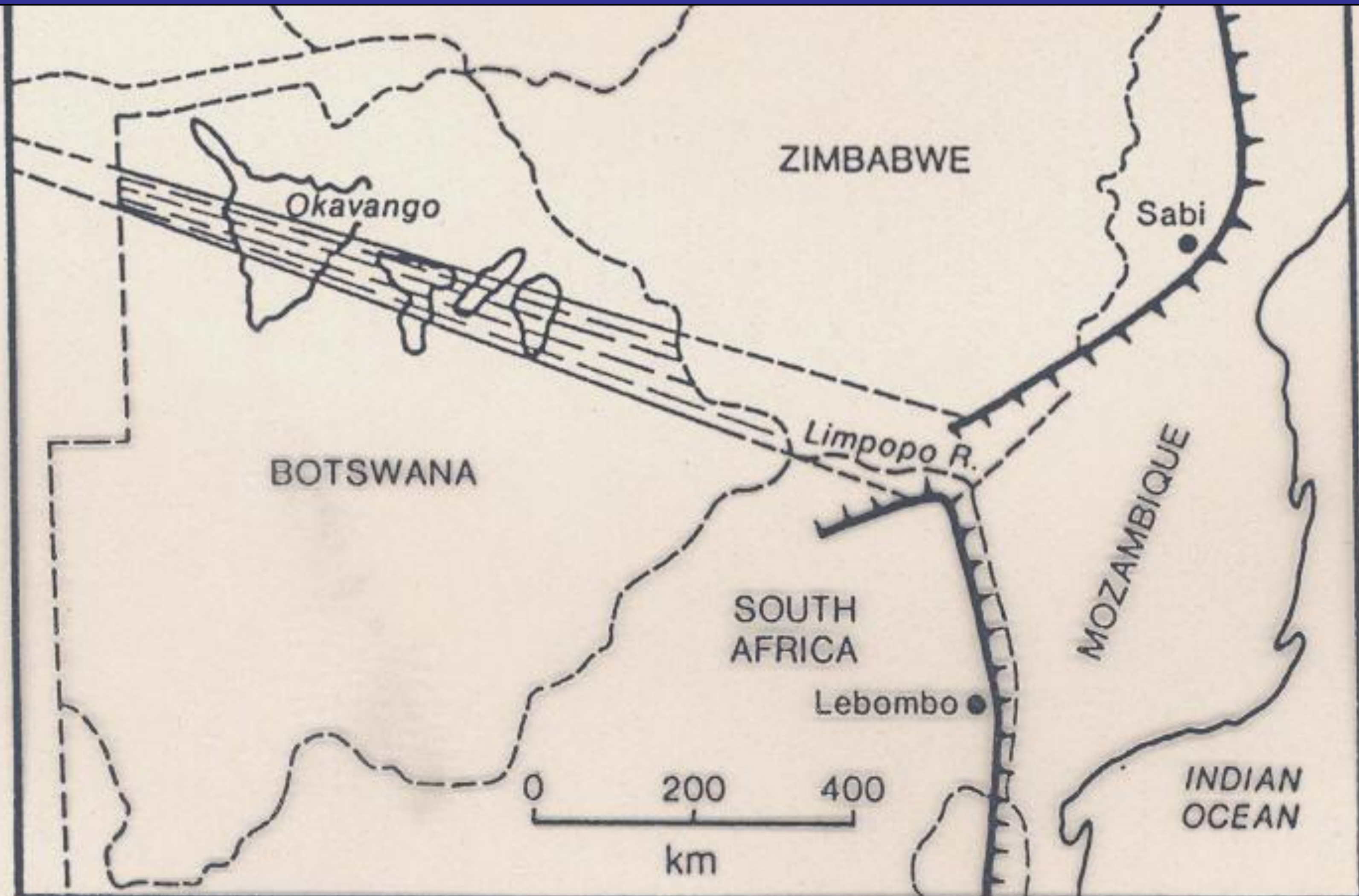


Figure 12.12 The Limpopo aulacogen, followed by a dyke-swarm. The other limbs are the Sabi and Lebombo monoclines (after Reeves, 1978)

Island Arc:

- Sites of many large deep - seated earthquakes
- Benioff zone dips with 30 ° - 35° to depths of 700km (1/10 of earths radius)
- movement causes earthquakes
- pushes the continent towards ocean (or the ocean under the continent) and
- topographically gives rise to the arc.

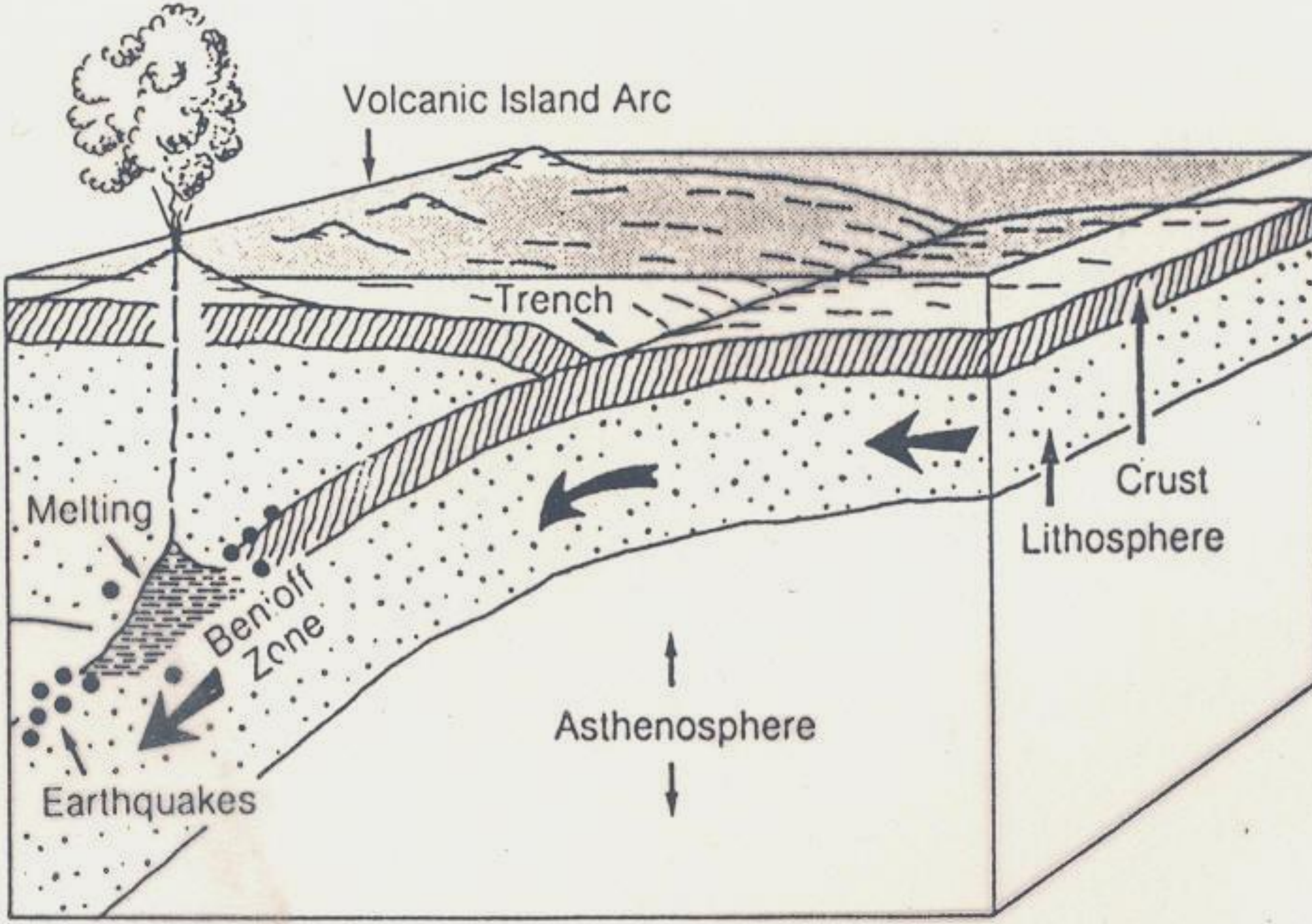


Figure 12.14 Diagram of plate tectonic explanation of subduction, the Benioff zone, and volcanoes

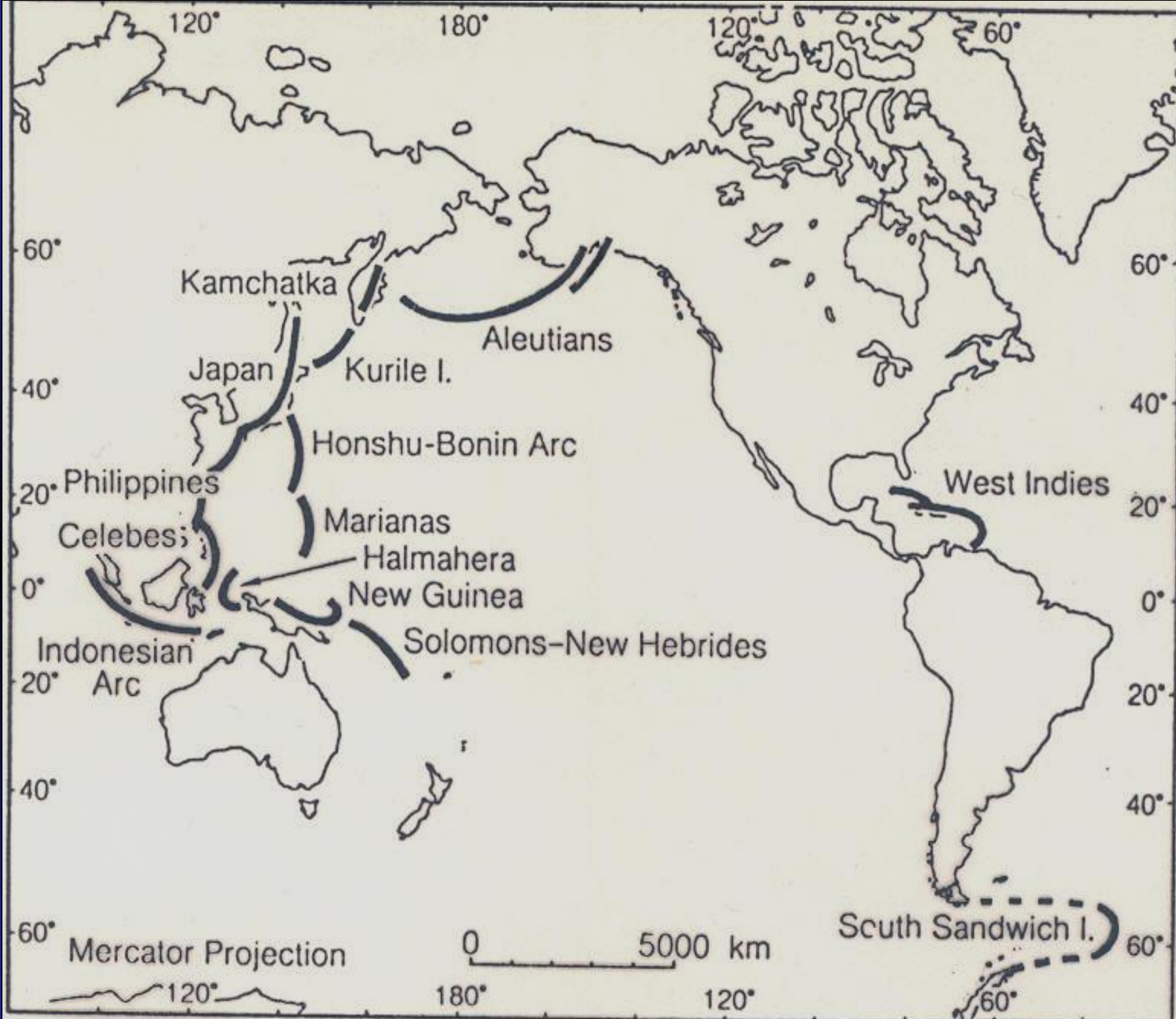


Figure 12.13 Island arcs

OTHER TYPES OF PLATE COLLISION:

→ **Continent & Continent** - **make plate extra thick Mountain building but devoid of volcanoes. INDIA-ASIA (Himalayan Mountains)**

→ **Continent & Ocean** - **Slab of oceanic crust over the continent eg: (Papua New Guinea)**

→ **Ocean - Ocean eg: (Scotia arc)** - **Marked by deep trenches, earthquake zone & volcanoes pacific into Atlantic**

→ **Arc - Arc** - **Phillipine (Two pre exhisting arc)**

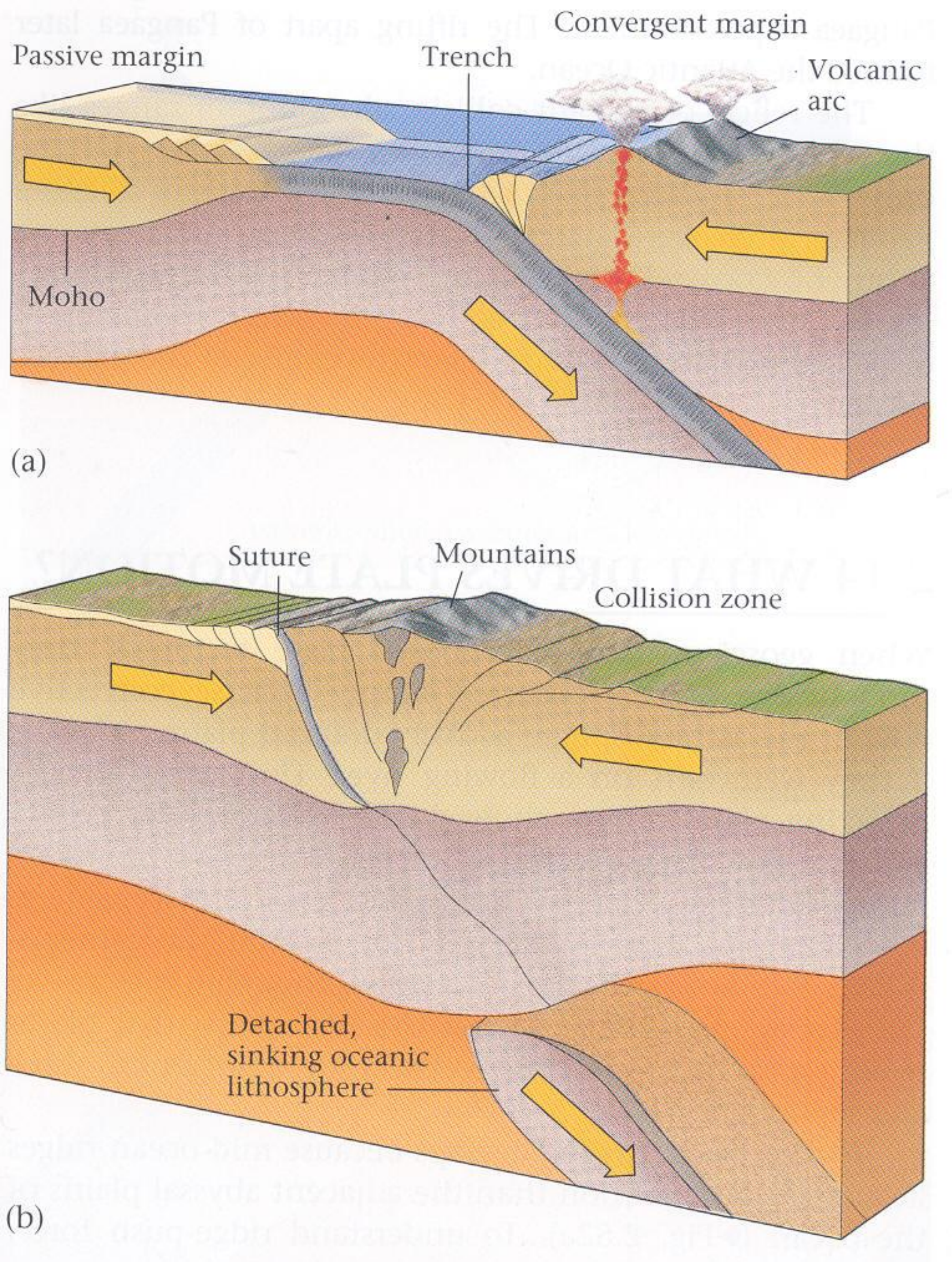


FIGURE 2.51 (a) Before a continental collision takes place, subduction consumes an oceanic plate until it collides with another plate. Here, a passive continental margin collides with a continental volcanic arc. (b) After the collision, the oceanic plate detaches and sinks into the mantle. Rock caught in the collision zone gets broken, bent, and squashed, and forms a mountain range. Slivers of oceanic crust may be trapped along the boundary, or suture, between what once had been two continents. As the crust squashes horizontally, it thickens vertically.

Andesite line:

Line that separates the central basaltic volcanoes from the surrounding area characterized by highly explosive andesitic volcanoes in the PACIFIC.

Volcanoes present dominantly in the PACIFIC area

(nearly 3/4 of world activity)

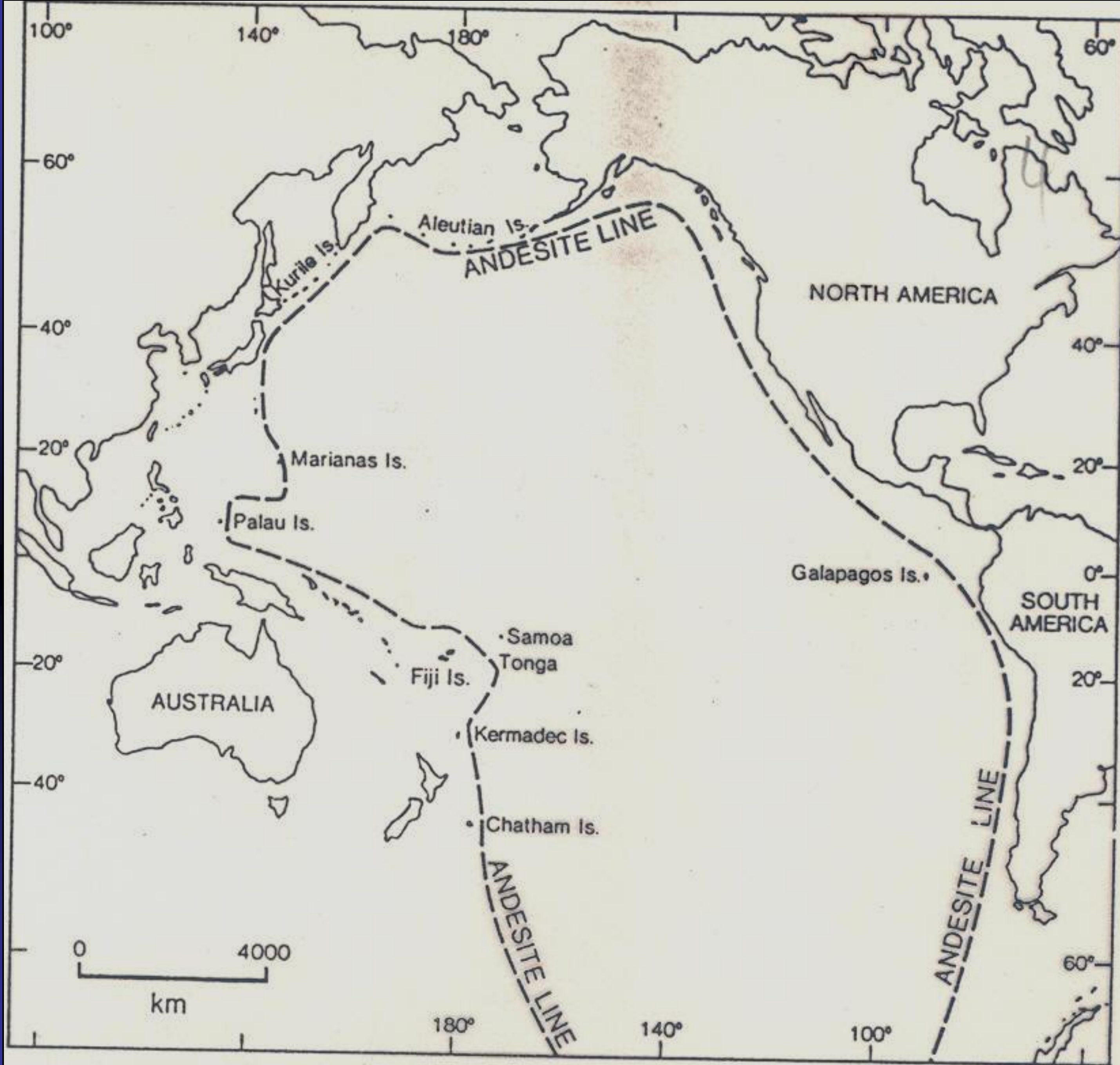


Figure 12.7 The Andesite Line

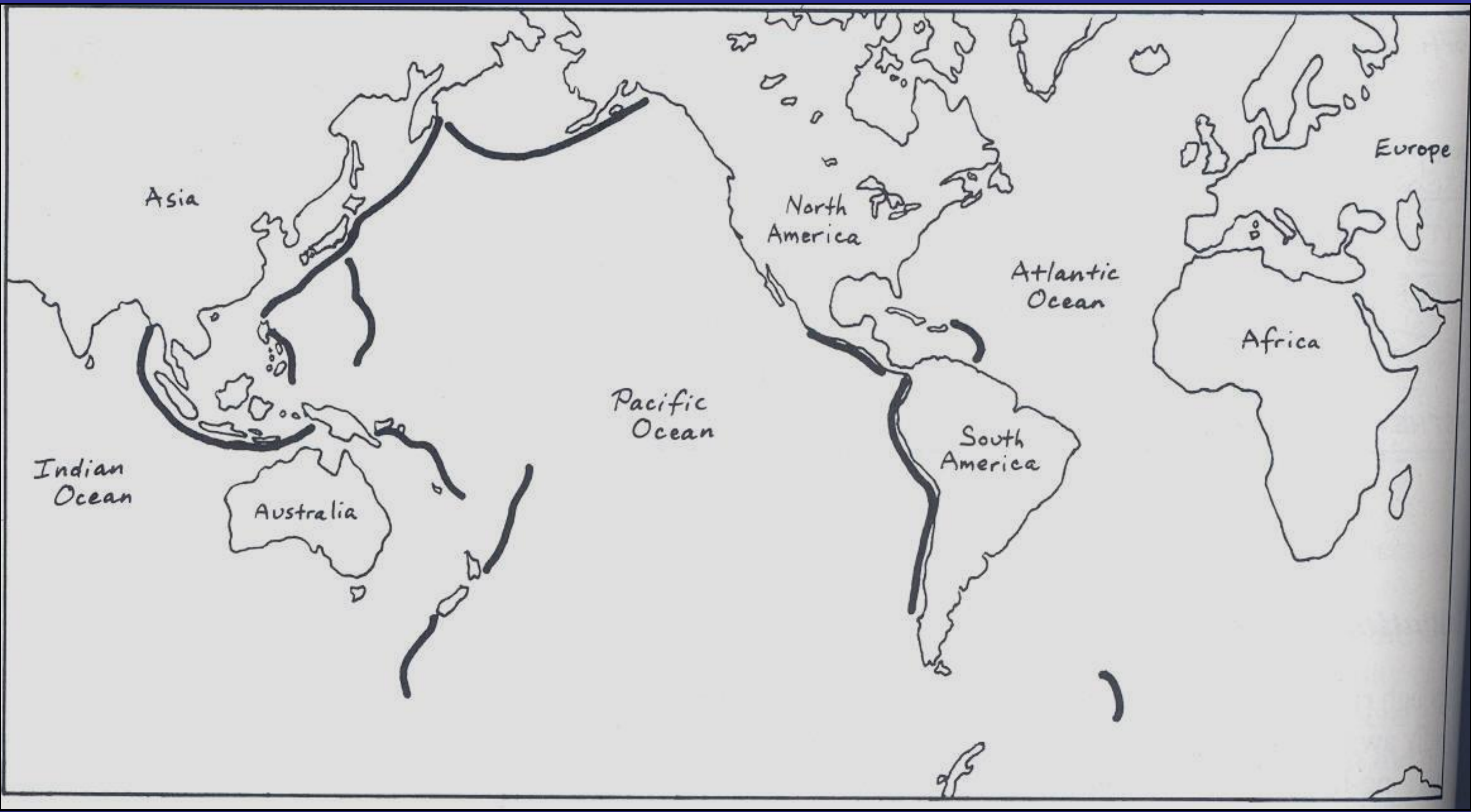
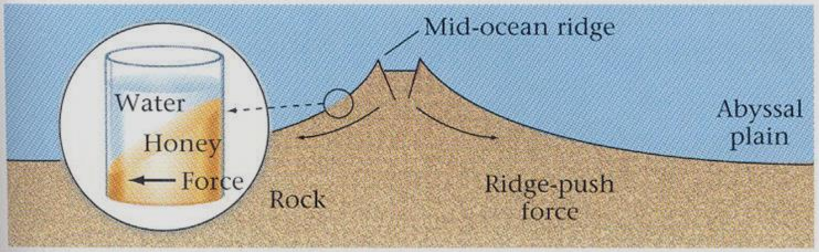
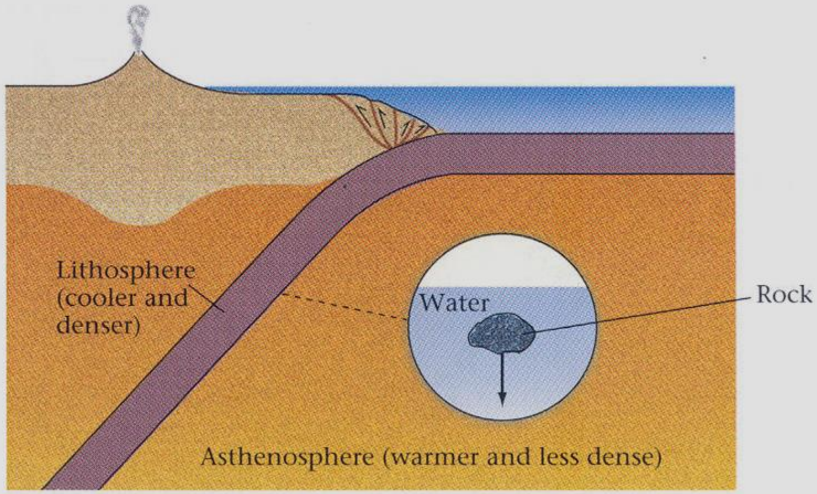


Figure 1-15.
Worldwide pattern of deep oceanic trenches.

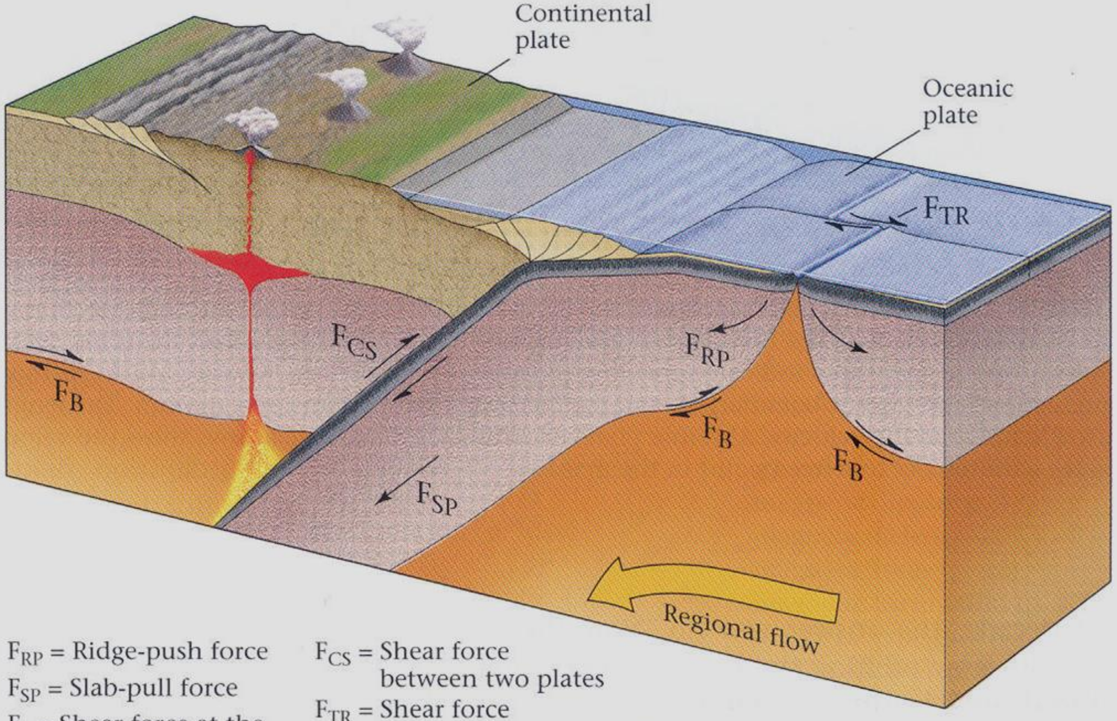


(a)



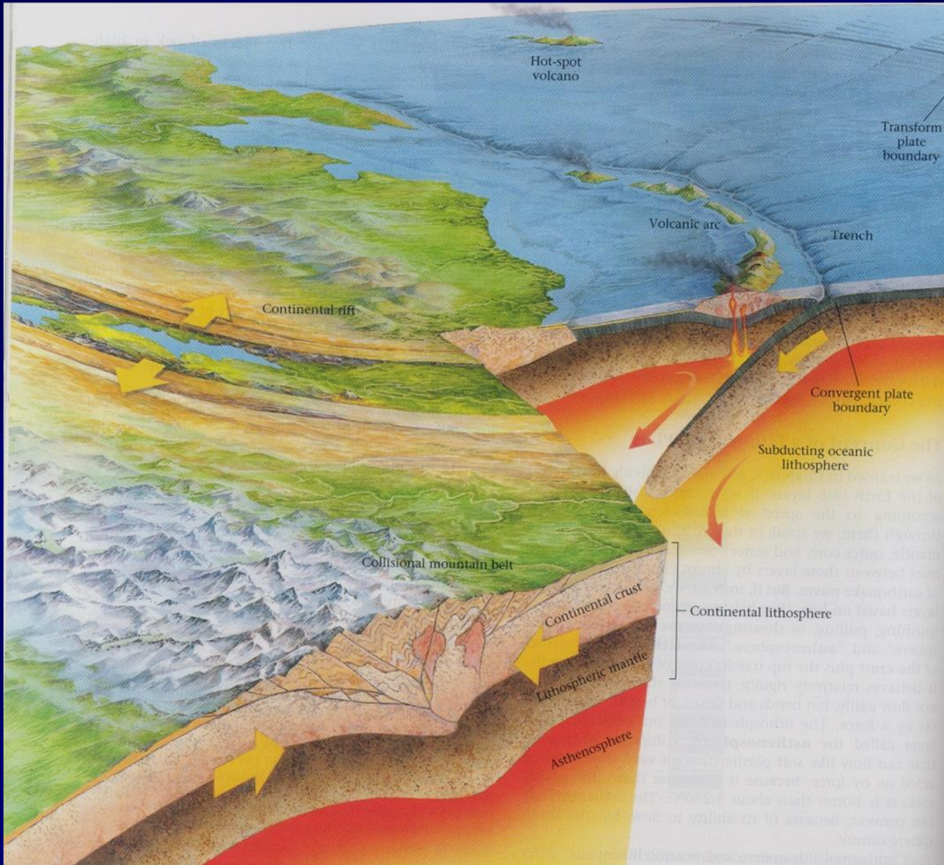
(b)

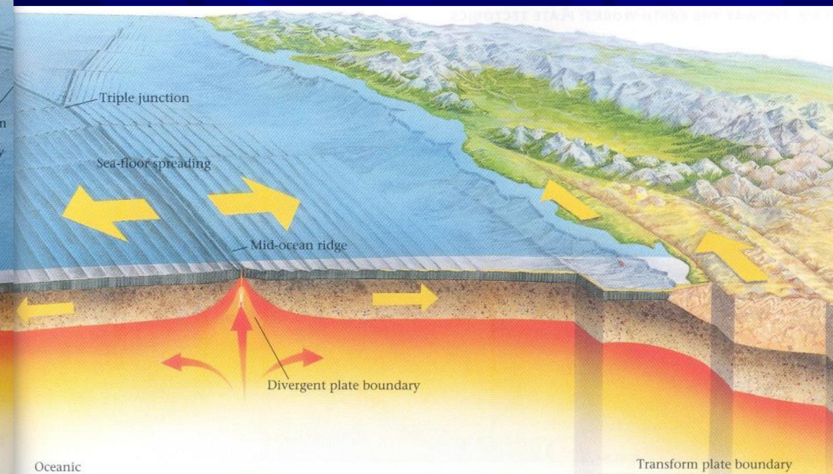
FIGURE 2.52 (a) A simplified profile (not to scale) of a mid-ocean ridge. Note that along the flanks of the ridge, the sea floor slopes. The elevation of the ridge causes an outward ridge-push force that drives the lithosphere plate away from the ridge. A similar situation exists in a glass containing honey and water. If the boundary between the honey and water tilts, the honey exerts an outward force at its base. (b) In this cross section illustrating slab-pull force, the oceanic plate is denser than the asthenosphere, so it sinks into the asthenosphere like a stone into water, only much more slowly. (c) In addition to ridge push and slab pull, the plates feel shear forces along their base as they move into the asthenosphere. Their movement may also be resisted by shear along transform faults or at the base of a continent at a subduction zone.



F_{RP} = Ridge-push force
F_{SP} = Slab-pull force
F_B = Shear force at the base of the plate
F_{CS} = Shear force between two plates
F_{TR} = Shear force along a transform fault

(c)



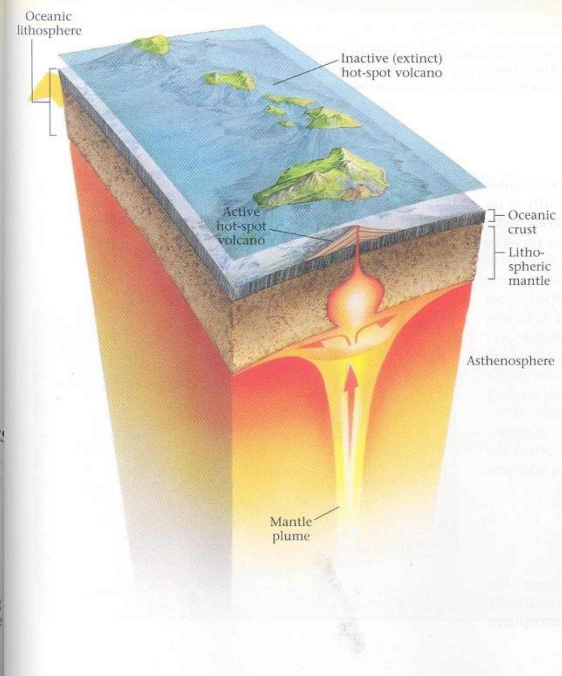


The Theory of Plate Tectonics

The outer portion of the Earth is a relatively rigid layer called the lithosphere. It consists of the crust (oceanic or continental) and the uppermost mantle. The mantle below the lithosphere is relatively plastic (it can flow) and is called the asthenosphere. The difference in behavior (rigid vs. plastic) between lithospheric mantle and asthenospheric mantle is a consequence of temperature—the former is cooler than the latter. Continental lithosphere is typically about 150 km thick, while oceanic lithosphere is about 100 km thick. (Note: they are not drawn to scale in this image.)

According to the theory of plate tectonics, the lithosphere is broken into about twenty plates that move relative to one another. Most of the motion is accommodated by sliding along plate boundaries (the edges of plates); plate interiors stay relatively undeformed. There are three kinds of plate boundaries.

1. Divergent boundaries: Here, two plates move apart by a process called sea-floor spreading. Divergent boundaries are marked by a mid-ocean ridge. Asthenospheric mantle rises



beneath a mid-ocean ridge and partia
forming magma. The magma rises to
ocean crust. The lithospheric mantle
progressively away from the ridge axi
cools.

2. Convergent boundaries: Here,
move together, and one plate subduc
another (it sinks down into the mant
oceanic lithosphere can subduct. At t
surface, the boundary between the tw
marked by a deep-ocean trench. Duri
subduction, melting above the downg
produces magma that rises to form a

3. Transform boundaries: Here, o
slides sideways past another, without
of a new plate or the subduction of a
The boundary is marked by a fault, a
which sliding occurs. Transform bour
segments of mid-ocean ridges. They r
through continental lithosphere.

A point at which three plate bour
is called a triple junction. This figure
triple junction where three mid-ocea
meet. Where two continents converg
collide and form a collisional mounta
This happens because continental cru
buoyant to be subducted. At contine
continent stretches and may break in
are marked by the existence of many
continent rifts apart, a new mid-ocea
develops. Hot-spot volcanoes form ab
of hot mantle rock that rise from nea
mantle boundary. As a plate drifts ove
it leaves a chain of extinct volcanoes.

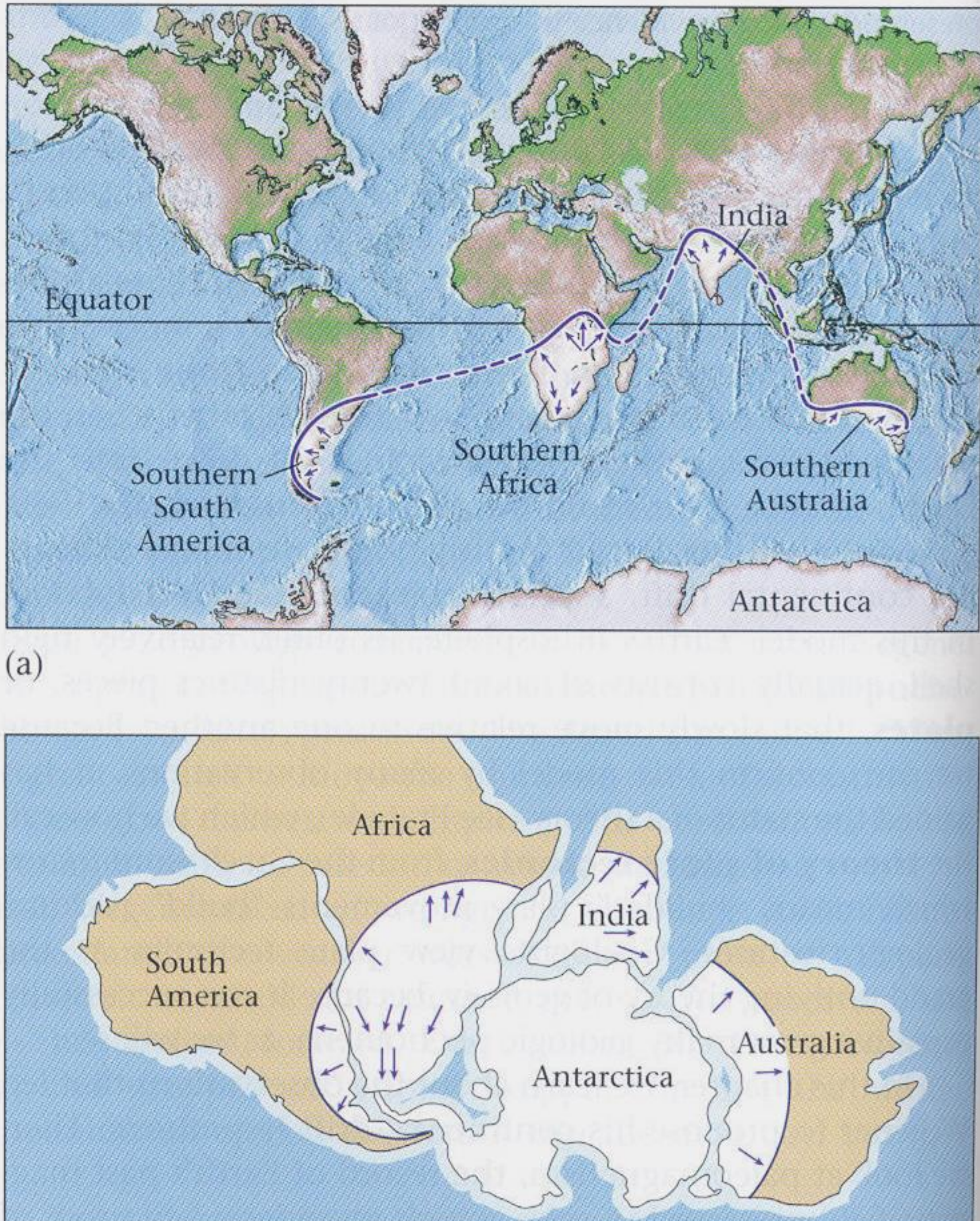


FIGURE 2.3 (a) The distribution of late Paleozoic glacial deposits on a map of the present-day Earth. The arrows indicate the orientation of striations. (b) The distribution of these glacial deposits on a map of the southern portion of Pangaea. Note that the glaciated areas fit together to define a polar ice cap.

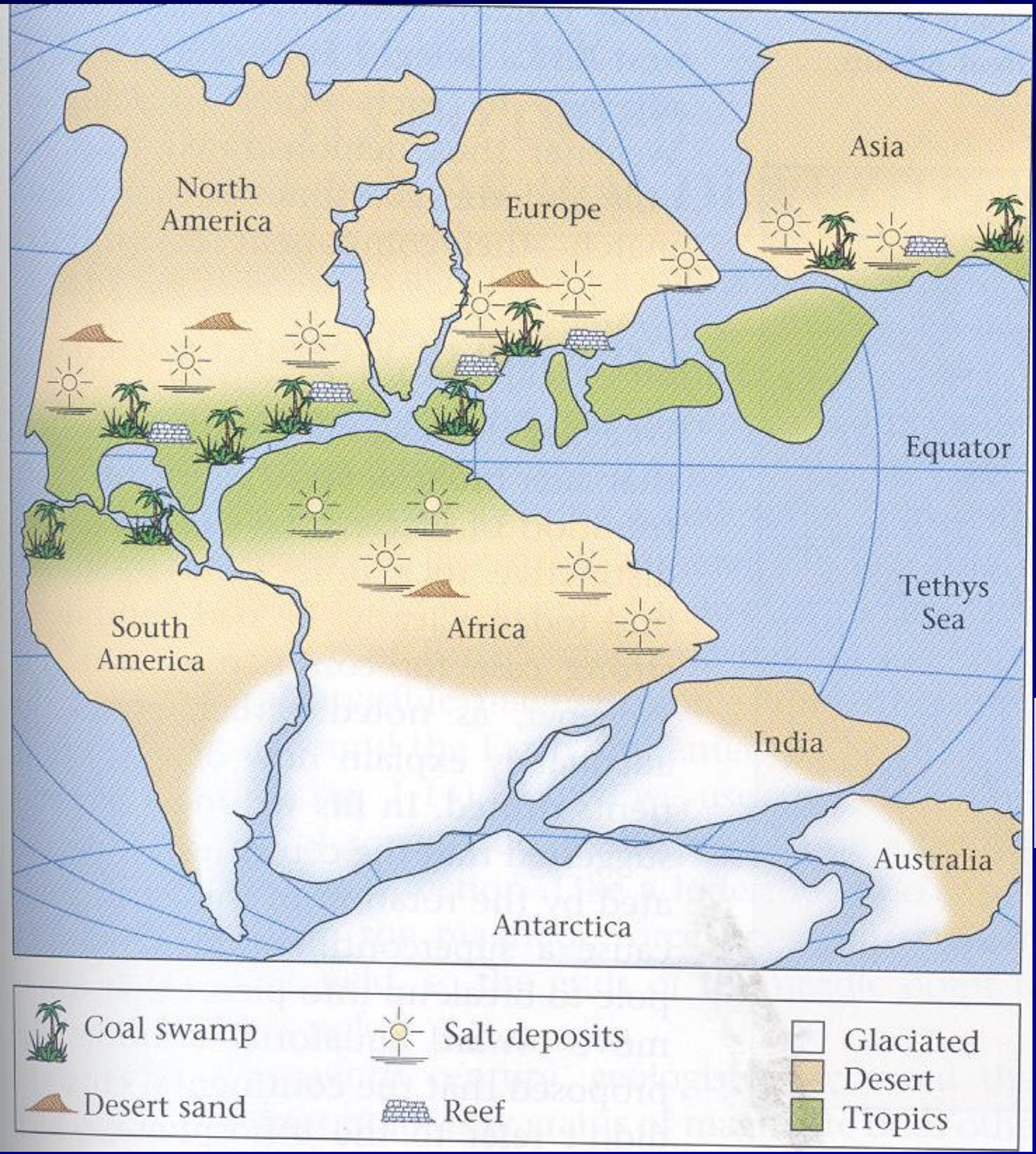


FIGURE 2.4 Map of Pangaea, showing the distribution of coal deposits and reefs (indicating tropical environments), and sand-dune deposits and salt deposits (indicating subtropical environments). Note how deposits now on different continents align in distinct belts.

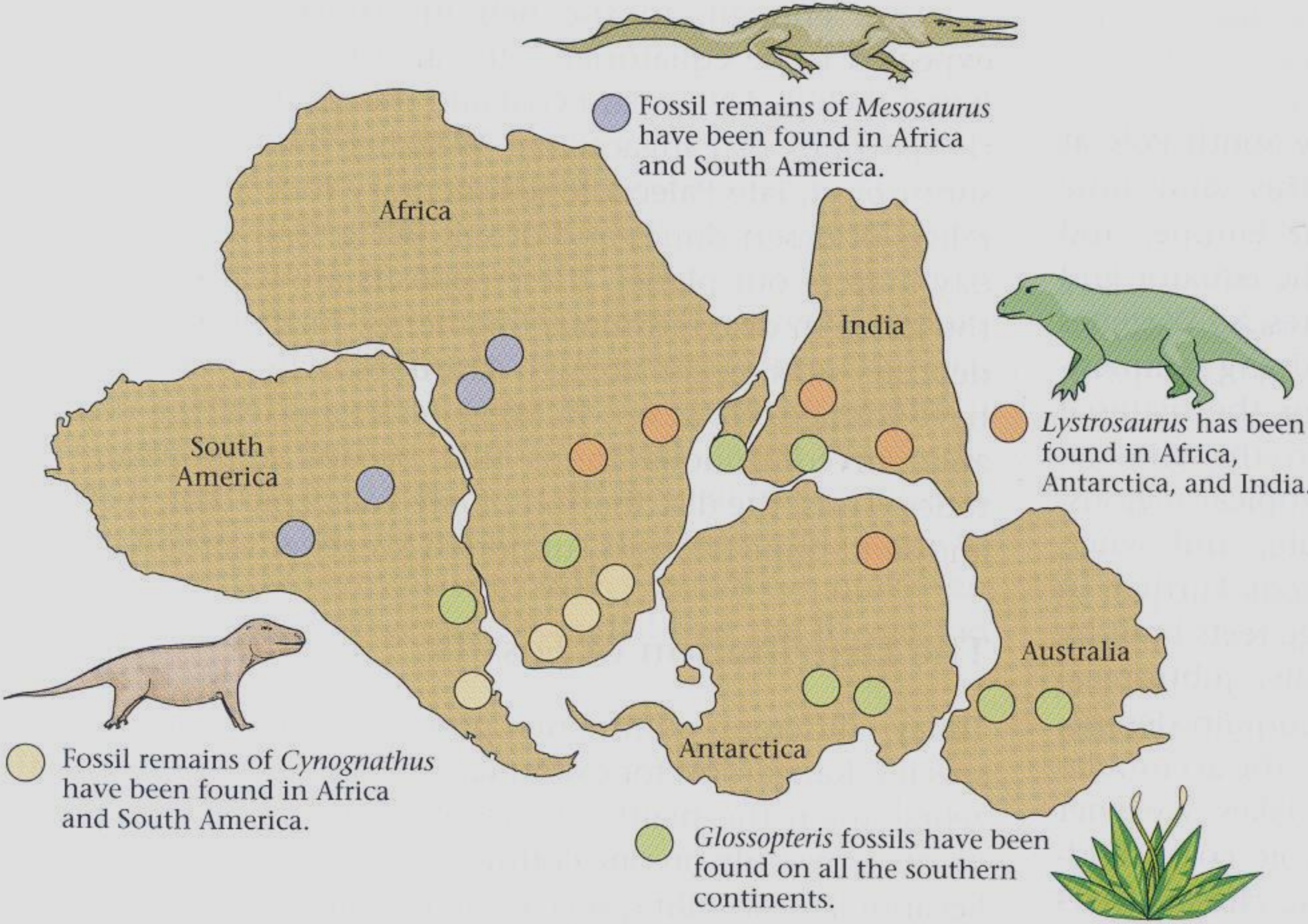
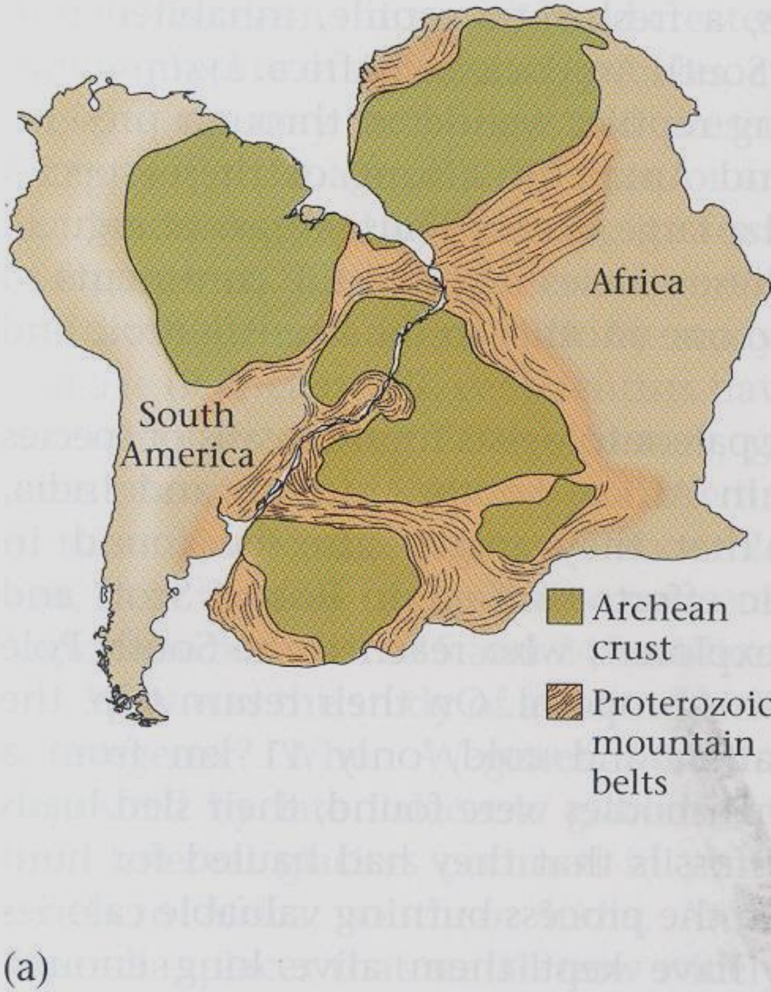
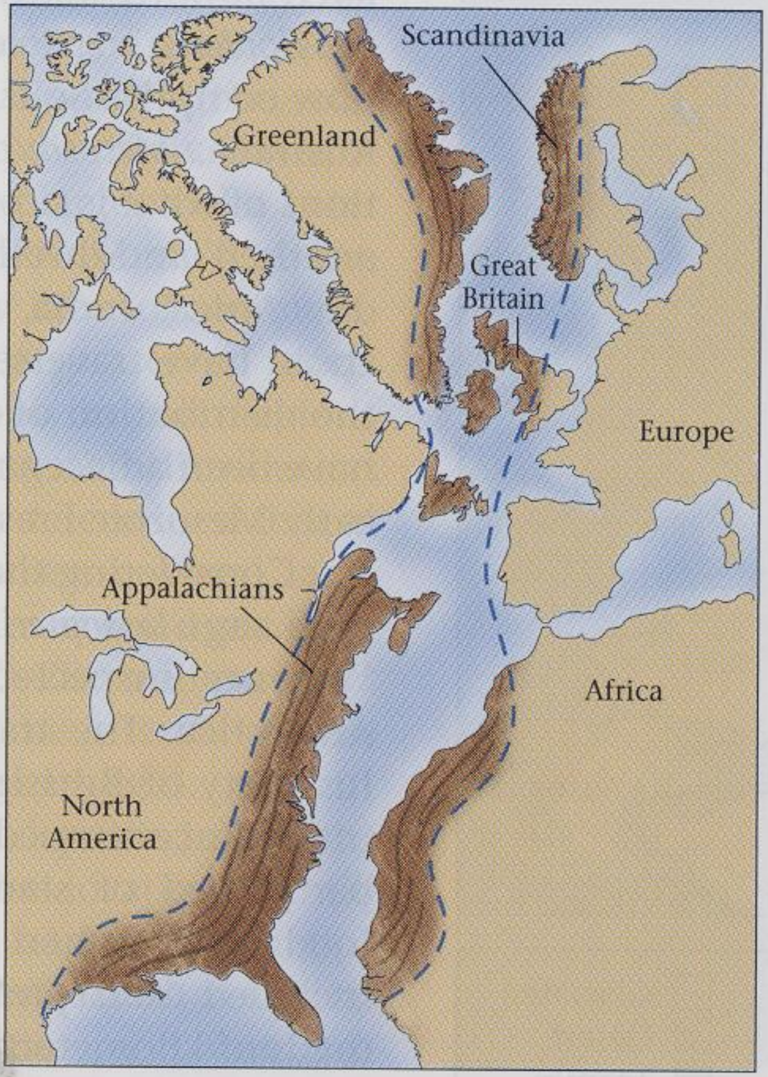


FIGURE 2.5 This map shows the distribution of terrestrial (land-based) fossil species. Note that creatures like *Lystrosaurus* could not have swum across the Atlantic to reach Africa.

FIGURE 2.6 (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.





PALEOMAGNETISM

Magnetism of the Earth:

- The earth behaves like a large magnet, and a magnetic field not only exists in its body but also surrounds it far in space.
- The earth's magnetic pole and equator do not coincide with the geographic pole and equator.
- The total magnetic intensity varies from 39,000 gammas in the equator to 70,000 gammas in the pole.
- The intensity of the field varies with respect to time.
- Daily variations in the earth magnetic field is know as **diurnal variations**.
- There are also variations which take place over much longer periods of time, known as **secular variations**.
- In dealing with earth's magnetism, two angular relations called the **declination** and the **inclination** are commonly denoted on topographic maps.

Paleomagnetism:

- Paleomagnetism of a rock provides a north arrow inscribed on the rock at the time of rock formation
- As a plate carrying the rock rotates about some pole, the north vector embedded magnetically in the rock also rotates to a new direction that is no longer north.
- It also tells us the latitude at which the rock formed.
- These information provides a clue or guide to rearrange the plates in its original position prior to its movement.

Magnetic Latitudes and Colatitudes:

- The distance from a point of observation to the north magnetic pole is <u>Magnetic Colatitudes.</u>
- <u>Magnetic Equator</u> is the midway between the two magnetic poles where the magnetic Colatitude is 90 (θ)
- <u>Magnetic Latitude (λ)</u> is the angular distance of a point of observation from the magnetic equator ($\lambda = 90 - \theta$)

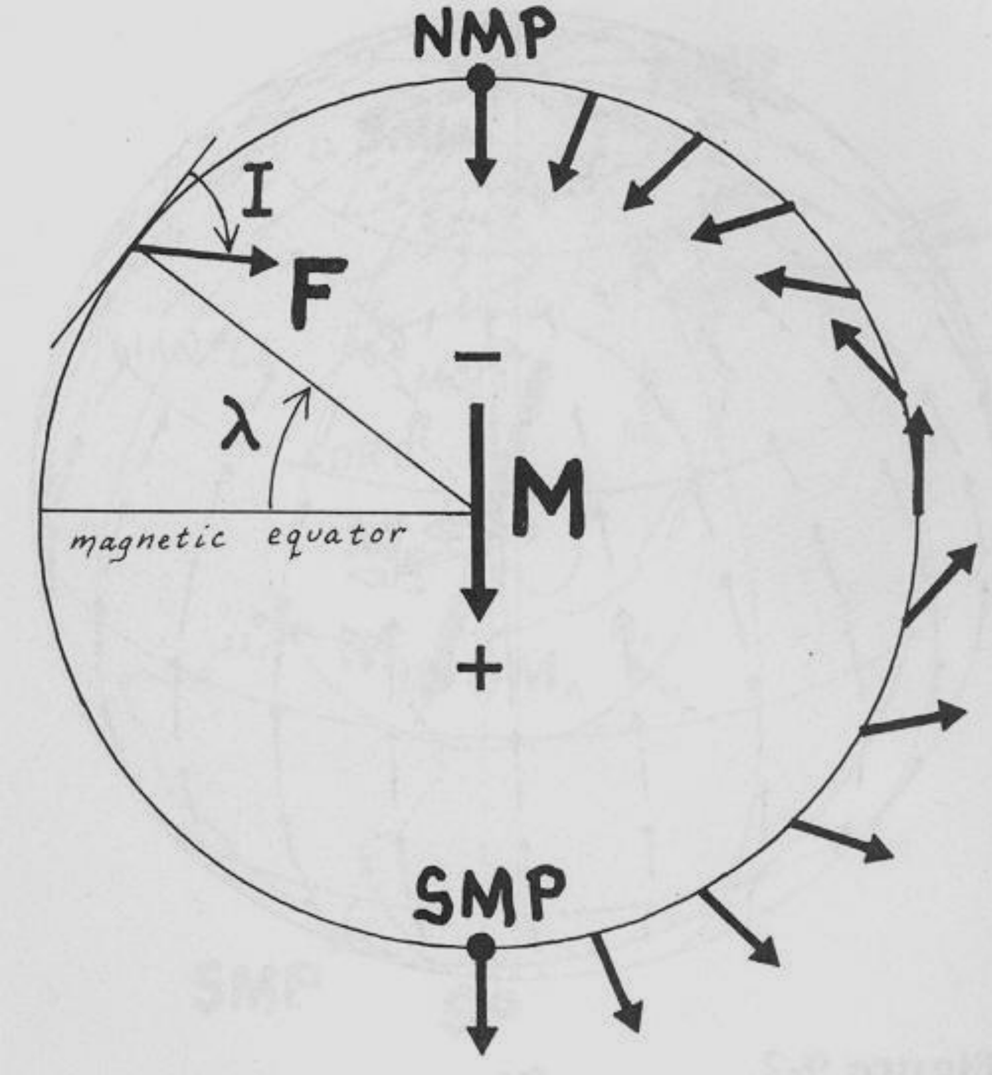


Figure 9-1.
Magnetic dipole **M** at the center of circle produces fields **F** shown along the circle. *I*: magnetic inclination or plunge beneath horizontal. λ: magnetic latitude. **NMP**: north magnetic pole. **SMP**: south magnetic pole.

- **For a dipole field (North & south pole) at all point along the magnetic equator where $\lambda=0$. F is horizontal and the magnetic inclination is Zero.**

- **At all points along each magnetic latitude circle the magnetic inclination (I) is constant.**

So the Magnetic Inclination (I)

$$I = \tan^{-1} (2 \cos \theta) \quad ; \theta = \cot^{-1} \{ (\tan I) /2\}$$
$$I = \tan^{-1} (2 \tan \lambda) \quad ; \theta = \tan^{-1} \{ (\tan I) /2\}$$

Samples / Rocks suitable for Paleomagnetic studies:

Volcanic rocks :

- ➢ Superb Magnetic recorder that too hot lava or ash flow rather than cold ash fall.
- ➢ Sampling needed from more lava layers with slightly varying age to remove the secular variation.

Sediments :

- ❖ Sediments of less than silt fractions
- ❖ Sediment deposited more faster
- ❖ Sediment not undergone any chemical change

But small sample of 1cm to 2cm size is enough even to remove the secular variation because this 1cm thickness of sediment deposition is taking place over a long space of time nearly 10my.

RED BEDS :

Positive aspect:

- Hematite (Fe2 03) is a good carrier of magnetic memory.
- Hematite is chemically stable
- The magnetic remanence of red beds, whether deposition of chemical in origin, is generally accrued over a long interval of time (so it averages secular variation)

Negative aspect:

- Fossils embedded give /provide uncertain ages for these red bed deposition
- Uncertainty sterns from the difficulty of determining whether red beds become magnetized during, shortly after or long after deposition.

Collection of samples:

- We need to collect oriented samples
- six to eight oriented samples spread over a lateral distance of several hundred meters from each stratum to get the internal consistency of the magnetization
- In the case of tilted lava flow & sedimentary layer – the direction & amount of tilt need to be recorded for tectonic correction.

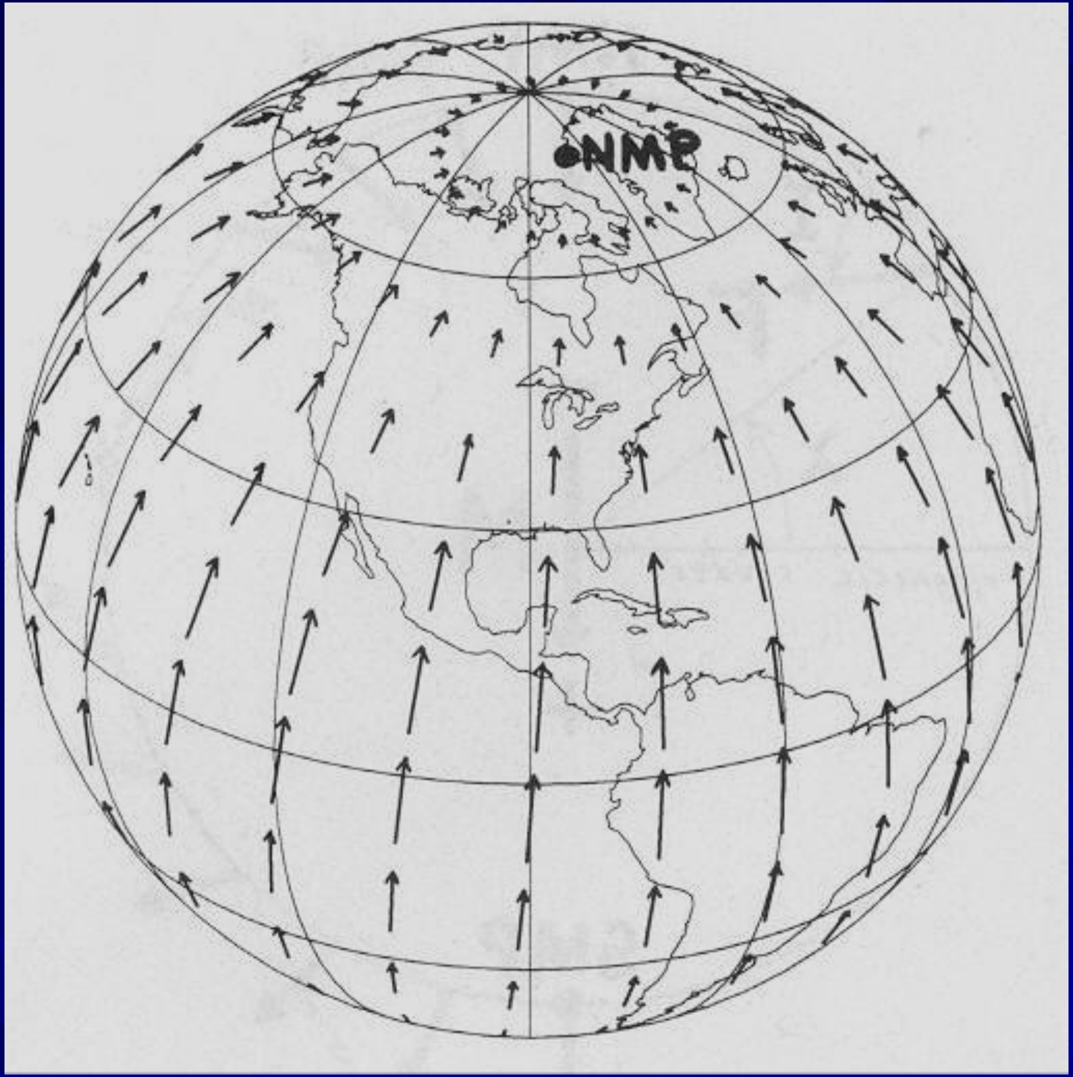


Figure 9-2.
Geomagnetic dipole field. Arrows show horizontal components of magnetic fields, **F**, which lie along great circles converging on the north magnetic pole, **NMP**.

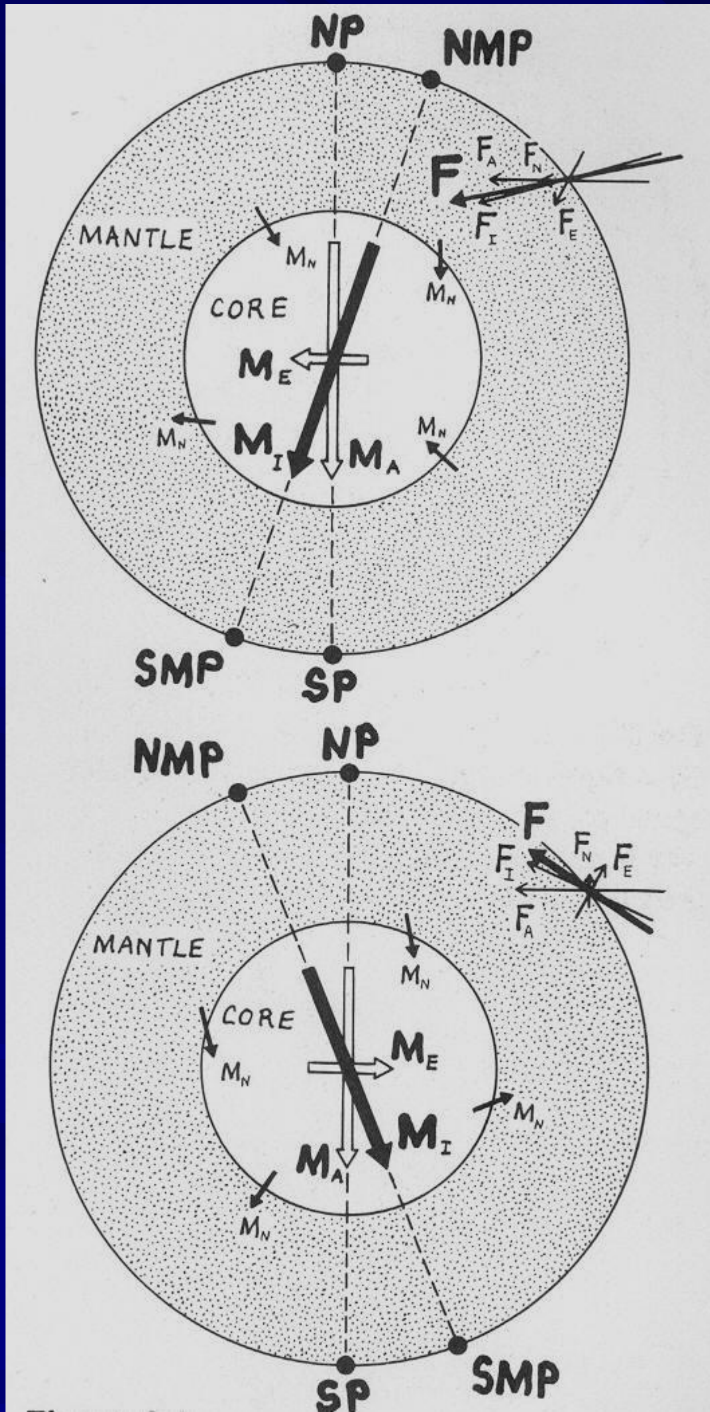
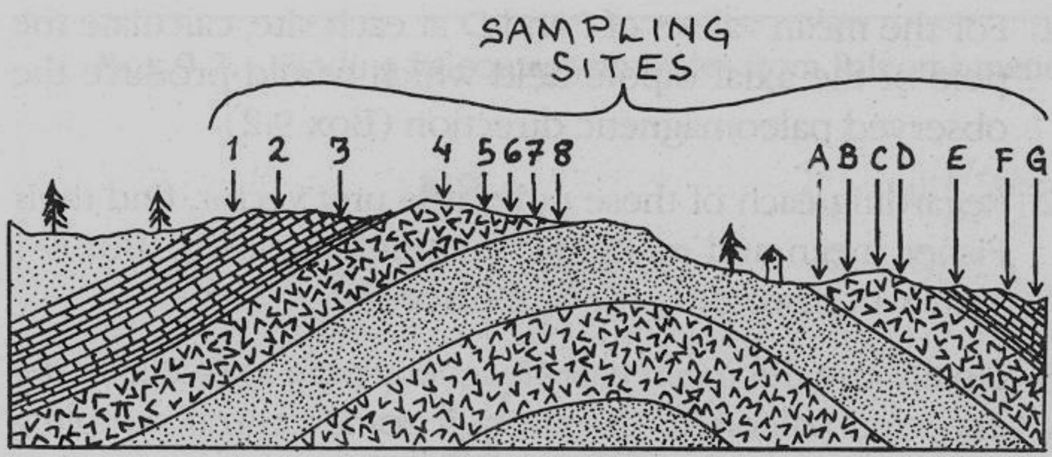


Figure 9-3.
Origin of magnetic field in the core can be represented by the following magnetic moments. $\mathbf{M}_A$: axial dipole moment. $\mathbf{M}_E$: equatorial dipole moment. $\mathbf{M}_I$: inclined dipole moment, the vector sum of $\mathbf{M}_A$ and $\mathbf{M}_E$. $\mathbf{M}_N$: nondipole sources, which can be modeled by small dipoles in the outer part of the fluid core. At right are shown the three components of the field, $\mathbf{F}$, produced at a site on the equator by the three sources in the core. Two snapshots of the core are shown taken 10^4 years apart. Time average of all components sum to zero except axial dipole component.



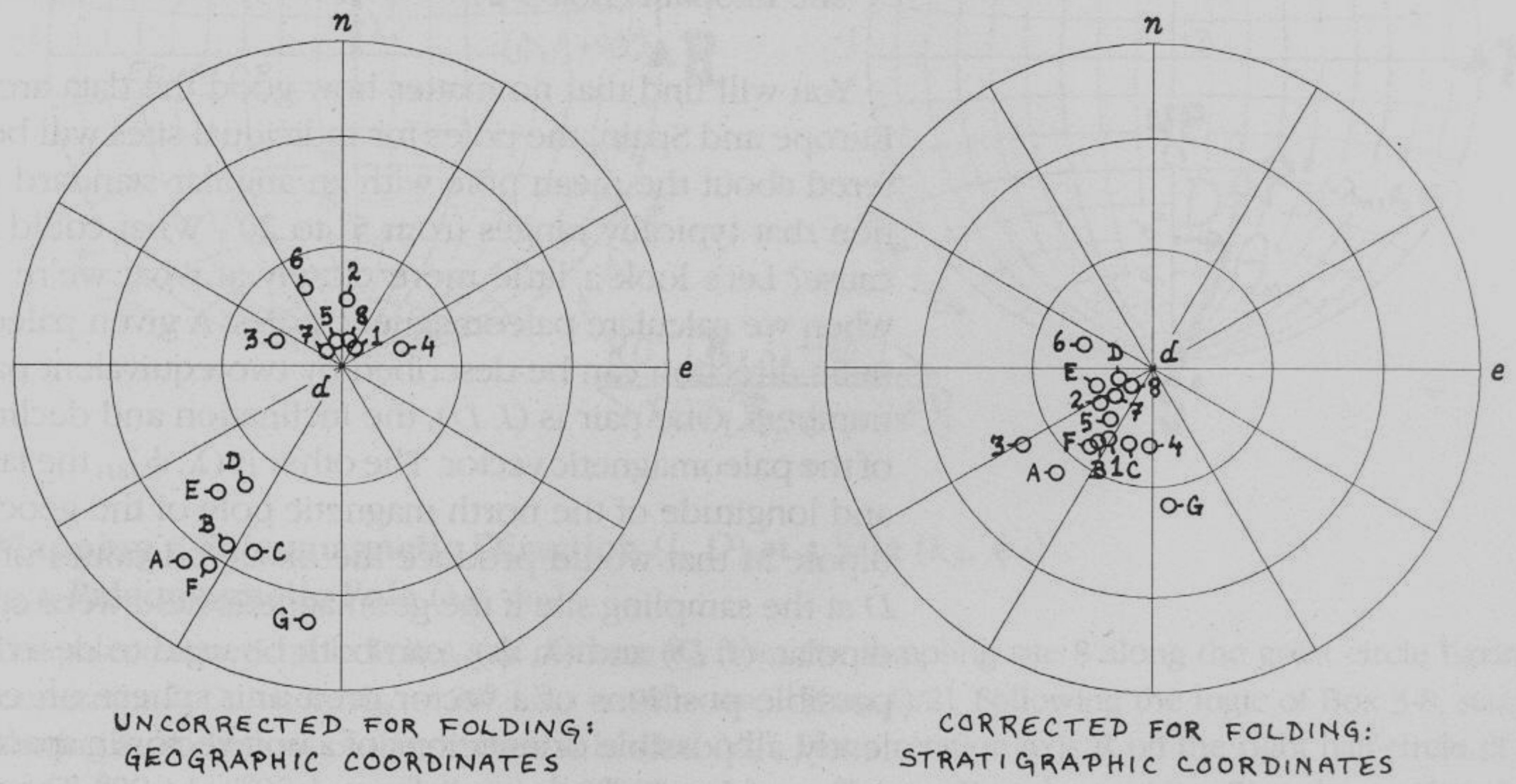
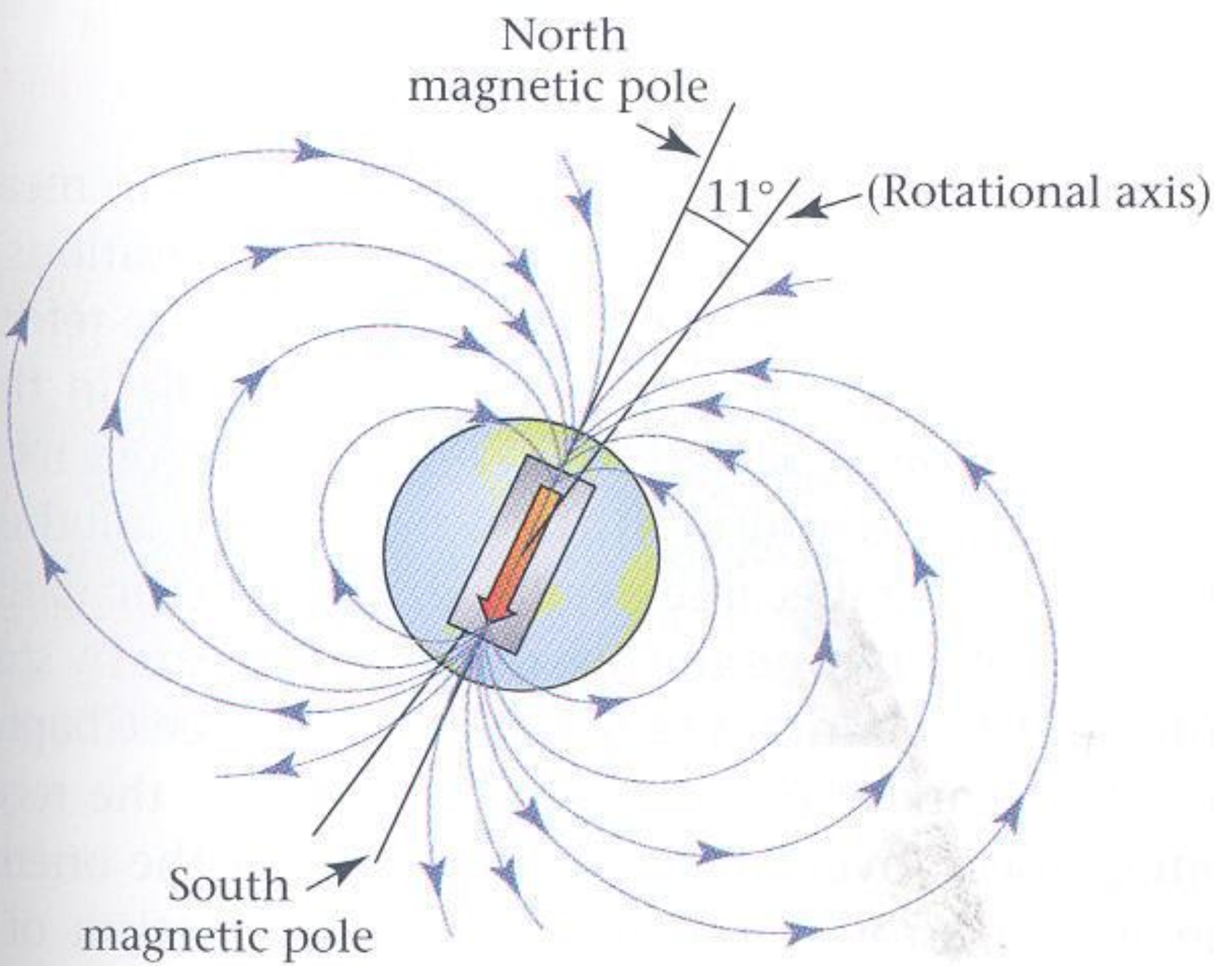


Figure 9-5.
Fold test. Correcting for the folding of this anticline brings the initially scattered paleomagnetic directions into a tight group. Therefore magnetization was acquired before folding.

FIGURE 2.8 We can picture Earth's magnetism by imagining that it contains a giant bar magnet. The dipole of this magnet points presently from the north magnetic pole to the south magnetic pole, and it pierces the Earth at the magnetic poles. Today, the magnetic poles do not coincide exactly with the Earth's geographic poles.



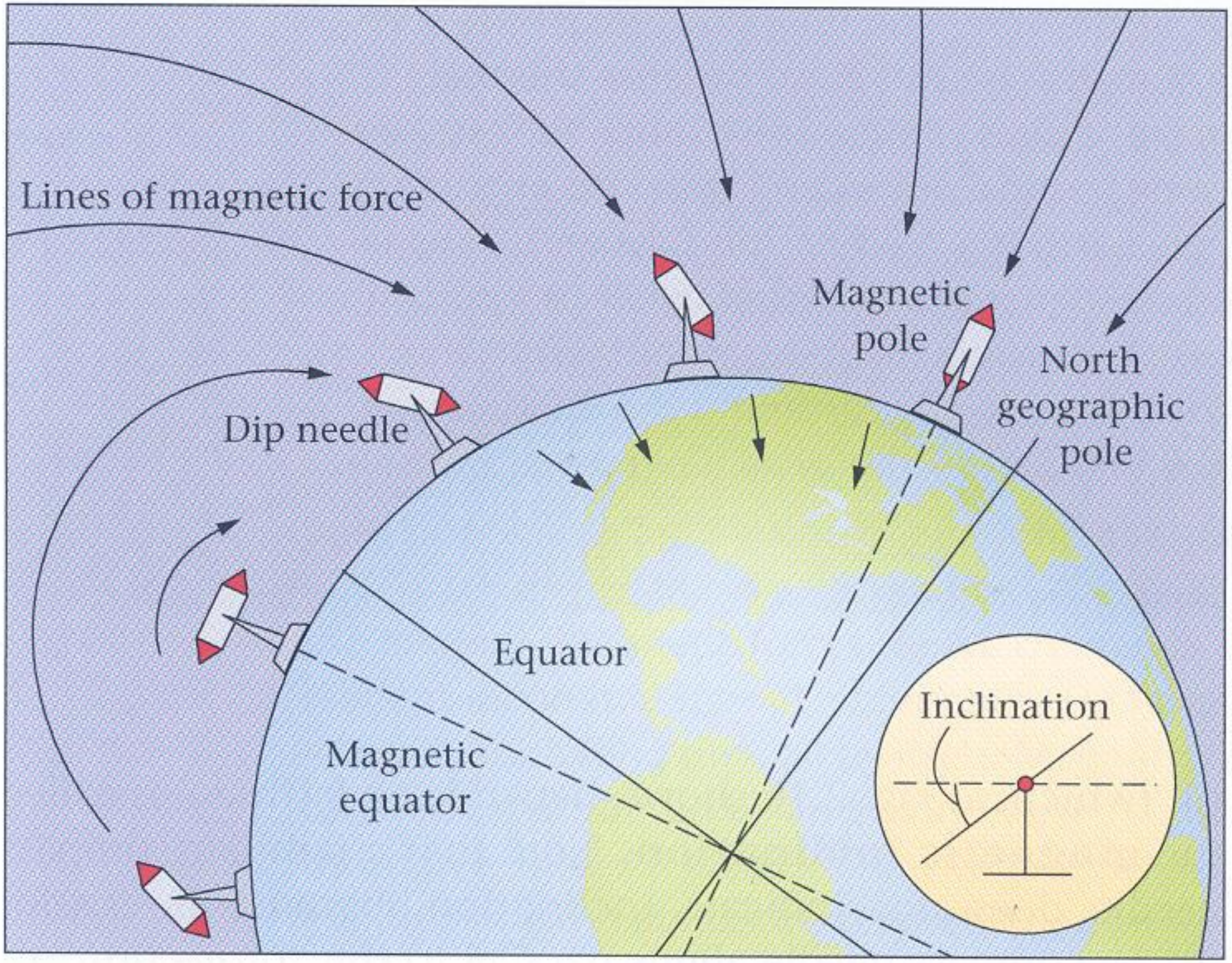


FIGURE 2.10 An illustration of magnetic inclination. A magnetic needle that is free to rotate around a horizontal axis aligns with magnetic field lines (here depicted in cross section). Because magnetic field lines curve in space, this needle is horizontal at the equator, tilts at an angle at mid-latitudes, and is vertical at the magnetic pole. Therefore, the angle of tilt depends on the latitude.

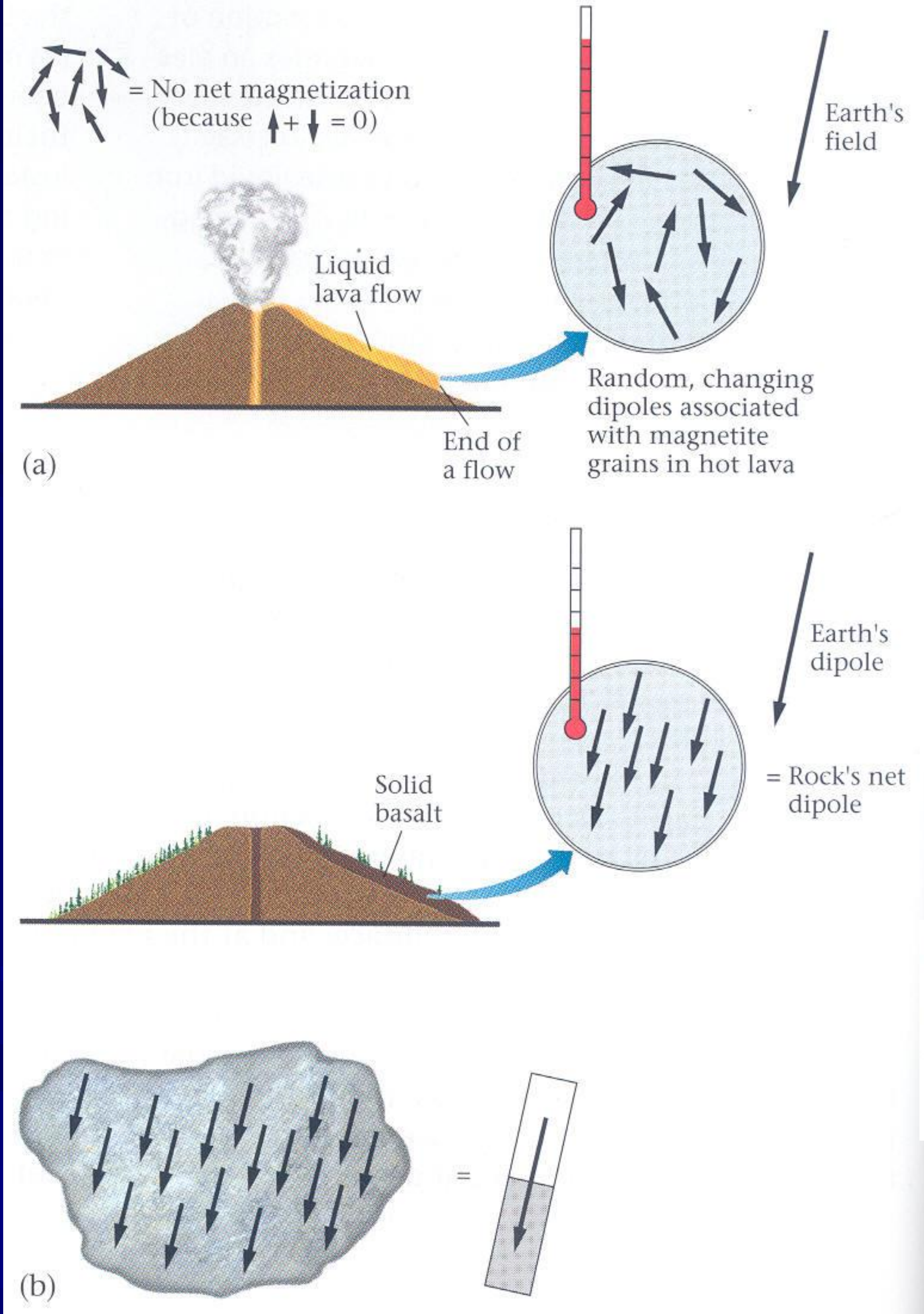


FIGURE 2.11 The formation of paleomagnetism. (a) At high temperatures (greater than 350°–550°C), thermal vibration makes atoms move randomly; the dipoles thus cancel each other out, and the sample has no overall magnetic dipole. (b) As the sample cools below 350°–550°C, the atoms slow down, and their dipoles lock into alignment with the Earth's field.

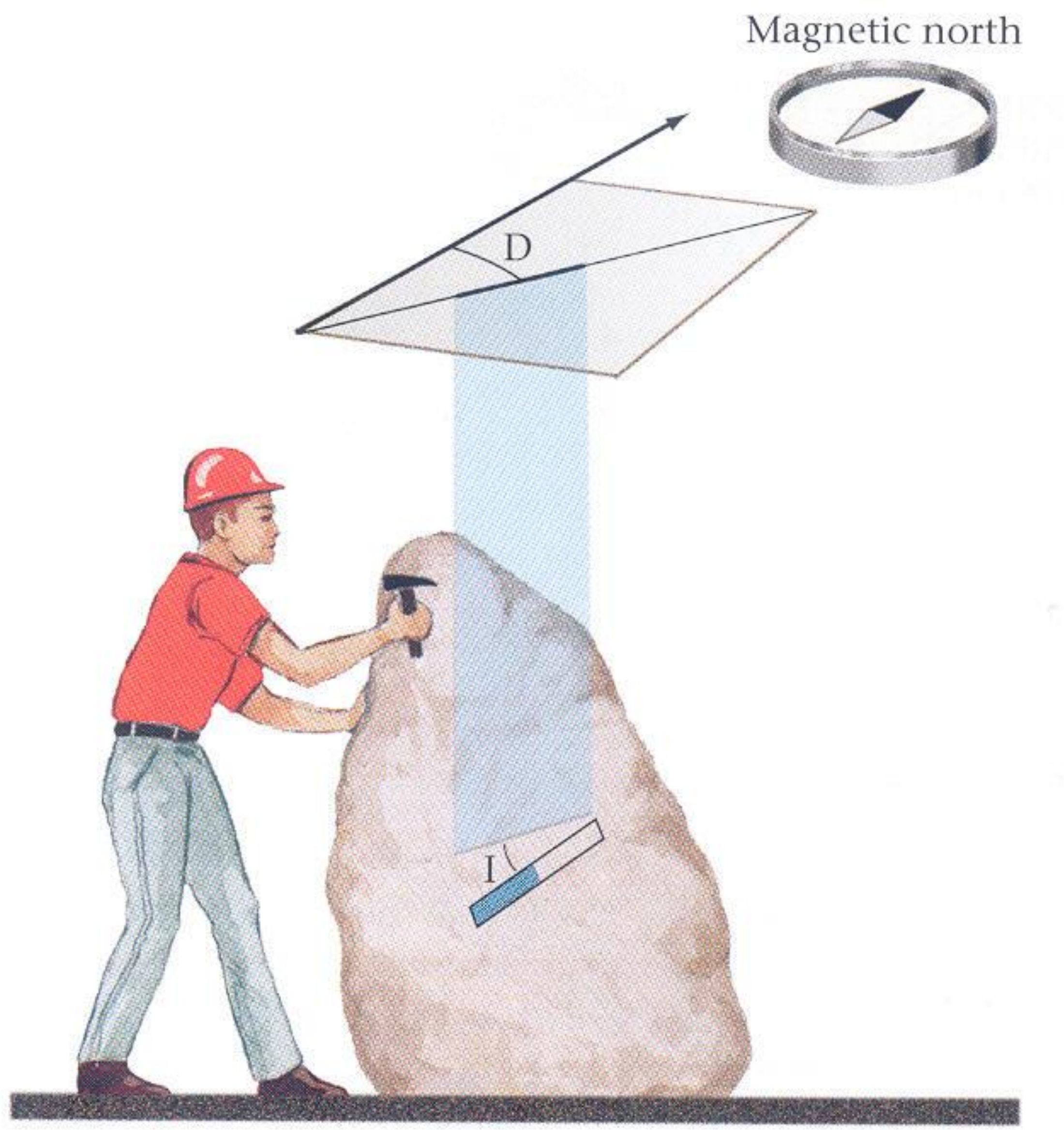
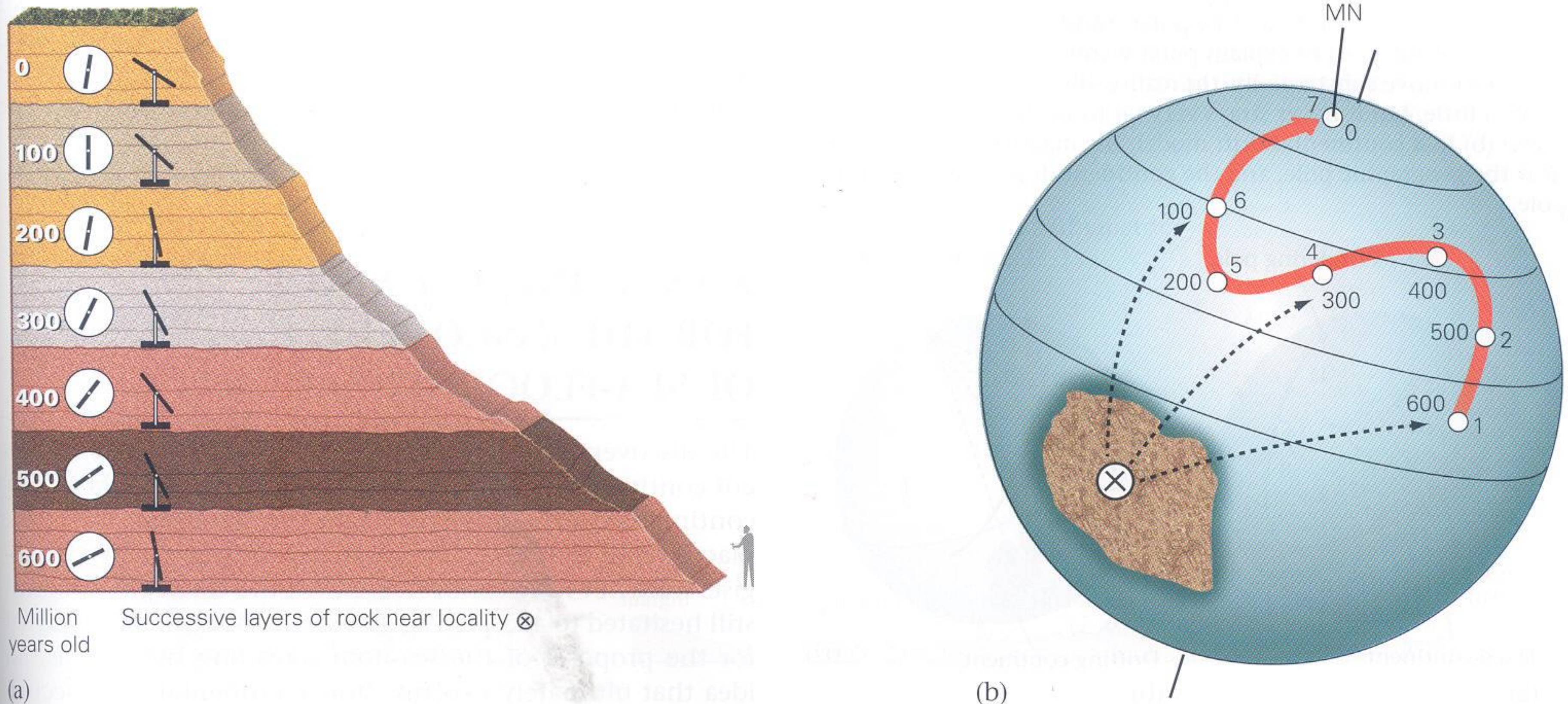


FIGURE 2.12 A rock sample can maintain paleomagnetization for millions of years. The dipole representing the paleomagnetism in this rock sample does not parallel the Earth's present field. Note that I and D are not 0°.

FIGURE 2.13 (a) A cliff at location X exposes a succession of dated lava flows. A geologist measures the orientation of the dipole in the rock. (The arrowheads aren't shown, as they don't matter here.) Here, we represent the changing inclination and declination indicated by the orientation of the dipole. The paleopoles are the places where the dipole intersects the surface of the Earth. (b) The succession of paleopole positions through time for location X defines the apparent polar-wander path for the location. The path ends at the position of the present-day magnetic pole, near the North Pole.



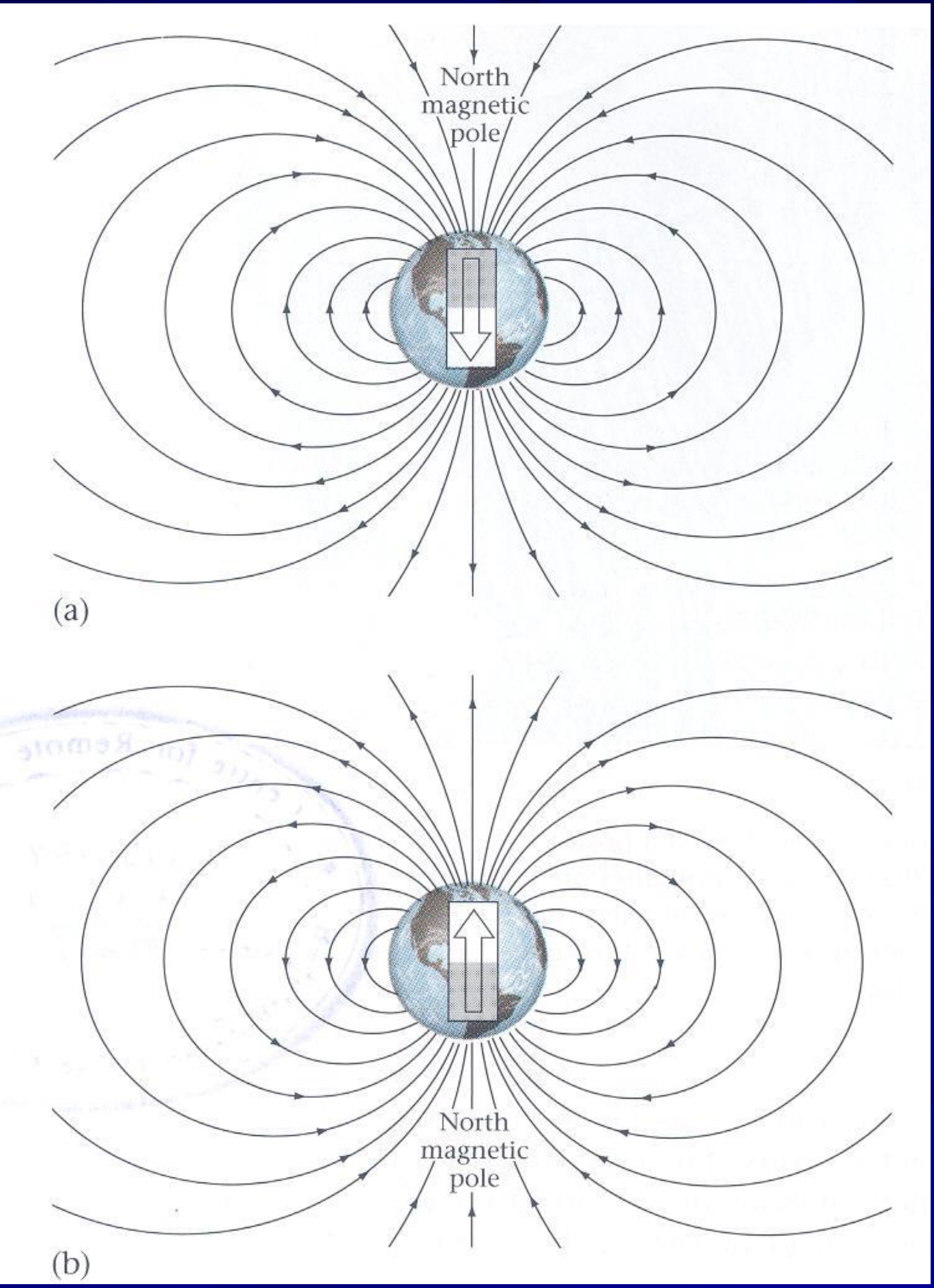


FIGURE 2.24 The magnetic field of the Earth has reversed polarity at various times during Earth history. (a) If the dipole points from north to south, Earth has normal polarity. (b) If the dipole points from south to north, Earth has reversed polarity.

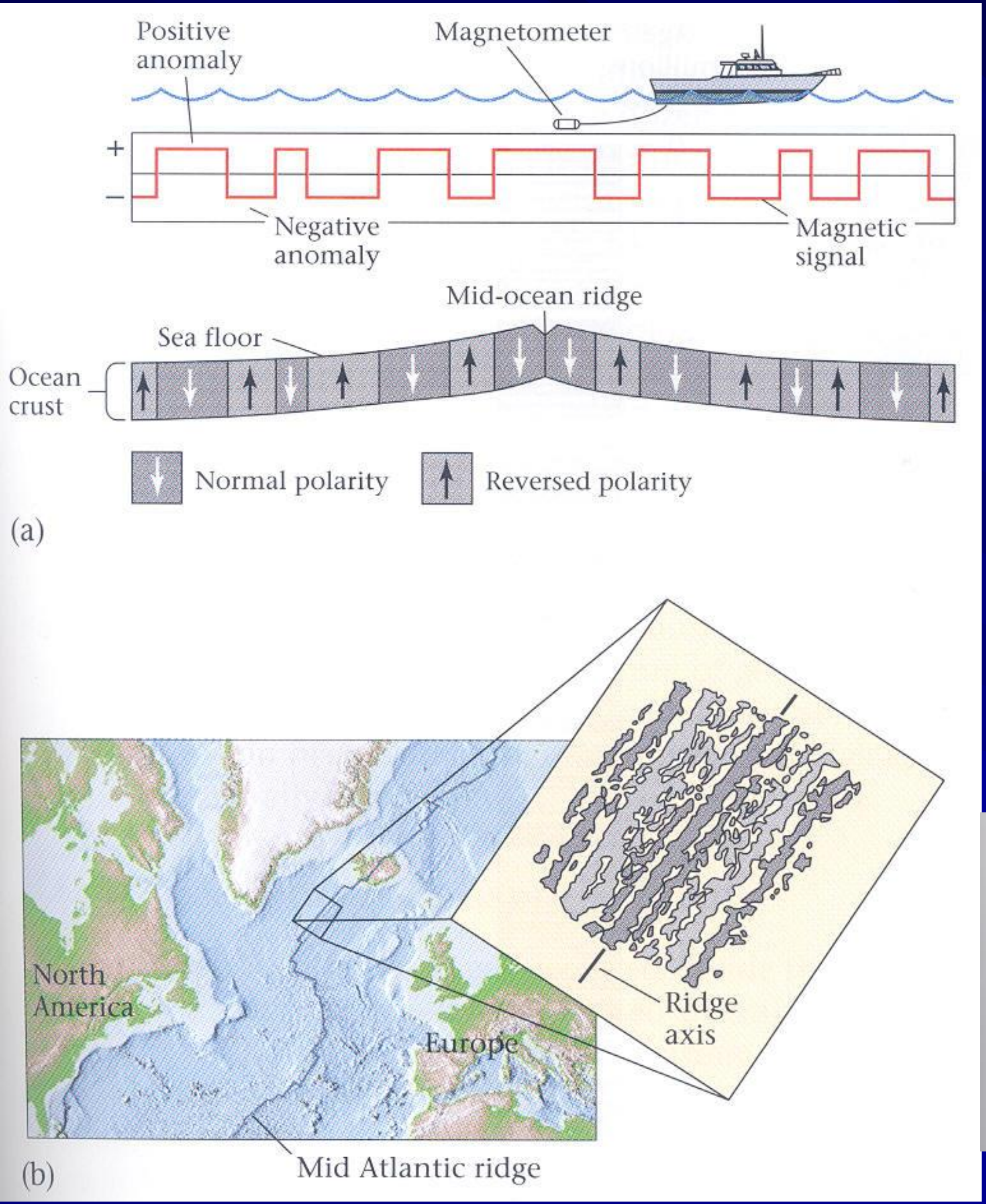


FIGURE 2.26 (a) The explanation of marine anomalies. The sea floor beneath positive anomalies has the same polarity as Earth's field and therefore adds to it. The sea floor beneath negative anomalies has reversed polarity and thus subtracts from Earth's field. (b) The symmetry of the magnetic anomalies measured across the Mid-Atlantic Ridge south of Iceland. Note that individual anomalies are somewhat irregular, because the process of forming the sea floor in detail happens in discontinuous pulses along the length of the ridge.

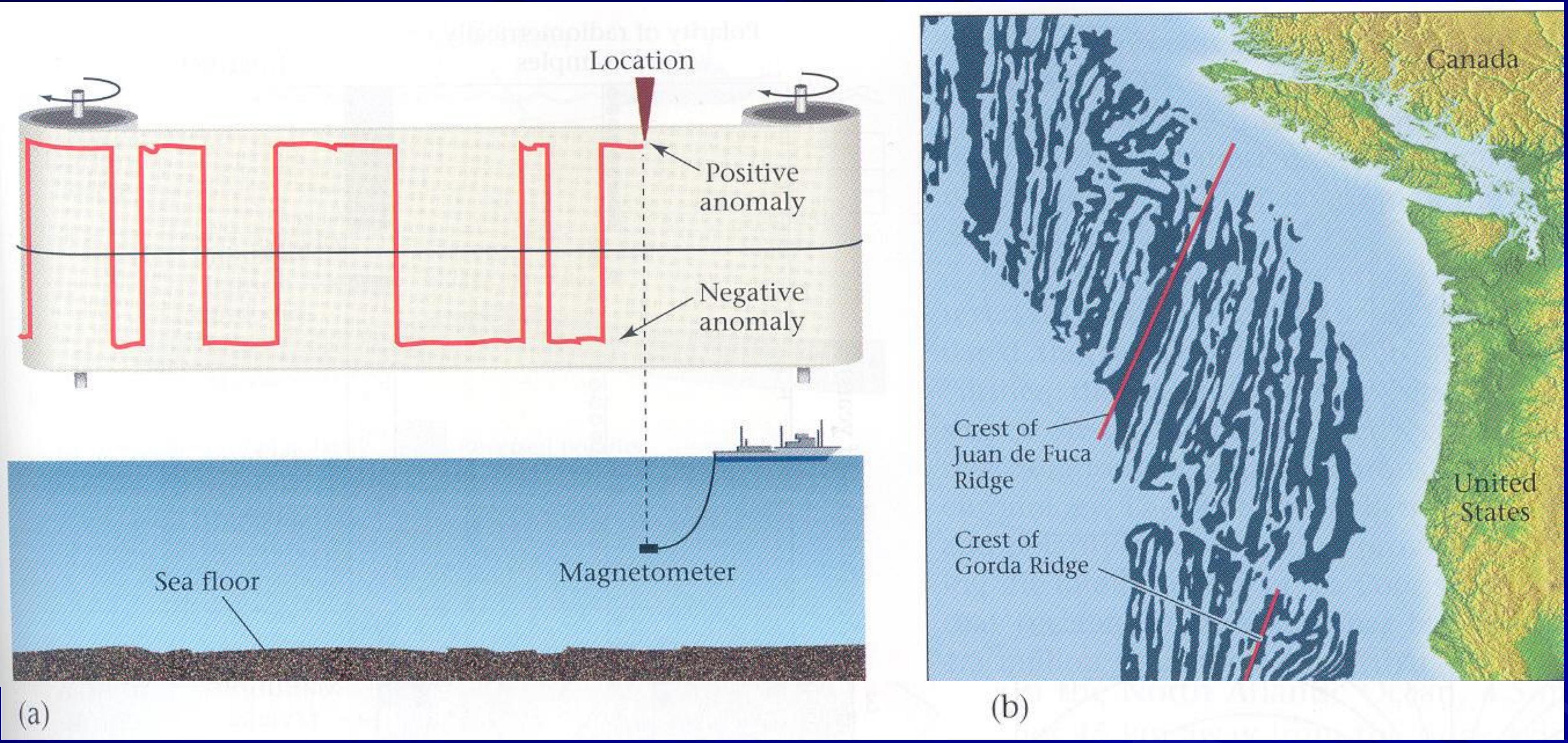


FIGURE 2.22 (a) A ship sailing through the ocean dragging a magnetometer detects first a positive anomaly then a negative one, then a positive one, then a negative one. (b) Magnetic anomalies on the sea floor off the northwest coast of the United States. The dark bands are positive anomalies, the uncolored bands negative anomalies. Note the distinctive stripes of alternating anomalies. A positive anomaly overlies the crest of the Juan de Fuca Ridge (a small mid-ocean ridge).

ISOSTASY

Isostasy:

- In general the high mountains have crustal roots ie., where the land surface rises to a higher elevation, the crust underneath is thicker
- The high mountains are nothing but similar to icebergs where small part of the ice float where as its huge mass is below the water surface but still it floats- this is due to Buoyancy.
- Here the crust acts like a buoy or float that holds the lithosphere up
- the bigger the buoy (thicker the crest) the higher the lithosphere floats.

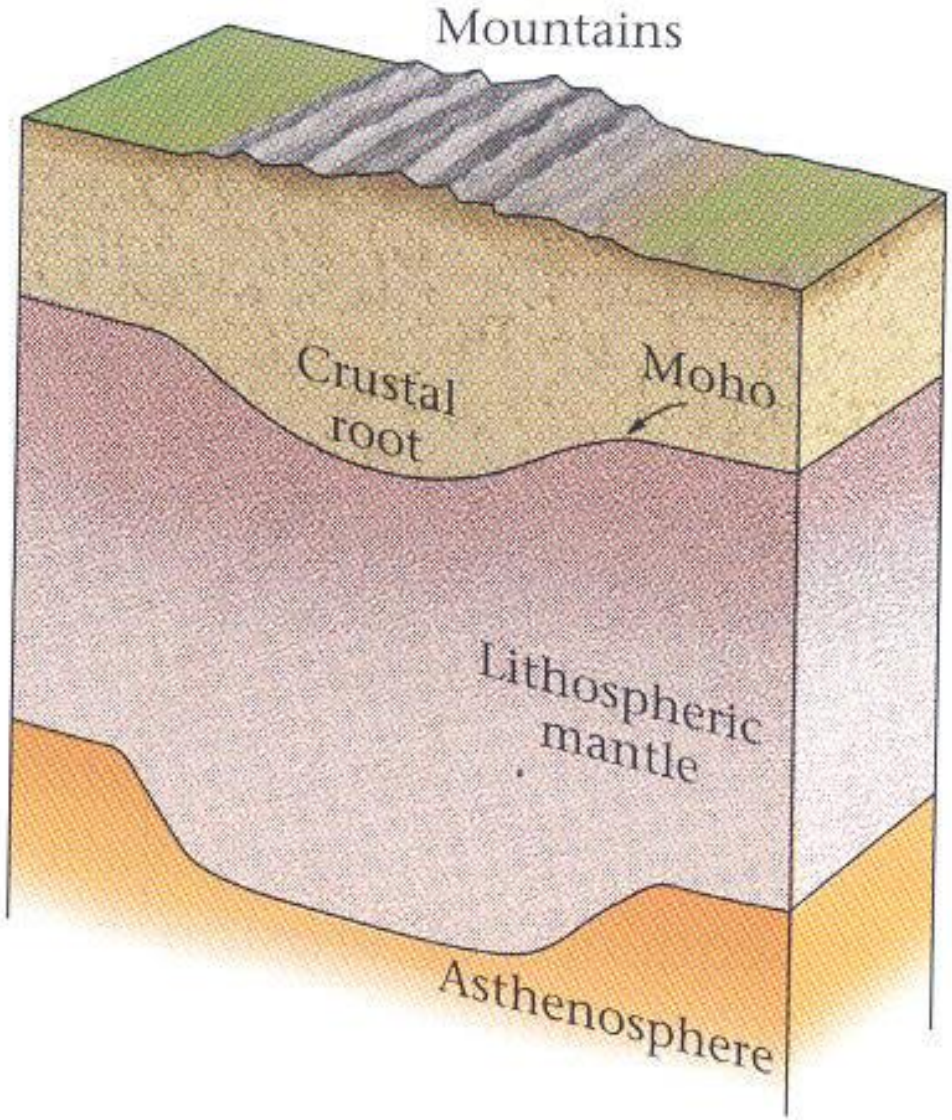


FIGURE 9.22 Mountain belts have crustal roots, meaning that where the land surface rises to a higher elevation, the crust underneath is thicker.

Isostasy: conti…….

- the pushing up of lithosphere due to buoyancy force is equals to gravitational force which pulls the lithosphere down – this is called ISOSTASY - Isostatic equilibrium
- The isostatic equilibrium exists at the surface of the crust.
- So that the surface elevation of the crust reflects the level at which the lithosphere naturally floats.
- If a geological event happens that changes the density or thickness of the lithosphere, then the surface of the crust slowly rises or falls to reestablish the isostatic equilibrium , a process called Isostatic Compensation.

Isostasy:

It is a mass balance theory based on density and topography variations.

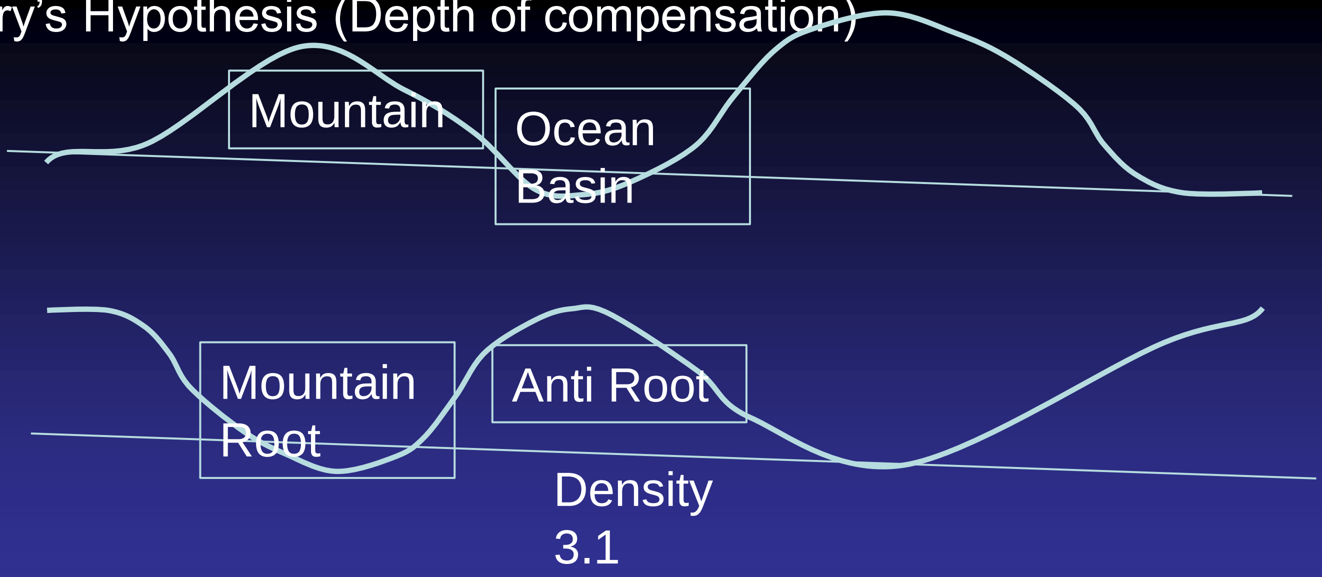
Isostatic Anomaly:

Gravity value either excess or short of the normal value.

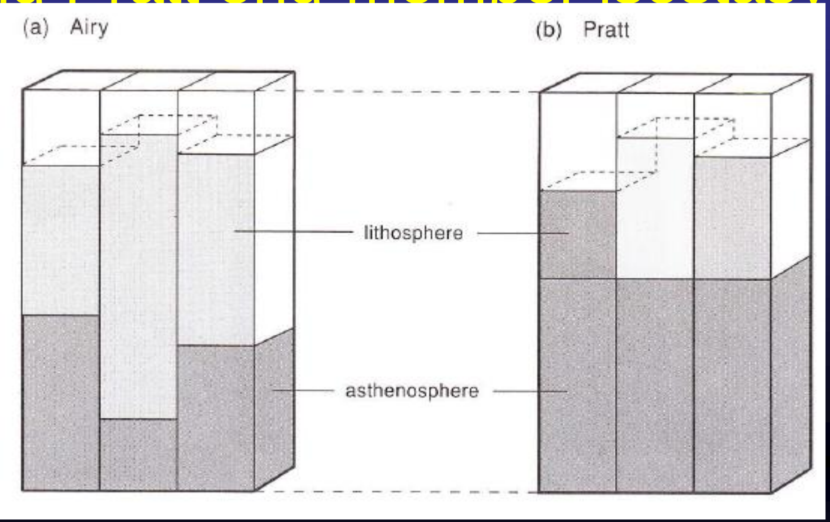
J.H.Pratt:

Error in astronomic survey

G.B.Airy's Hypothesis (Depth of compensation)



Airy and Pratt end-member isostasy models



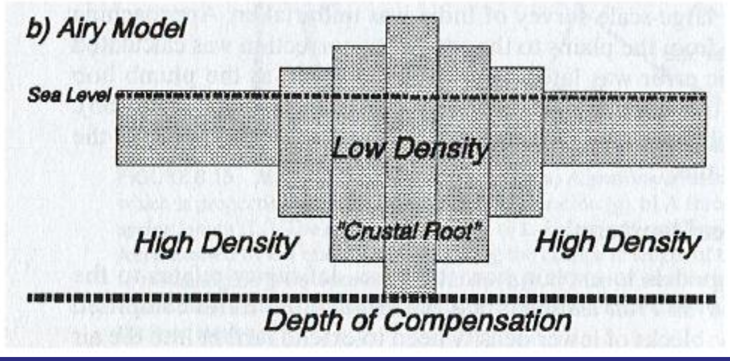
This was a big debate in 1855 after a British gravity/geodetic survey in India.

Mr. Pratt suggested that mountains do NOT have roots but instead the topography is compensated by a less dense (hence lighter) block. And, that all topography was compensated at the same depth.

Mr. Airy suggested that mountains had thick low density roots supporting mountains and that the depth of compensation was NOT constant, but the density of the blocks was constant.

Airy's Hypothesis

- Rigid upper layer and substarte are assumed to have a constant density ρ_u and ρ_s, respectively.
- Isostatic compensation is achieved by deep roots (iceberg)

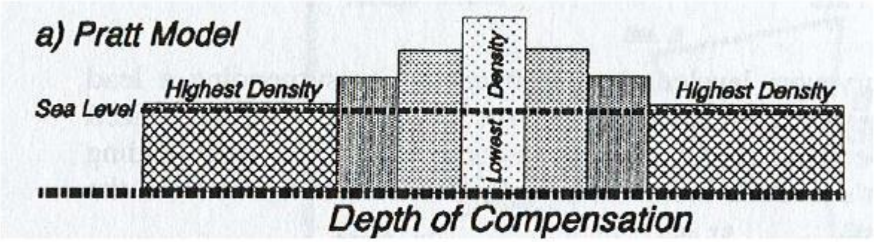


Pratt Isostasy

Depth of the base of upper level is constant.

Isostatic equilibrium is achieved by composing

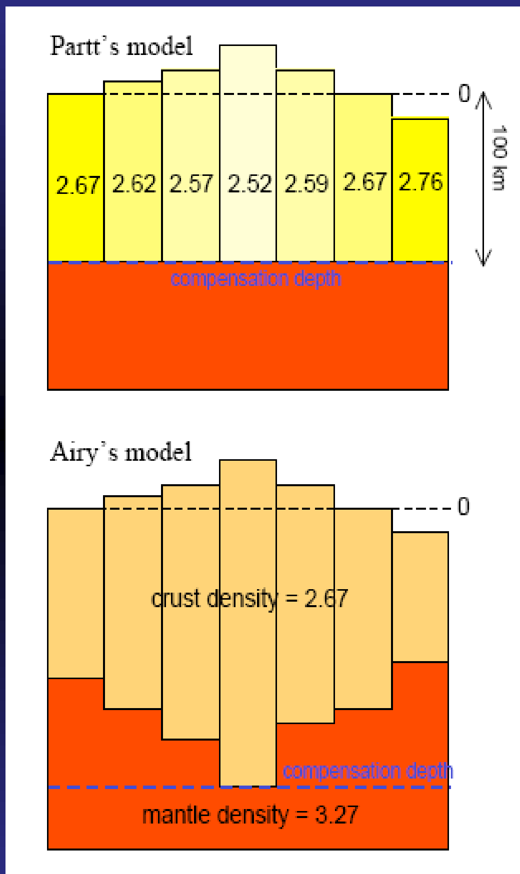
the upper layer of columns of constant density



$$(h_{lith}\rho_{lith})_A = (h_{lith}\rho_{lith})_B$$

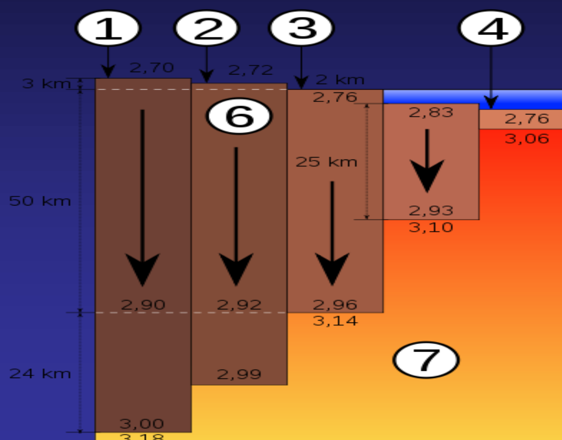
•Or simply, "the weight of all columns above the compensation depth are equal"

Who was correct ?



Airy was mostly correct about what supports large (wide) mountains, but it took until the 1970's to prove this with seismic work that measured the thickness of the crust and lithosphere beneath mountains.

Pratt was correct in that the difference between the low standing ocean basins and the high standing continents is partially due to the fact that oceans have dense gabbroic composition crust whereas continents have lighter less dense 'Andesitic' composition crust.



OROGENY & EPIOROGENY

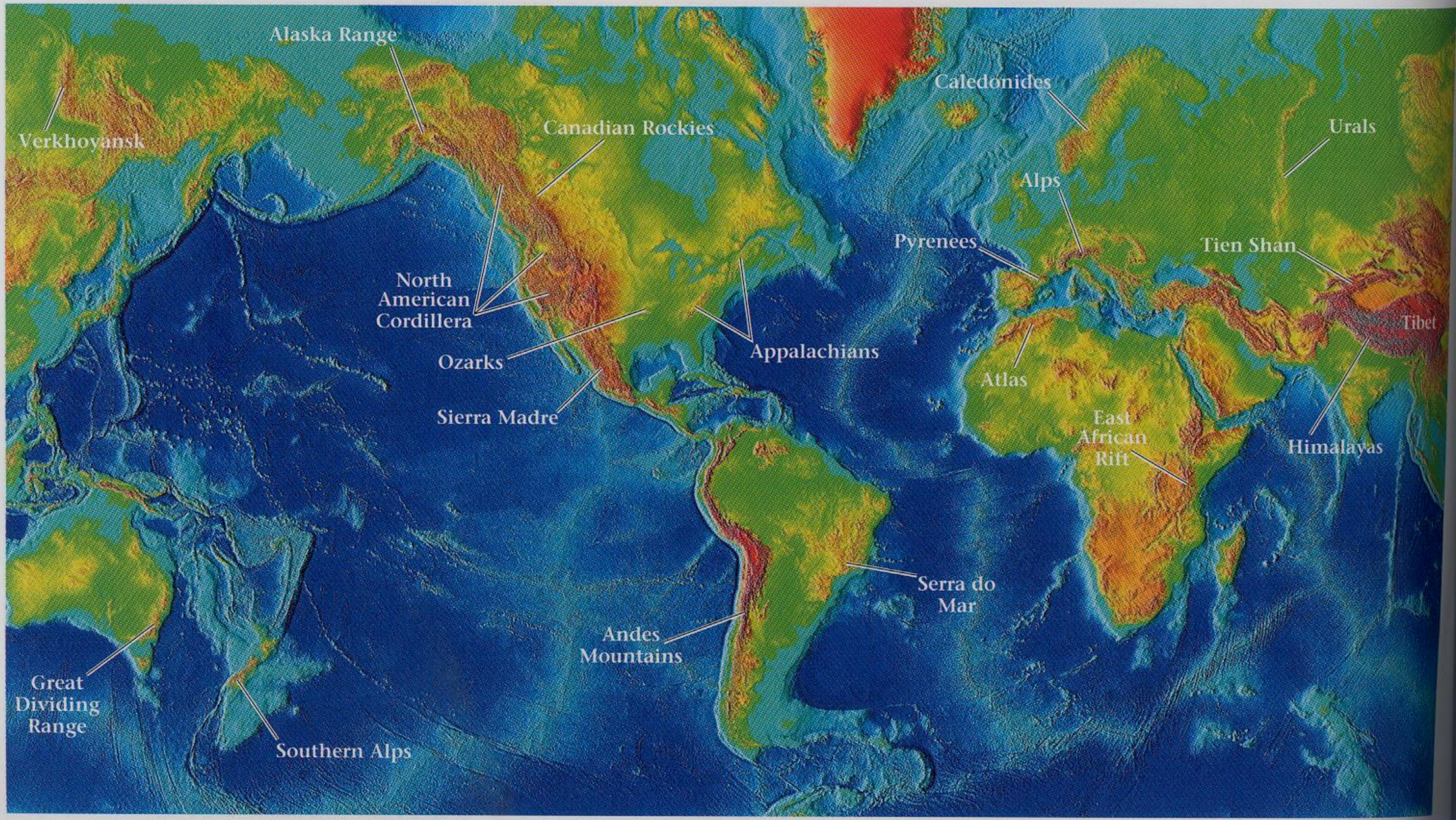
Orogeny:

- Except the Hot spot volcanoes, no mountain occur in isolation
- Rather they occur linear ridges with series of hills and valleys.
- They are called “Mountain Belts” – “Orogenic belt” or “ Orogens”

  Greek word Oros – Mountain

  Genesis - Formation
- The mountain building event or orogeny has a limited life time – of the order of millions of years and then ceases.
- After Orogen ceases the erosion level the land surface to sea level during a period of 50my
- The present mountain ranges are of post cretaceous

FIGURE 9.2 Digital map of world topography, showing the locations of major mountain ranges.



- Several orogenic event might have happened during the entire geological time.

  Alleghenian Orogeny – 290my – Beginning of Permian – Pangaea form.

  Sevier Orogeny – 100my -Middle cretaceous

  Laramide Orogeny -65my – Paleocene epoch

- Orogeny causes deformation-bending-breaking-squashing-stretching or shearing which yield geological structures.
- An Orogen forms during an Orogeny or mountain building event
- Orogens are a consequences of continental collision, subduction at convergent plate boundary or at rift.
- Even after erosion we can see in linear belts of metamorphic and igneous rocks at the root of collision or convergent margin orogen

Seismic belts of the earth

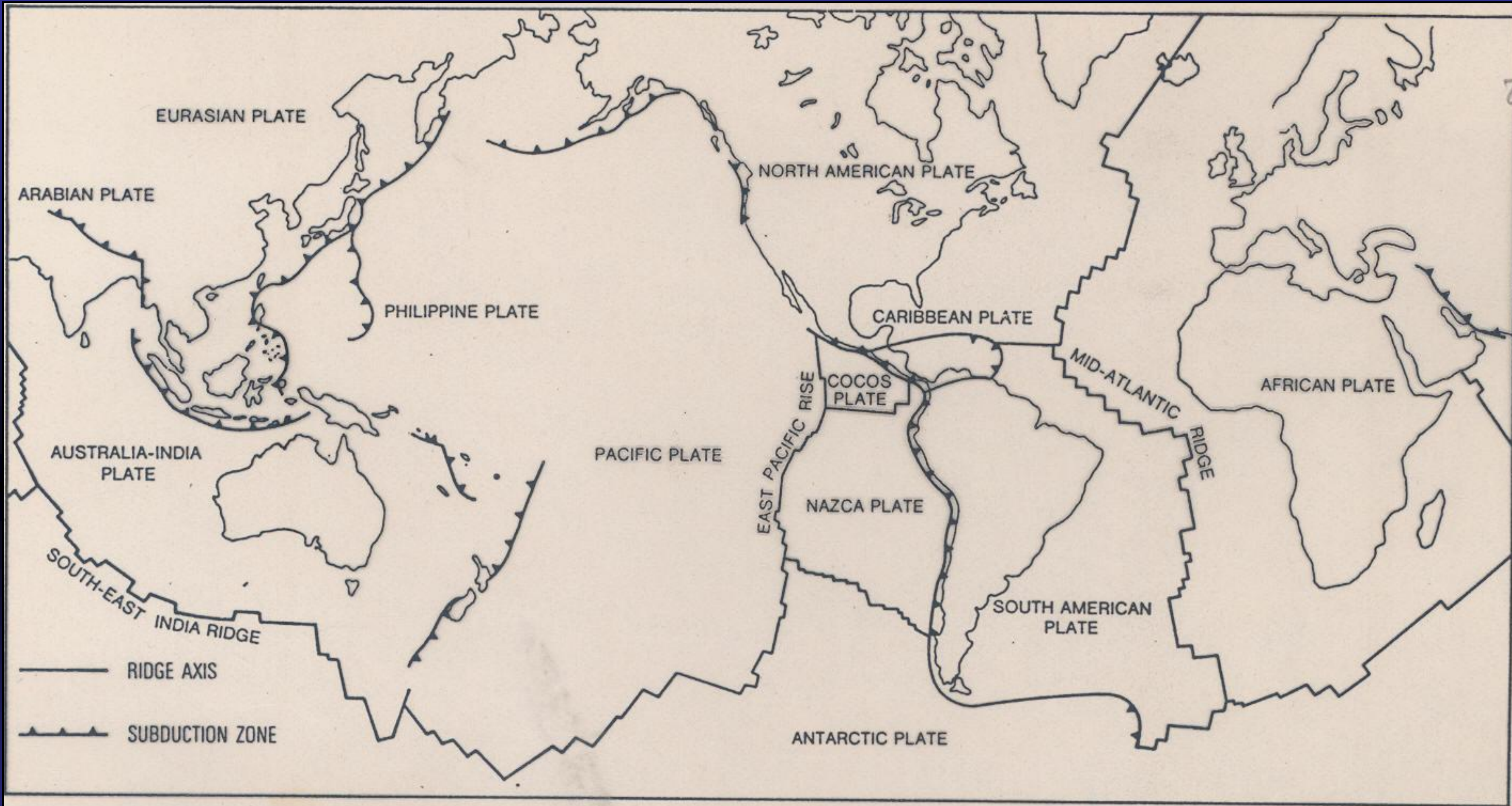


Figure 12.8 The major plates, ridges and subduction zones of plate tectonics

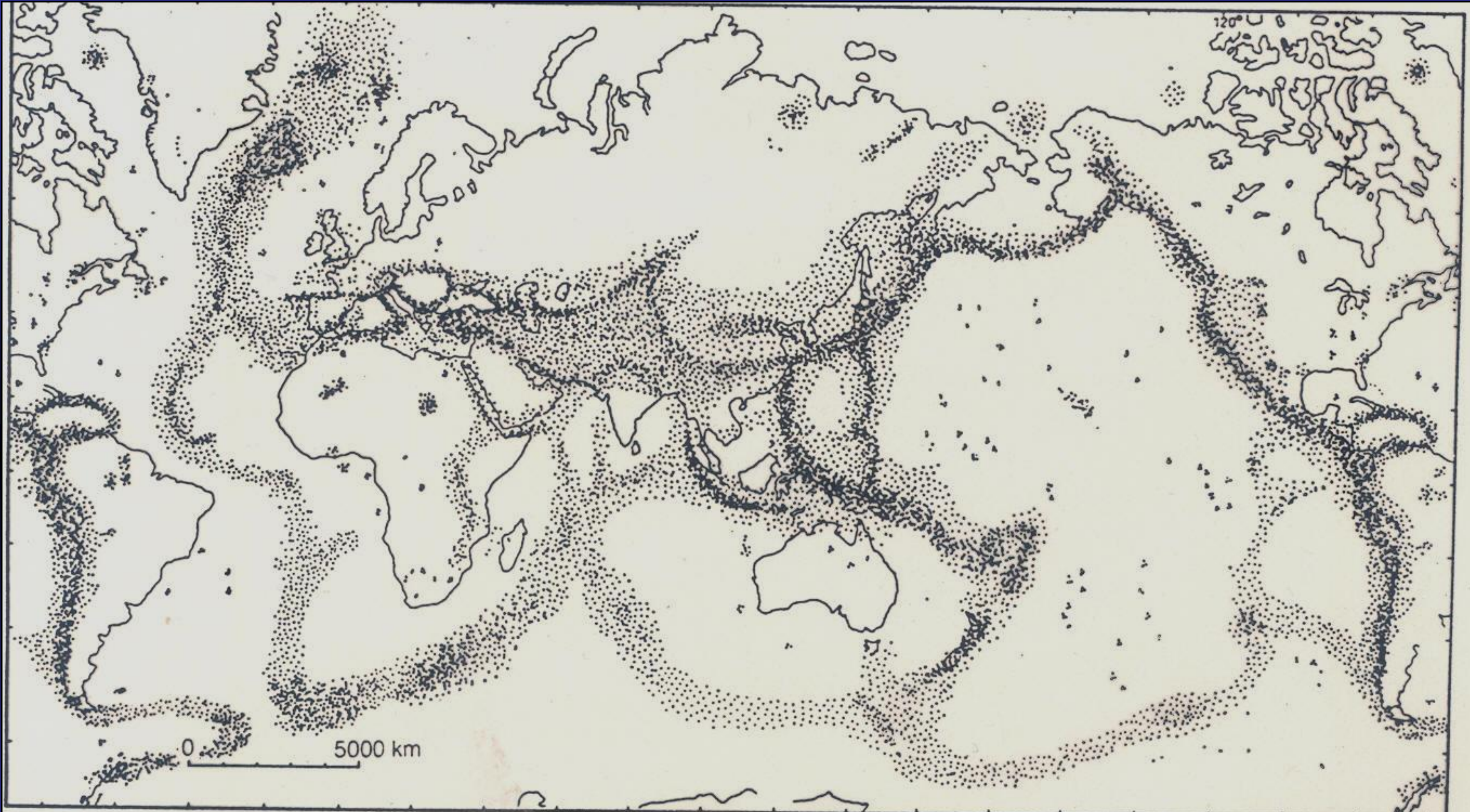


Figure 12.5 Distribution of earthquake activity

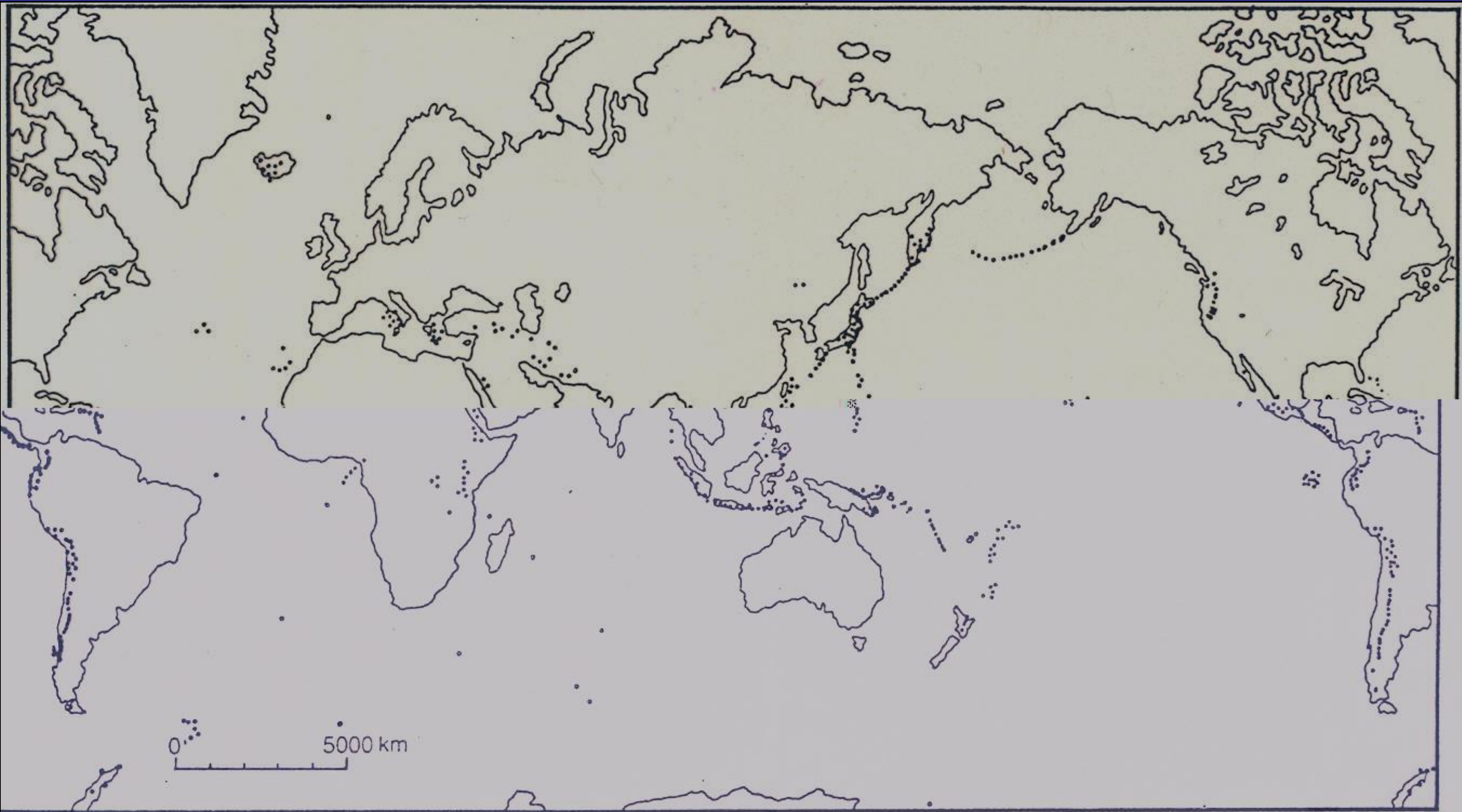


Figure 12.4 Distribution of active volcanoes of the world

SEISMICITY & PLATE MOVEMENT

SEISMICITY & PLATE MOVEMENT

- Most Earthquakes originate along plate boundaries
- Due to highly variable friction along the fault plane between two plates
- Where the friction is low the plate move fast each other quietly
- When the friction is high (much below the surface) the plate moves very slowly and get struck temporarily
- Continued motion produces distortion in the form of elastic strain in the vicinity of rough spot

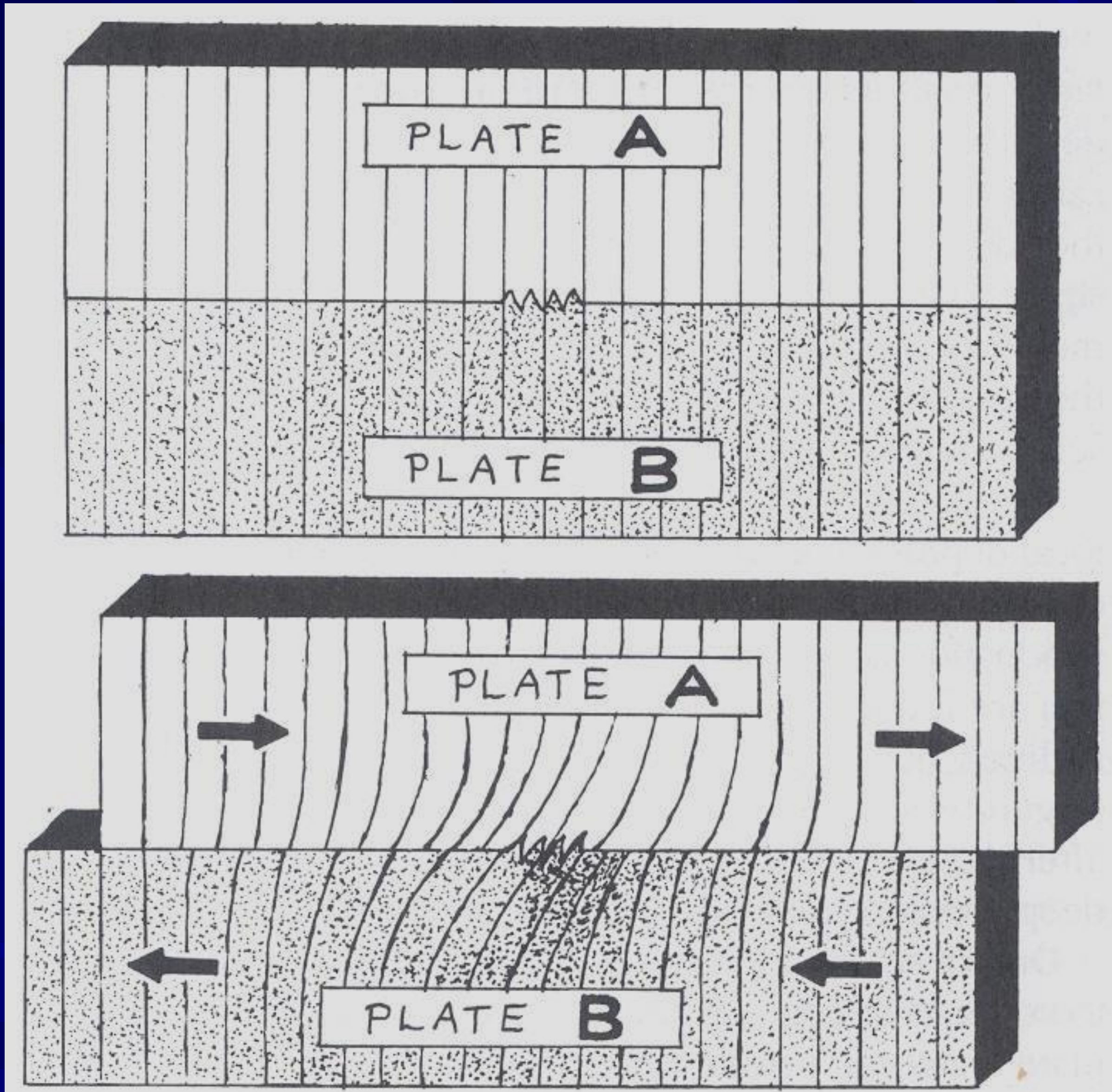


Figure 6-2.
Friction between plates A and B is concentrated at the rough spot near the center of the fault. Straight lines painted on the two blocks prior to plate movement (above) are bent as plates move past each other (below). Elastic energy is stored in the rocks adjacent to the rough spot. Crowding together of lines indicates regions of compression.

SEISMICITY & PLATE MOVEMENT Cont…..

- The accumulated elastic strain when it get released it is earth quake and the energy propagates as seismic waves in the direction of its release (ie., either side of the fault.
- The magnitude / size of the earthquake depends on 2 factors.
  - Amount of elastic energy per unit area of the fault is released at the time of rupture
  - The total area of rupture (larger the rupture greater is the earth quake.

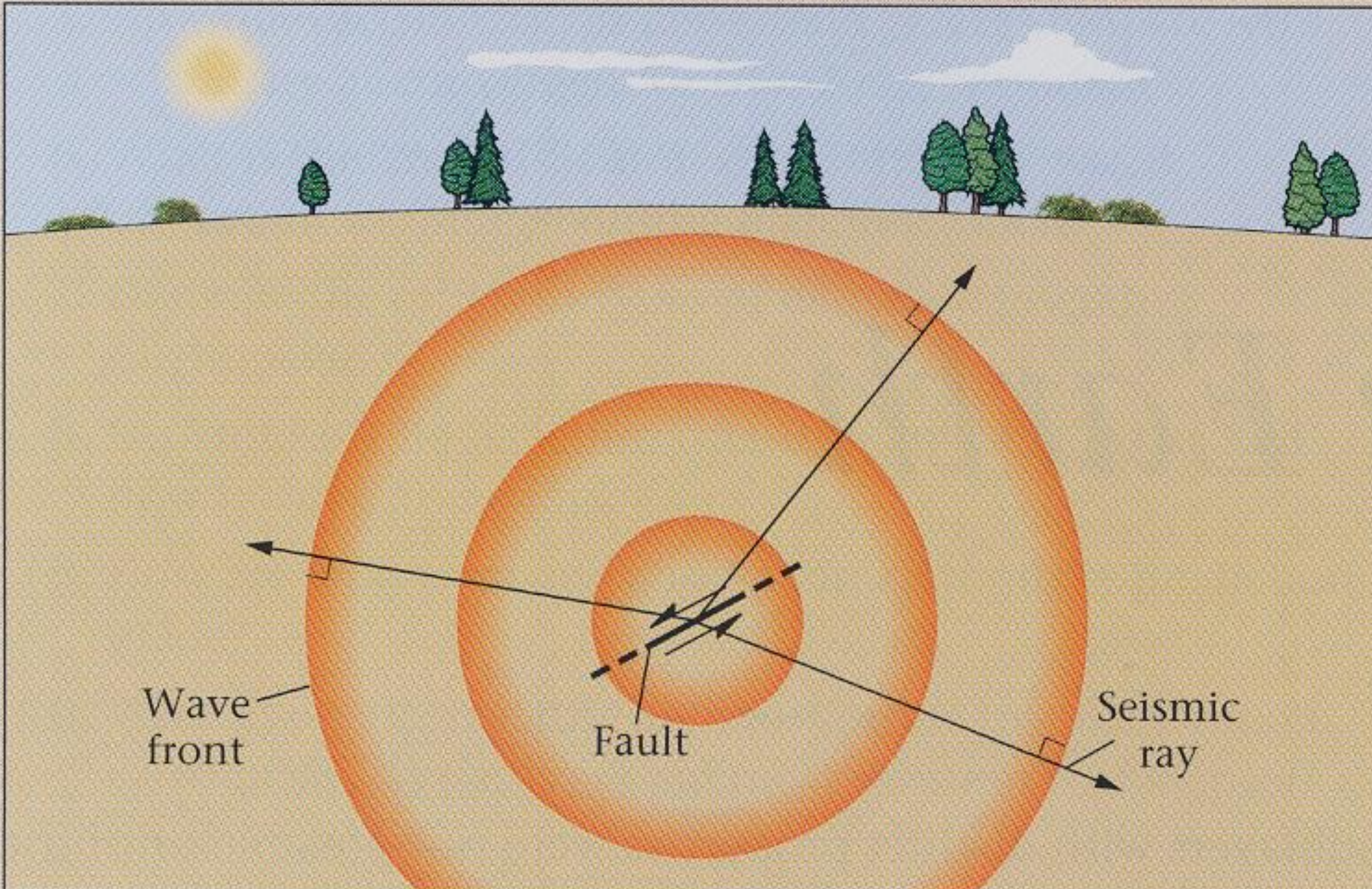


FIGURE C.2 An earthquake sends out waves in all directions. Seismic rays are perpendicular to the wave fronts.

FIGURE C.5 (a) At a nearby seismograph station, seismic waves traveling through the crust reach the seismograph first. Seismic rays refract at the Moho, the crust-mantle boundary. (b) At a distant station, seismic waves traveling through the mantle reach the seismograph first, which means that seismic waves travel at a faster velocity in the mantle than in the crust. The Moho lies at a depth of 35–40 km beneath continental interiors.

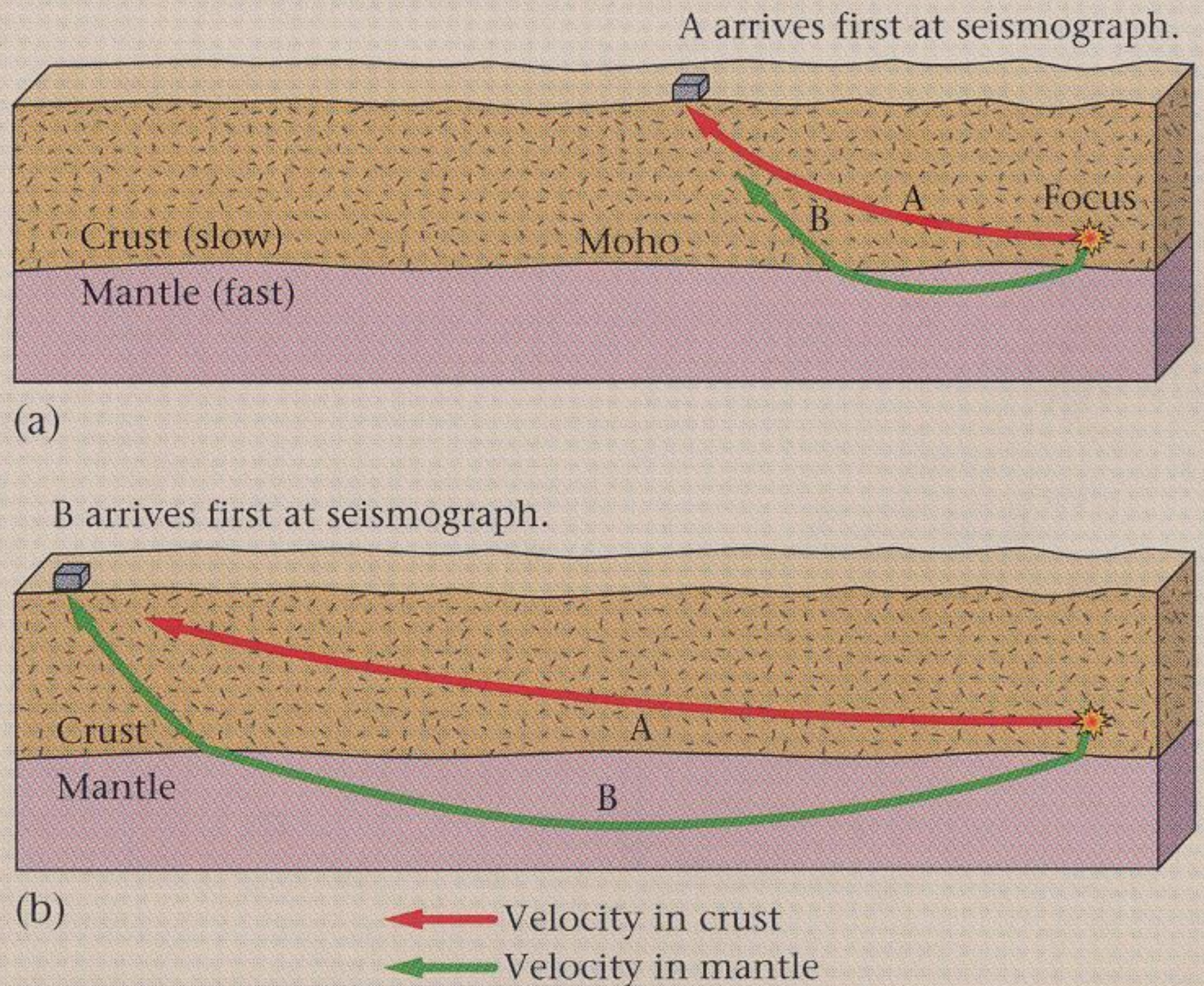


FIGURE C.6 The velocity of P-waves in the mantle changes with depth. Note the low-velocity zone between 100 and 200 km, and the sudden jumps in velocity in the transition zone between 400 and 670 km.

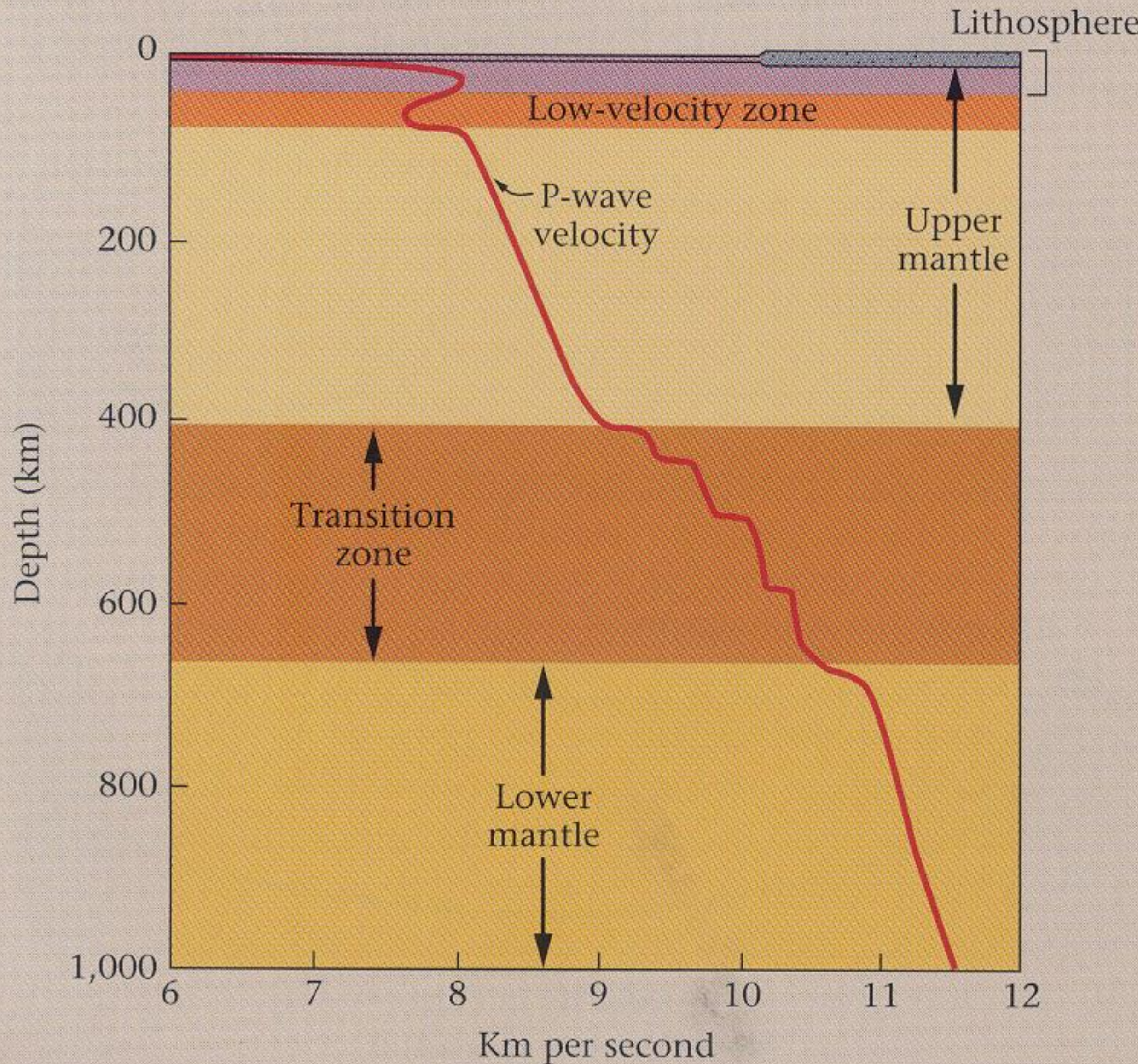
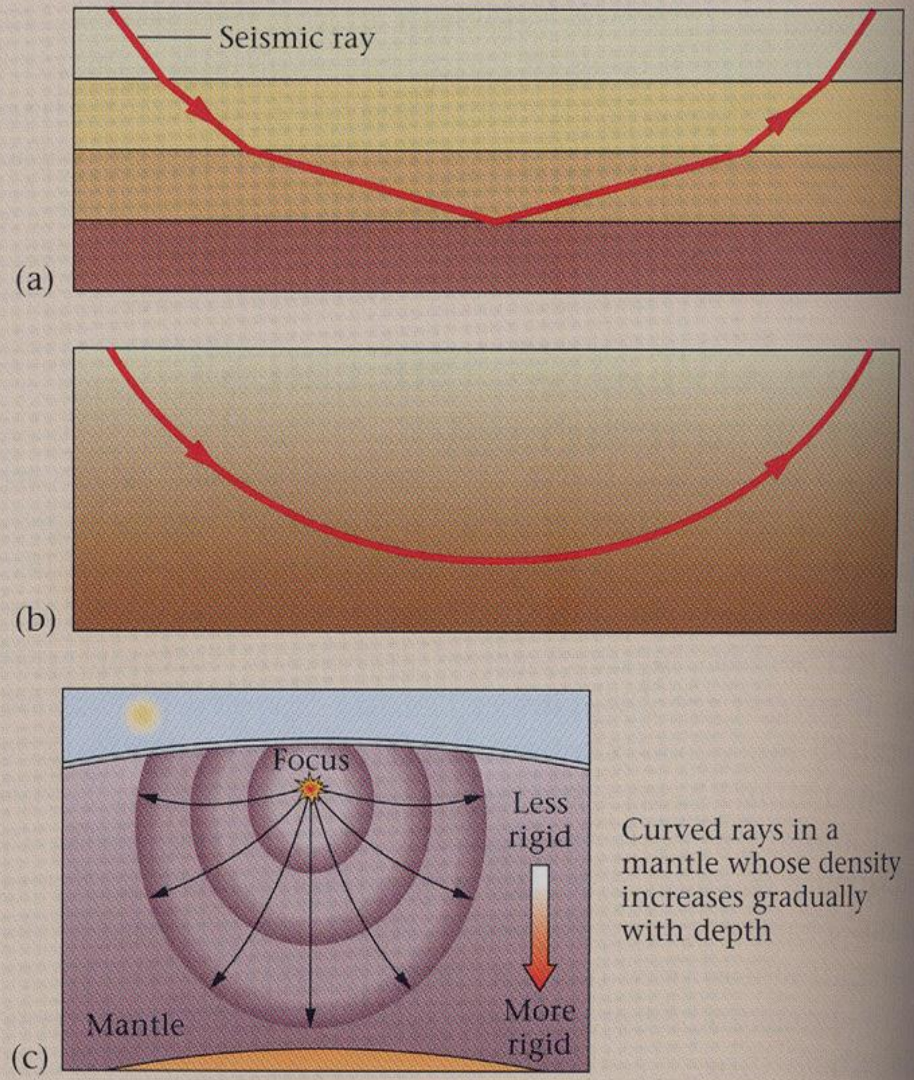


FIGURE C.7 (a) In a stack of layers in which seismic waves travel at different velocities (fastest in the lowest layer), a seismic ray gradually bends around and heads back to the surface. The curve consists of several distinct segments. (b) If the mantle's density increased gradually with depth, the ray would define a smooth curve. (c) Since the velocity of seismic waves increases with depth, wave fronts are oblong and seismic rays curve.



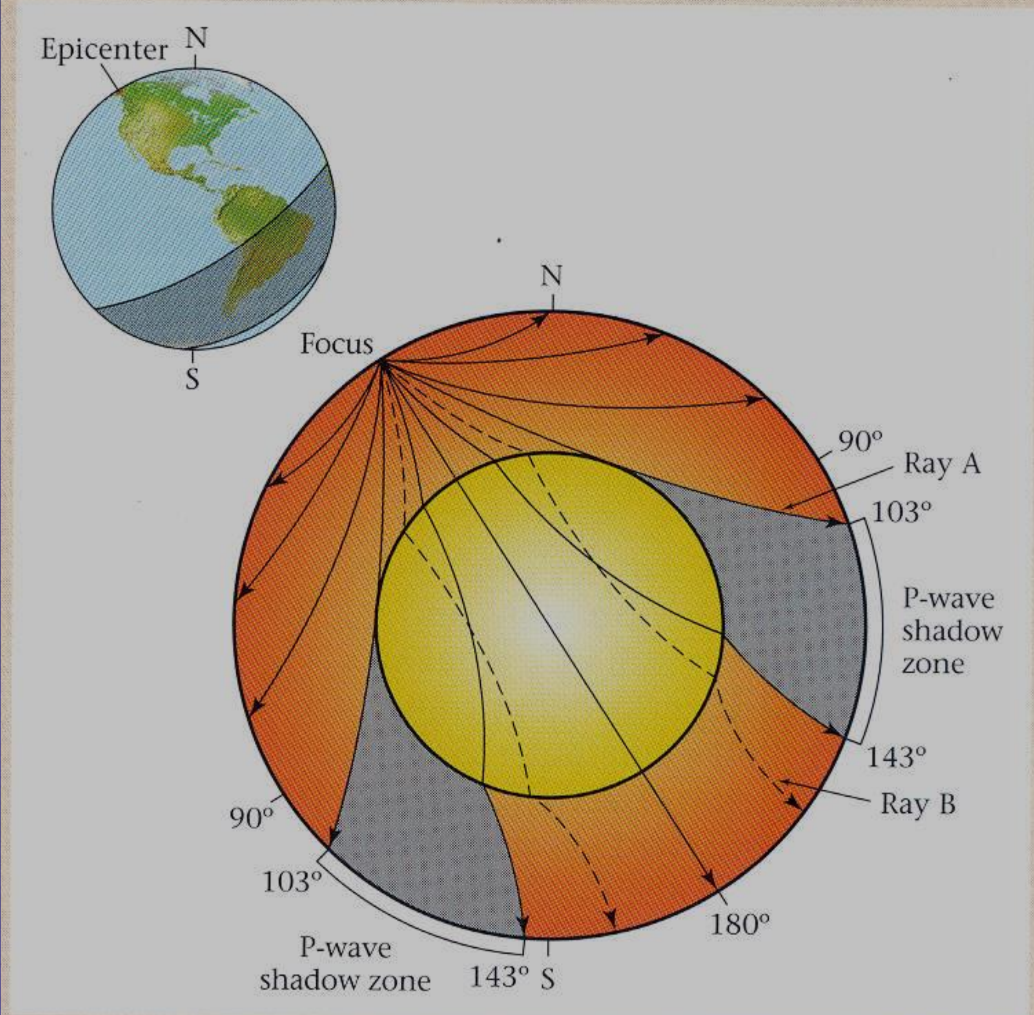


FIGURE C.8 P-waves do not arrive in the interval between 103° and 143° from an earthquake's epicenter, defining the P-wave shadow zone. The wave that arrives at 103° passed just above the core-mantle boundary. The next wave bent down so far that it arrives at about 160°. And the wave that arrives at 143° bent only slightly as it passed through the core. The inset shows the shadow zone on a globe. Note that P-waves bend down at the core-mantle boundary because velocities are slower in the core than in the mantle (the core is less rigid).

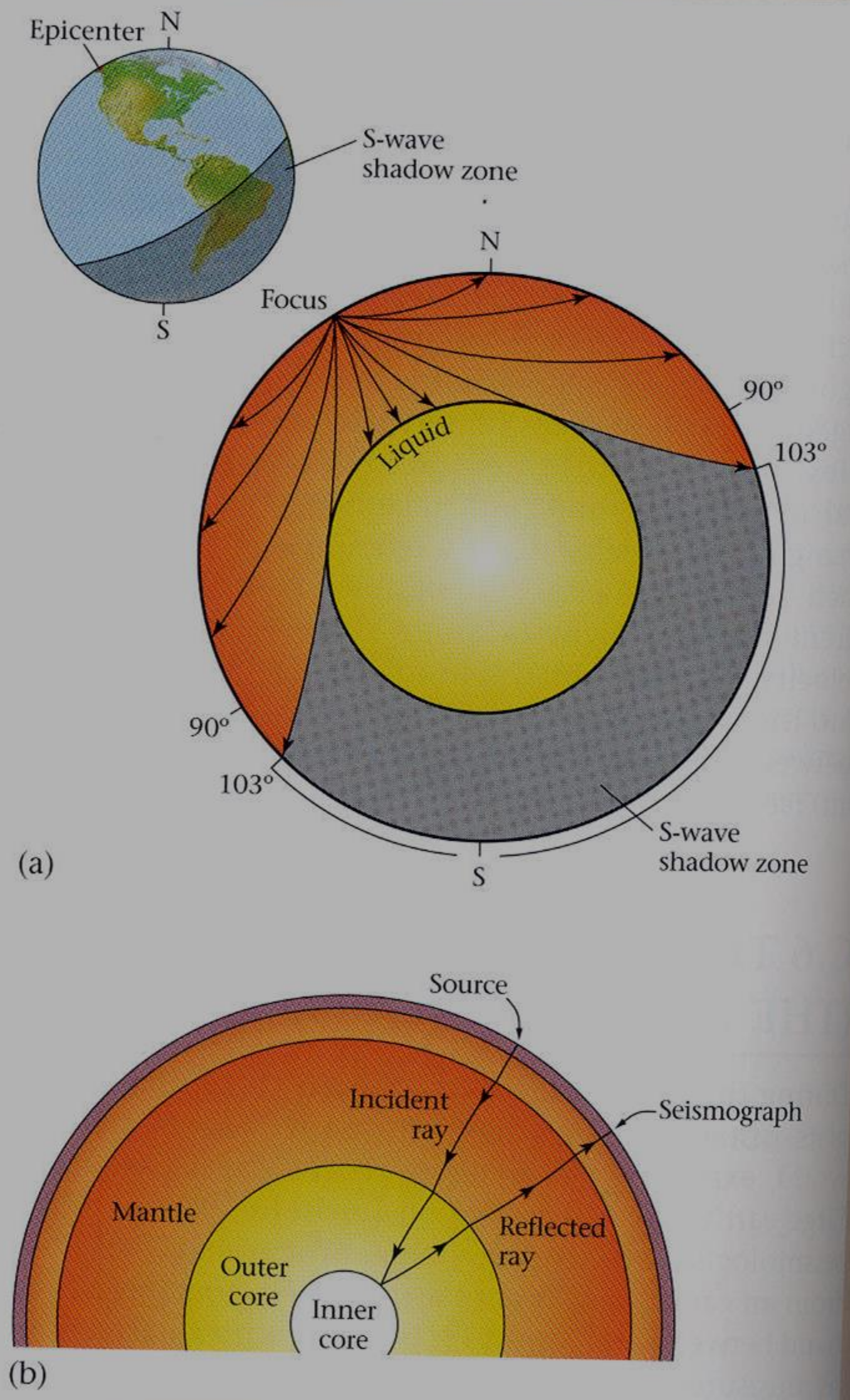
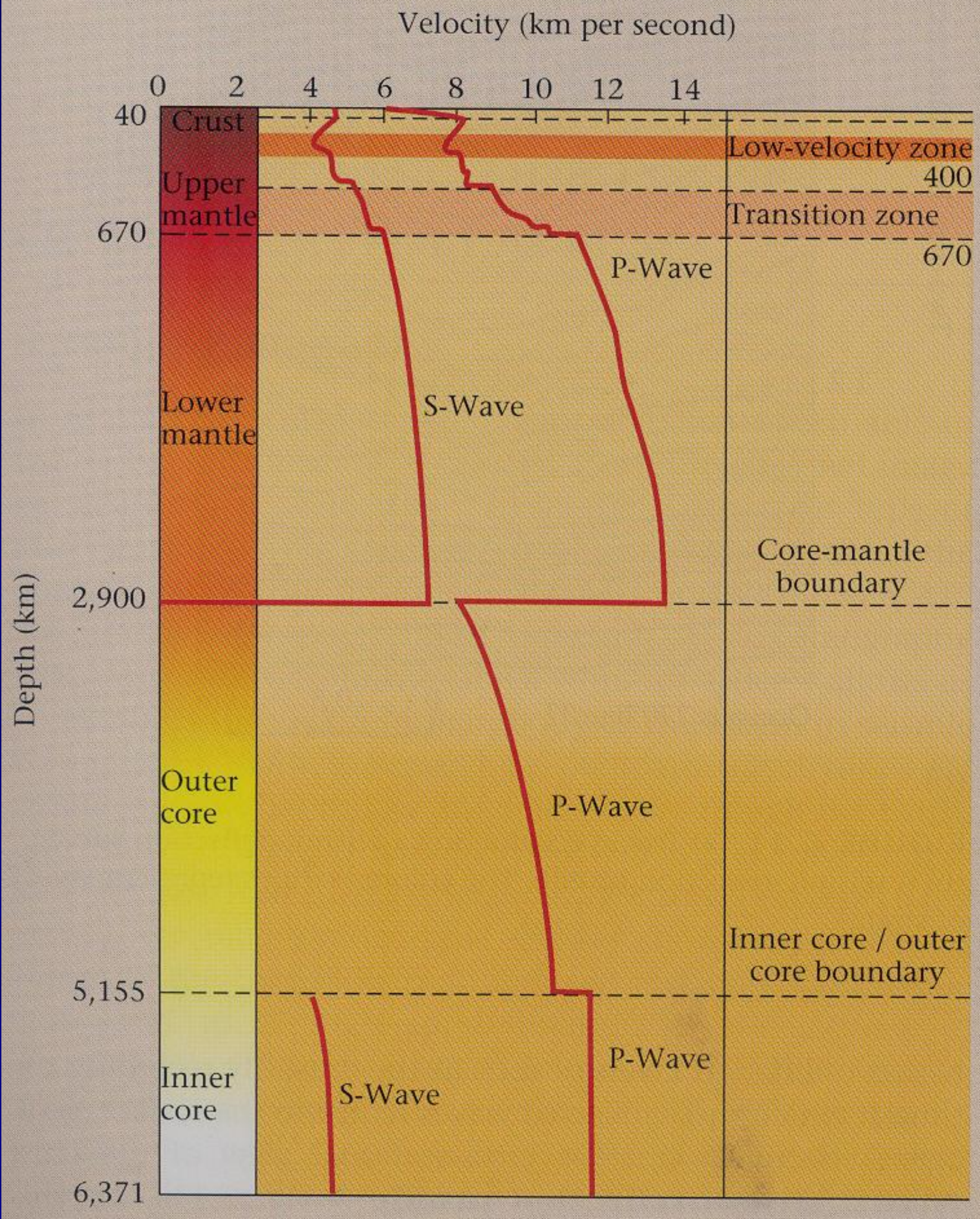


FIGURE C.9 (a) The S-wave shadow zone covers about a third of the globe, and exists because shear waves cannot pass through the liquid outer core. (b) The solid inner core was detected when seismologists observed that some seismic waves generated by nuclear explosions reflected off a boundary within the core.

FIGURE C.12 The velocity-versus-depth profile for the Earth.



Origin of Earth Quake:

- At the first point of rupture (FOCUS or HYPOCENTRE) The point vertically above the focus or Hypocenter is EPICENTRE

- The seismic wave may propagate from one point or may be from different parts of rupture

- When these multiple energies crosses with each other, echoes of earth quake formed from the earth’s different layers, so earth may rings like a bell

Seismic records:

From the seismogram records the following 3 basic information are derived

i) Epicenter location : by measuring the exact time of arrival of the earthquake signals at different stations

ii) Focal depth : determined from the timing of arrival and also from the shape of the recorded waveform

iii) Magnitude : determined from the amplitude of the ground motion

Depth vs SEISMICITY:

- **Deeper the condition the rock is more plastic so not much of stored elastic strain so less magnitude of earthquake.**

- **Shallower the condition, the rock is more brittle, breaks and rupture suddenly and the sudden release of accumulated elastic strain – high magnitude earthquake.**

But,

- **In the zones of subduction the earthquake happens at deep level with high magnitude because the fast moving cold slab reduces the temperature even at deeper level so the brittle failure can happen at the level, hence the magnitude is high.**
- **If the in this zone itself the movement is very slow or gradual then at shallow level itself the brittle failure takes place**
- **So earthquakes can be at Transform zone, at ridges and even trenches.**

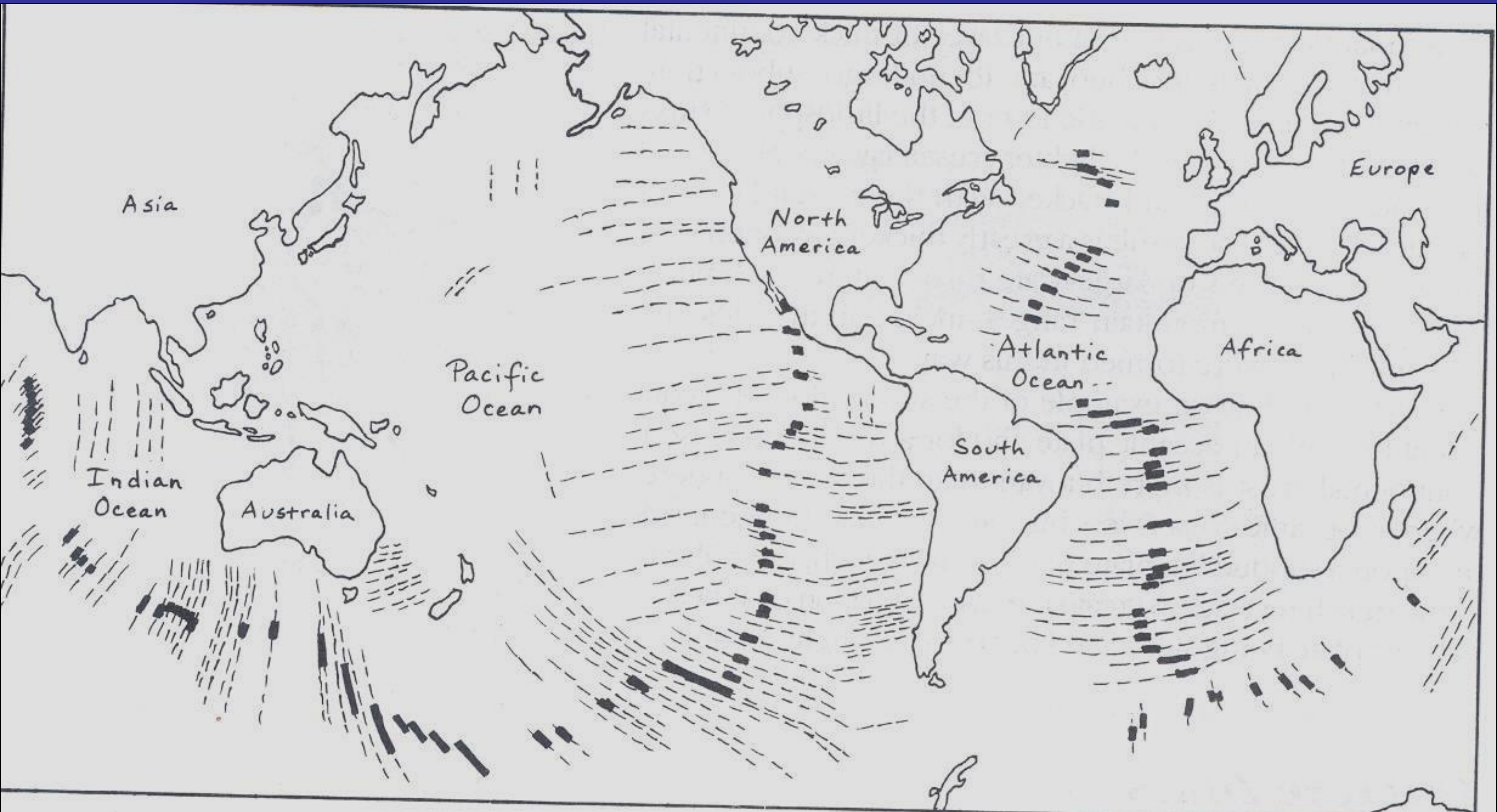


Figure 1-21.
Major fracture zones accompanied by earthquakes (heavy lines) and without earthquakes (dashed lines).

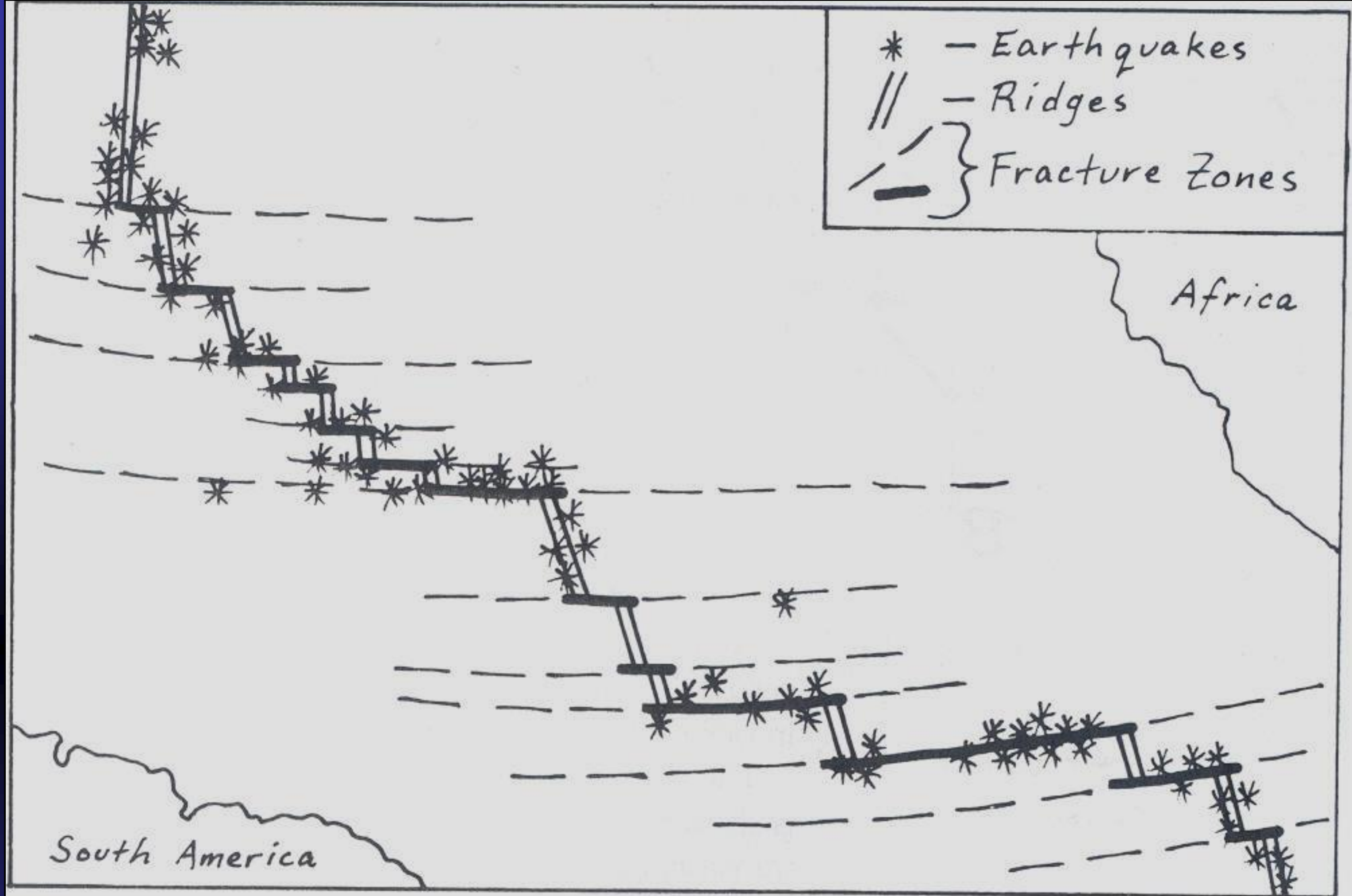


Figure 1-22.
Close-up of Mid-Atlantic Ridge showing association of earthquakes with sections of fracture zones linking ridge segments, and absence of earthquakes along fracture zones away from ridge segments.

EARTHQUAKE PROVINCES

Geodynamics of Indian Plate

Geodynamics of Indian Plate:

- Himalayan mountains in the northern limit of Indian plate are the consequences of the collision of Indian plate of very strong continental block of lithosphere with Asia plate about 55my ago.

- The collision of India with Asia has uplifted the Himalayas and Tibet

- Where as the portion of China and Southeast Asia have slipped to the east to “Escape” the collision.

- Faults in the central Asia have become active causing uplift of ranges like Tien-Shan, as compressive forces build up.

Geodynamics of Indian Plate: Conti……

- Since then the strong lithosphere of India has continued to push slowly into soft lithosphere of Asia – The Himalaya was raising constantly.

- As the raising Himalaya came to a maximum raise it has started providing obstruction to the still ongoing plate movement forces.

- So the Indian Plate started whirling like a worm with ups and downs (Arches and Deeps)

- The related fractures started developing in N-S,E-W, NE-SW and NW-SE directions.

Plate Tectonics

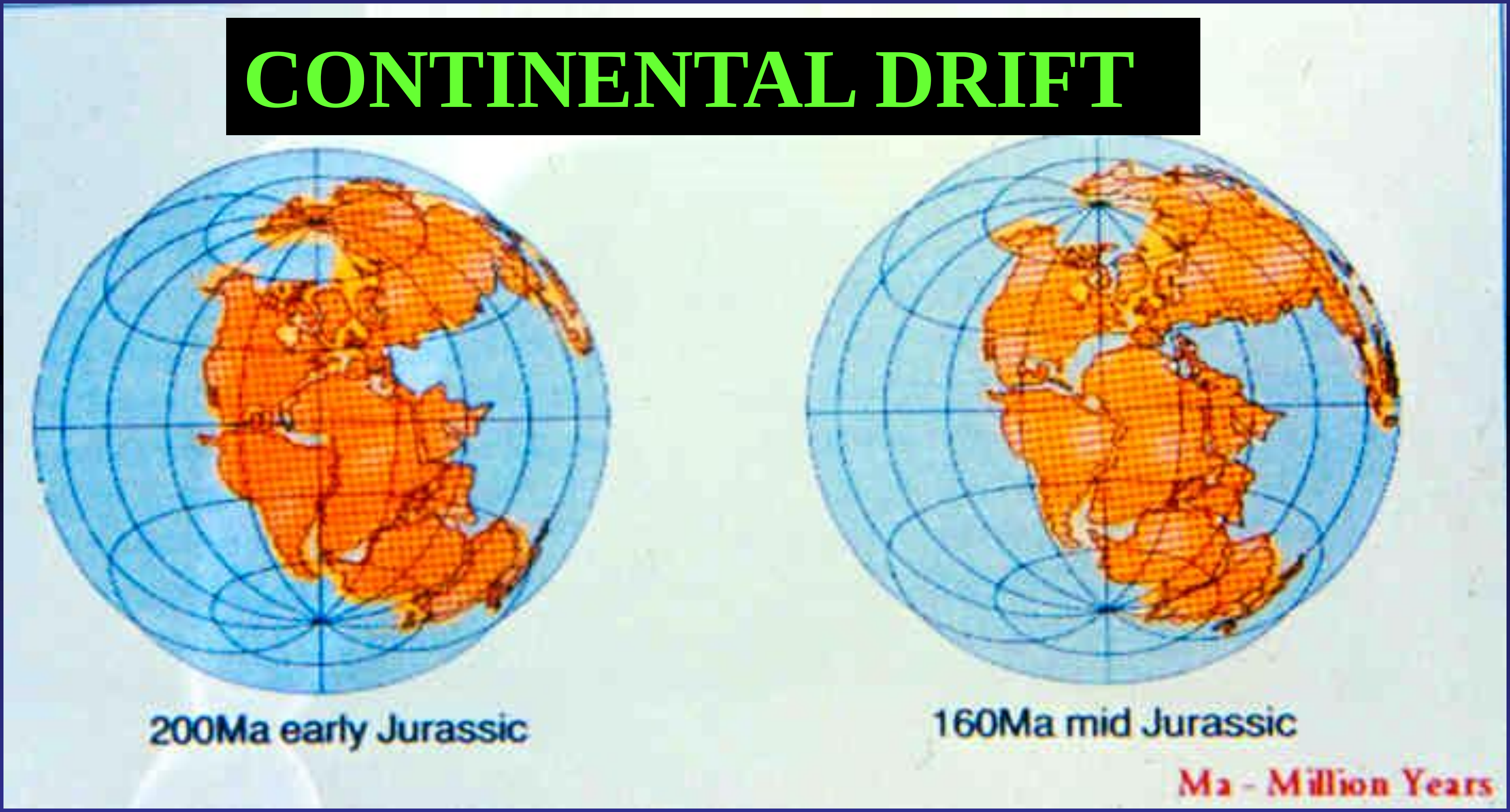


Plate Tectonics

CONTINENTAL DRIFT

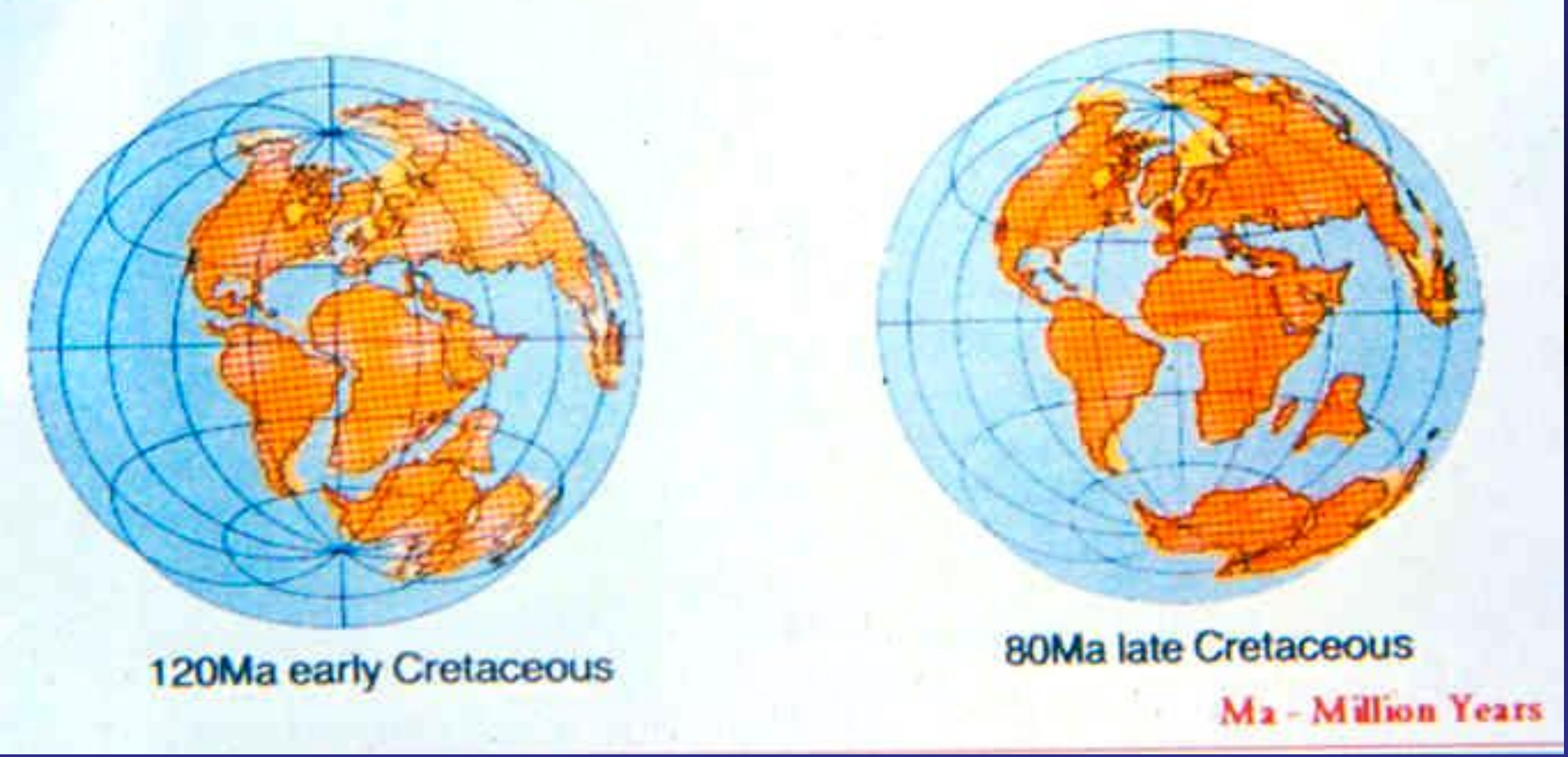
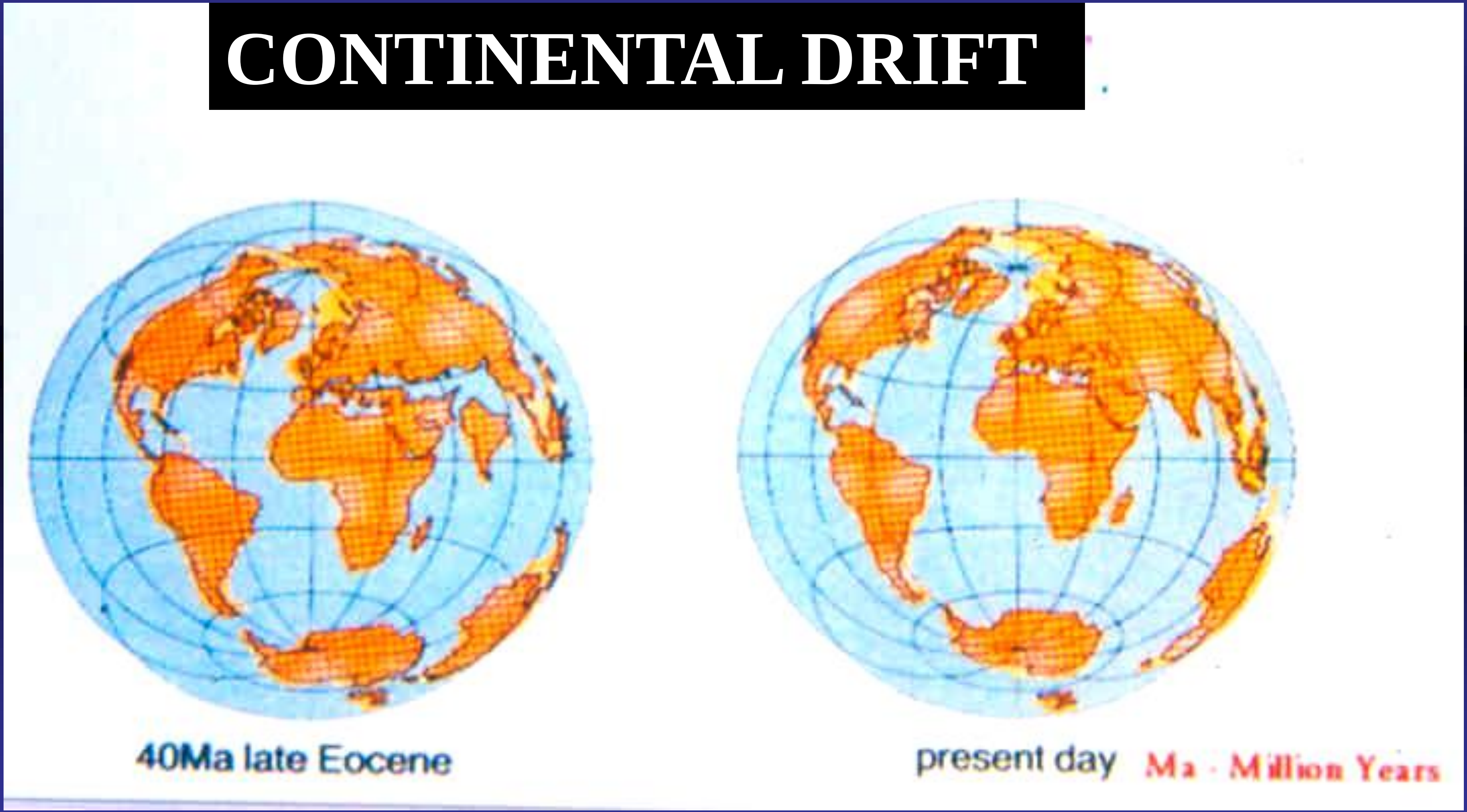
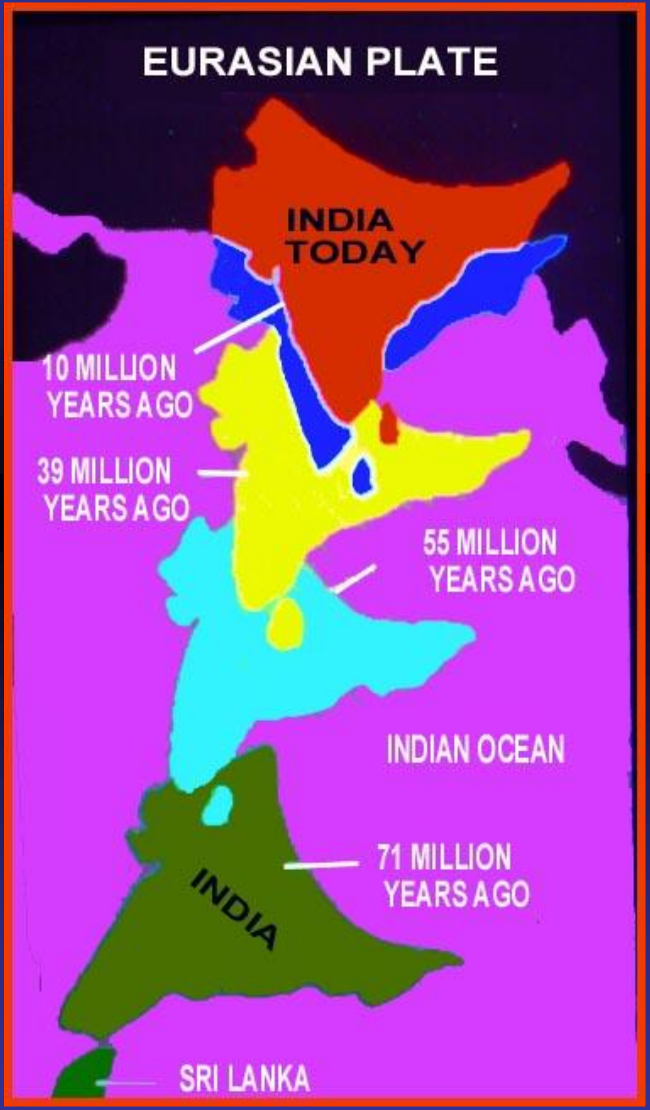


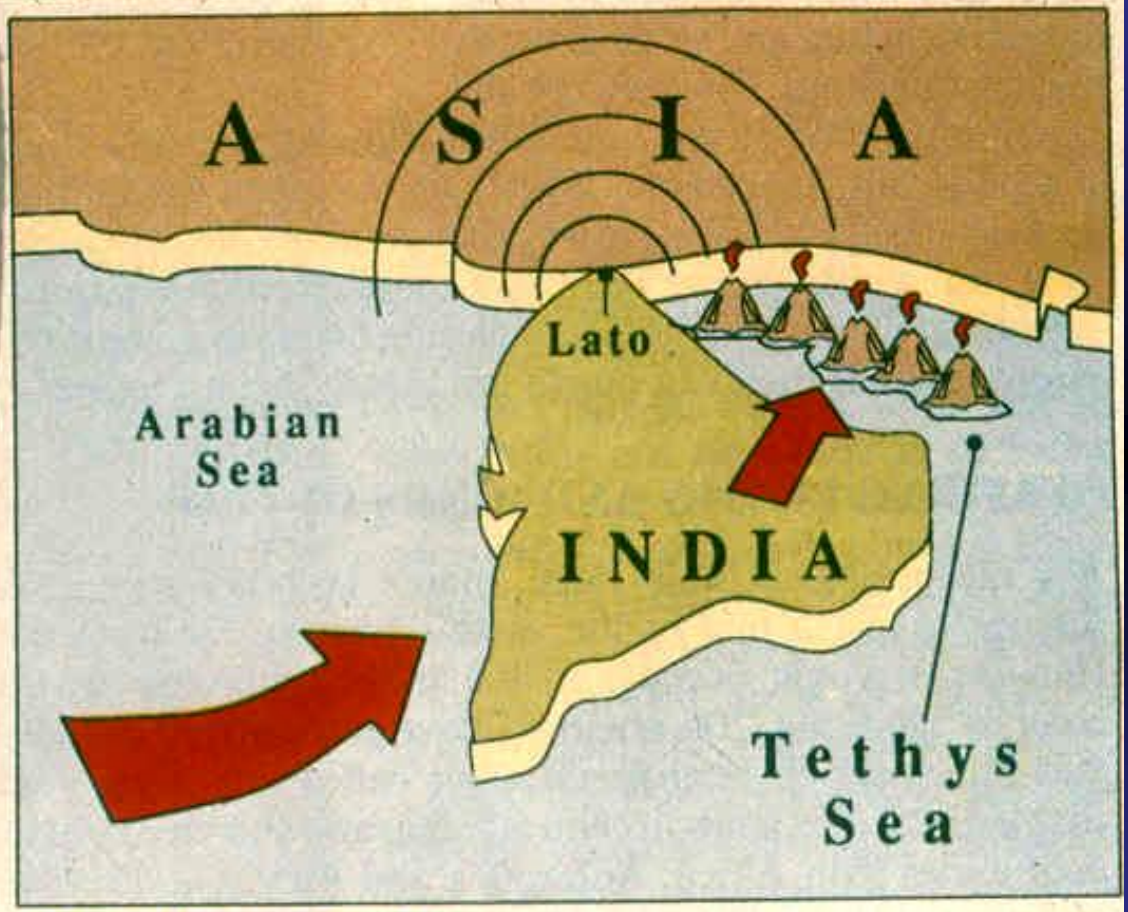
Plate Tectonics



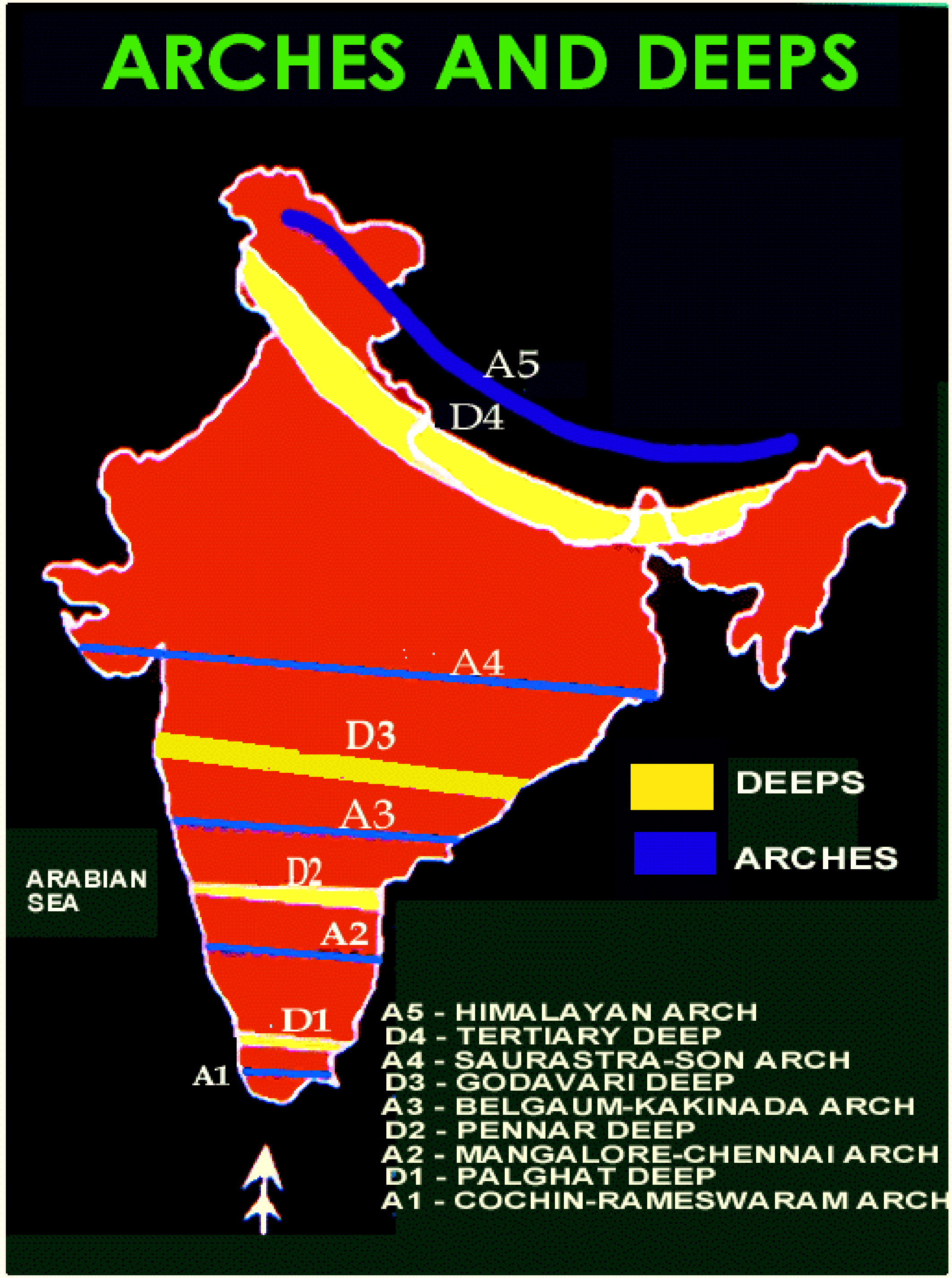
Drifting of Indian Subcontinent



India’s Locking Up



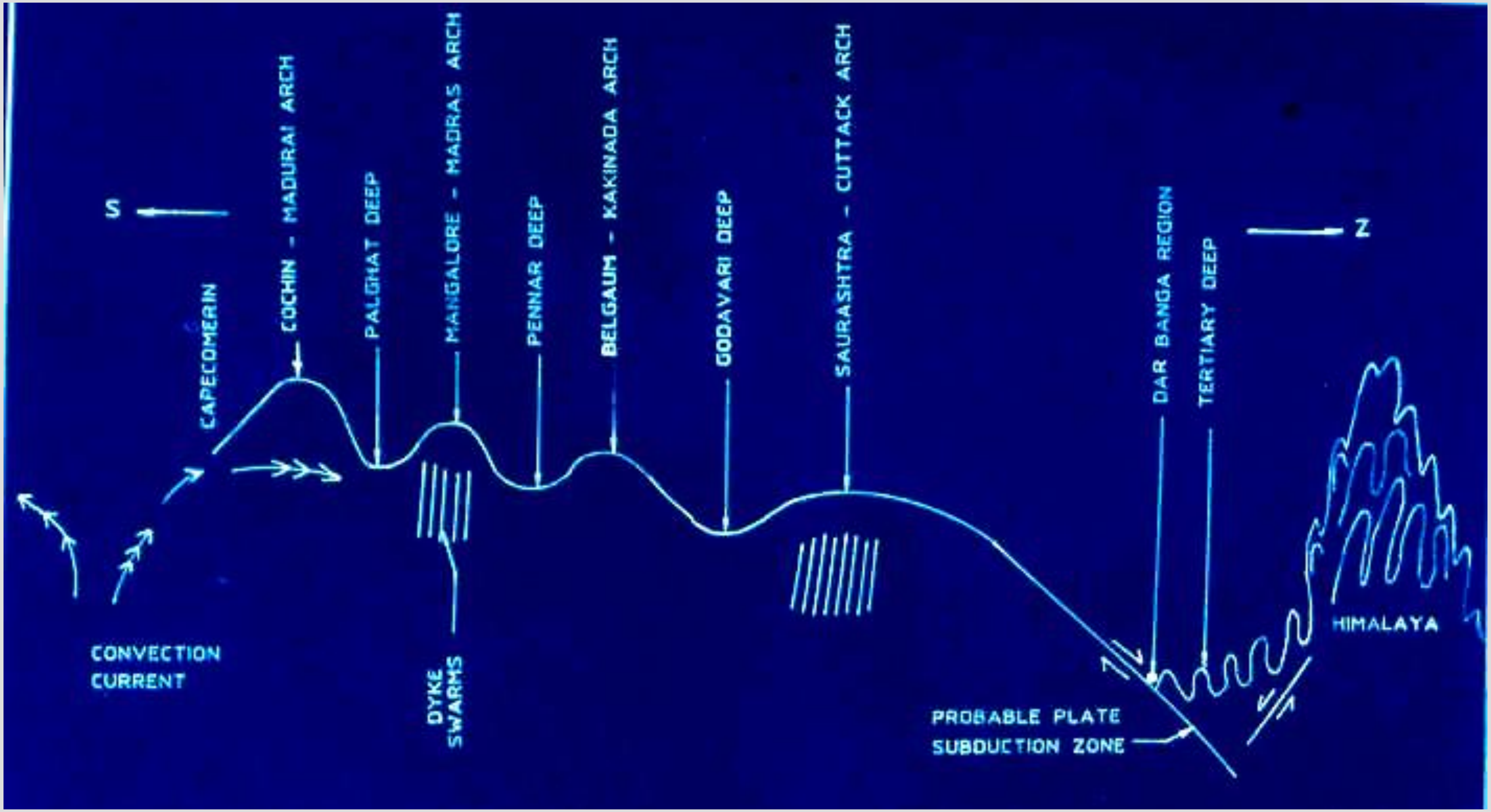
60 million years: Ending its 6,000 km long journey the northern tip of India crashed into Asia eventually causing the Himalayas to rise.



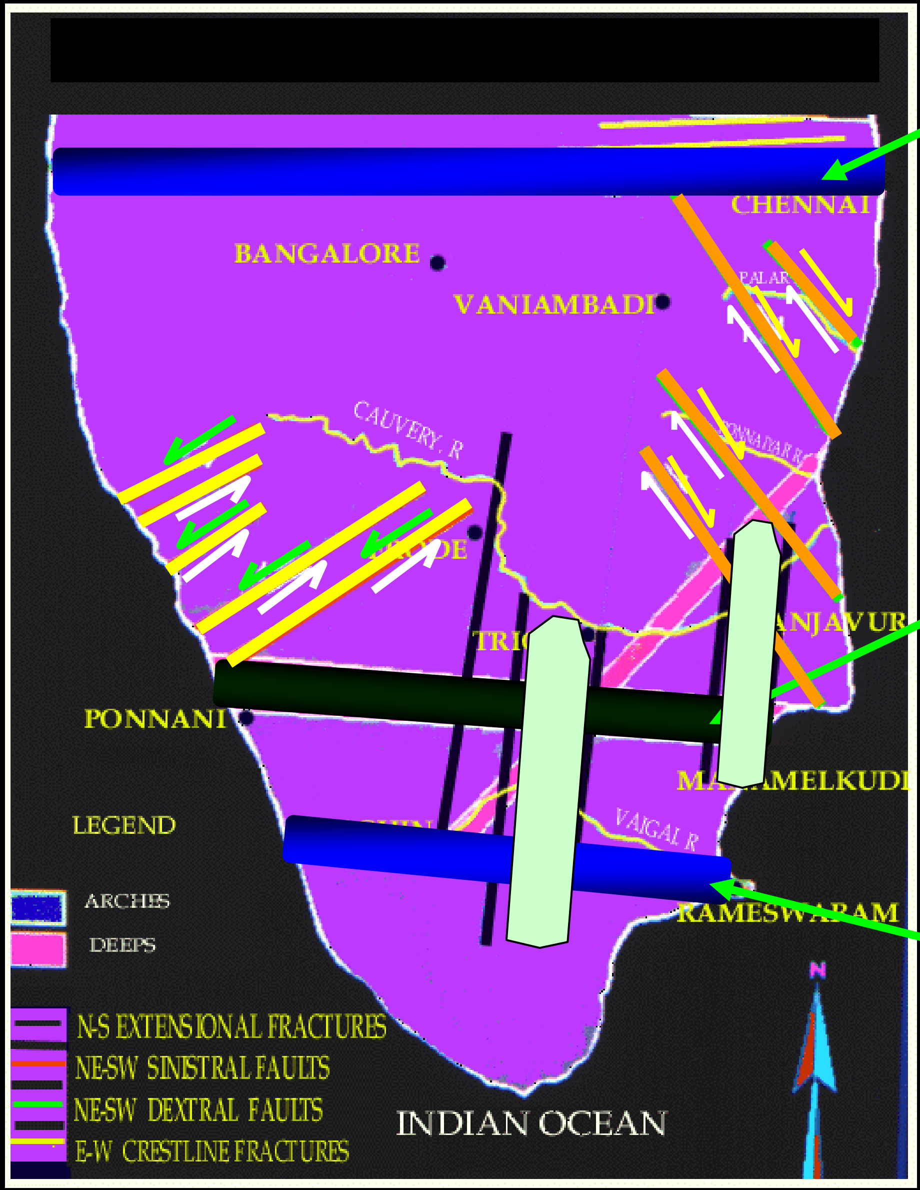
ARCHES AND DEEPS
A5
D4
A4
D3
A3
D2
A2
D1
A1
ARABIAN SEA
DEEPS
ARCHES
A5 - HIMALAYAN ARCH
D4 - TERTIARY DEEP
A4 - SAURASTRA-SON ARCH
D3 - GODAVARI DEEP
A3 - BELGAUM-KAKINADA ARCH
D2 - PENNAR DEEP
A2 - MANGALORE-CHENNAI ARCH
D1 - PALGHAT DEEP
A1 - COCHIN-RAMESWARAM ARCH

Geological section

(Cape Comerion – Himalayas)



QUATERNARY TECTONIC SCENARIO

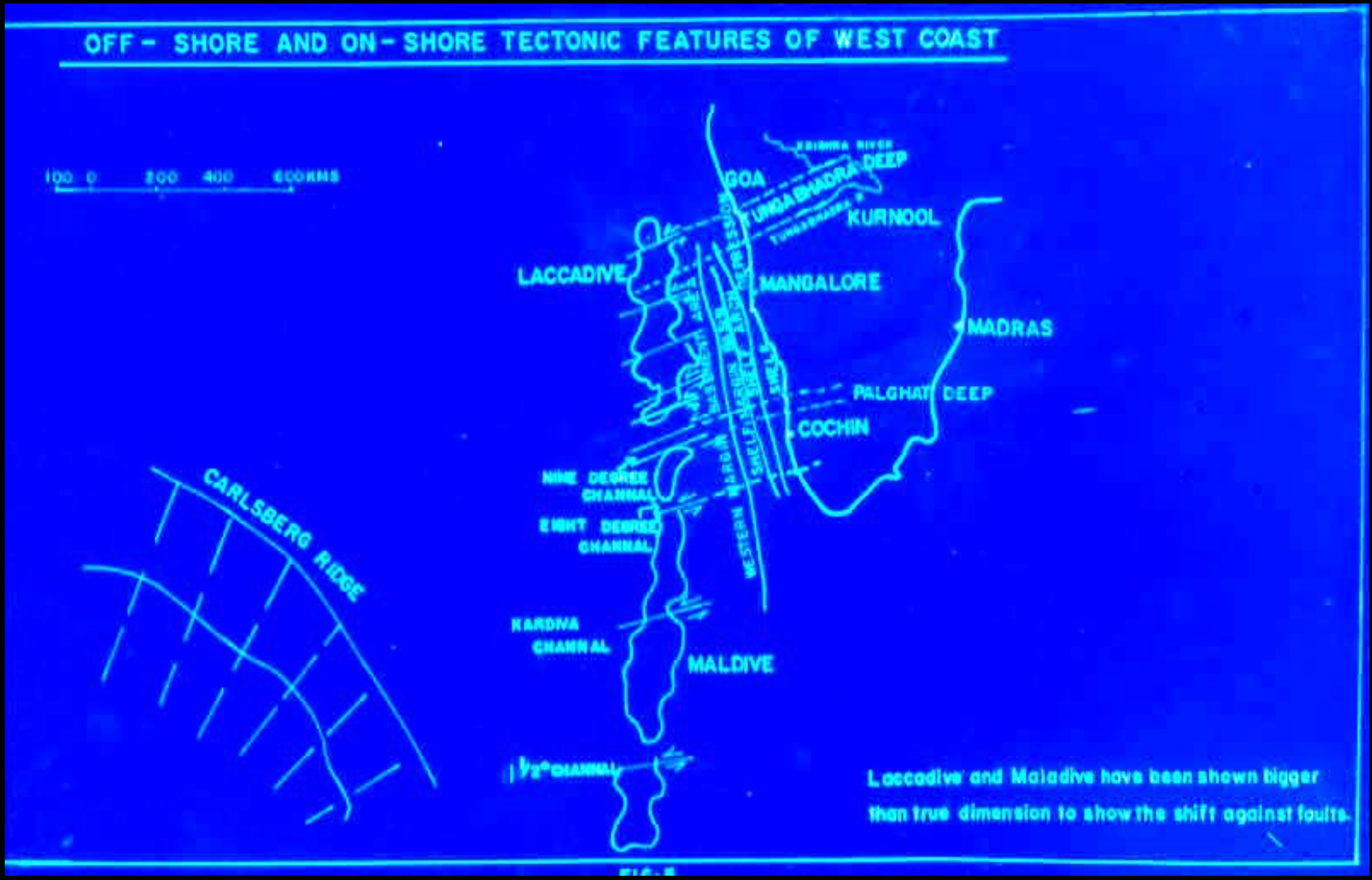


Rising Bangalore - Madras region

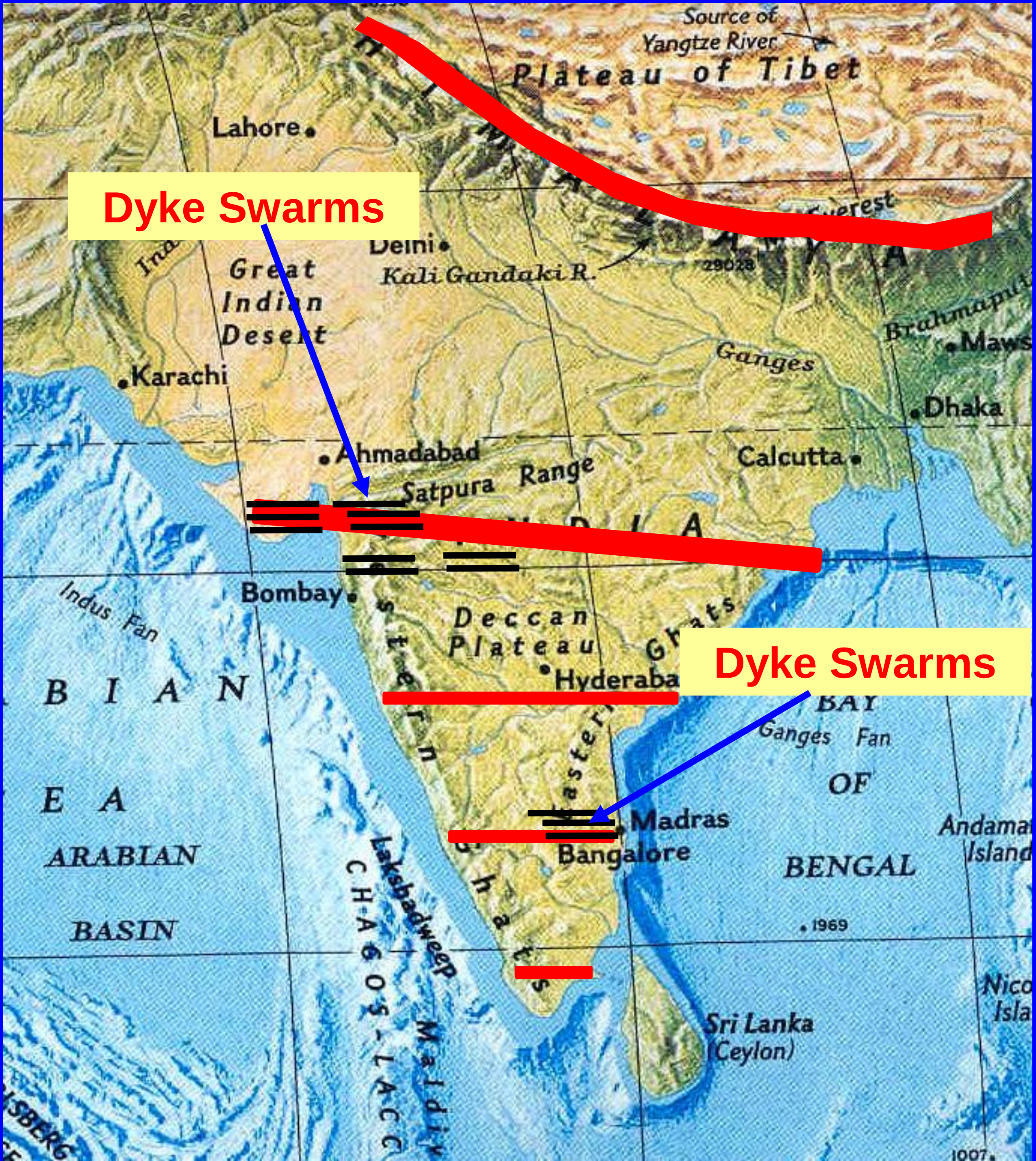
Subsiding Ponnani - Manamelgudi region

Rising Cochin - Ramnad region

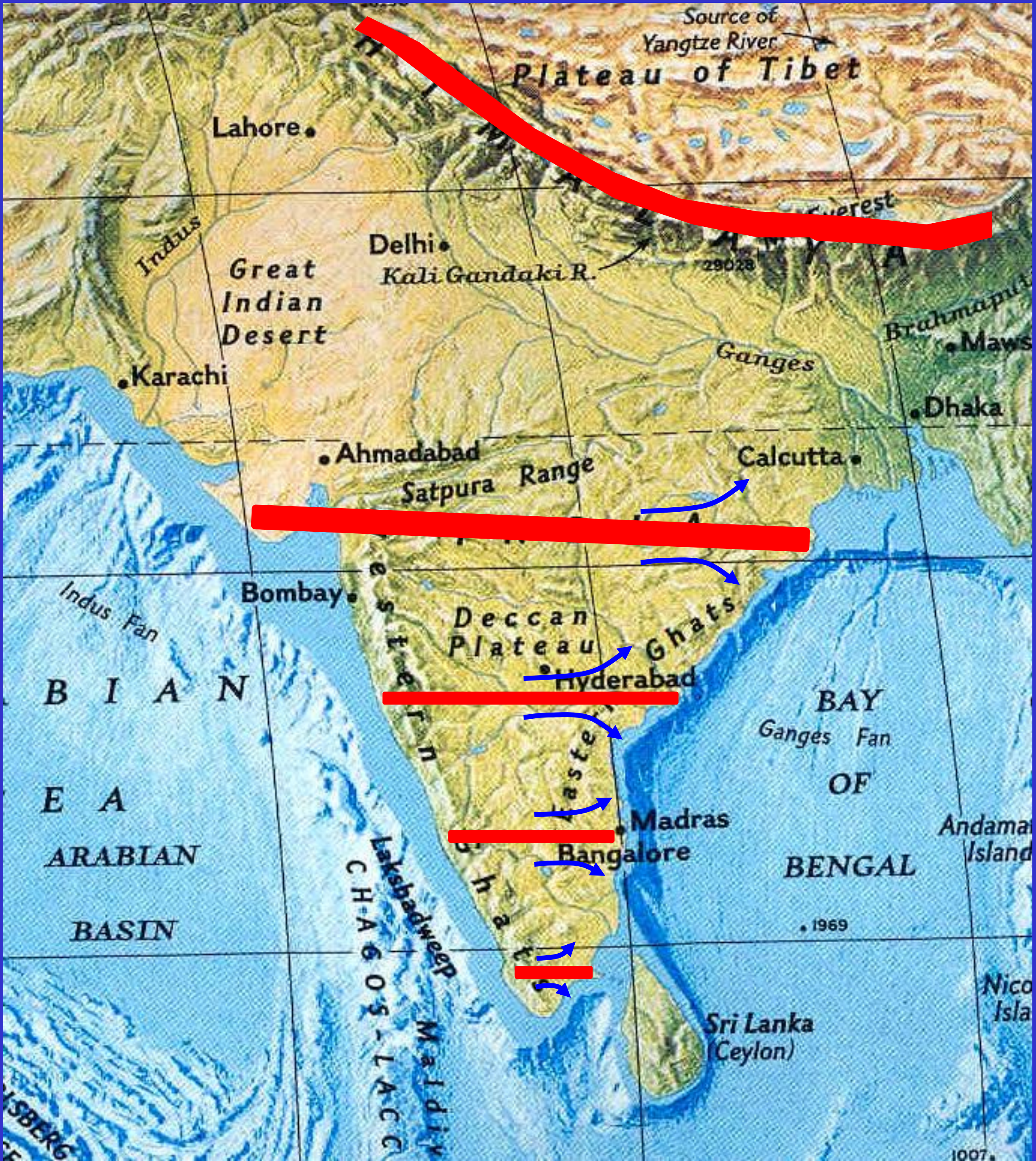
Faults in Loccadives



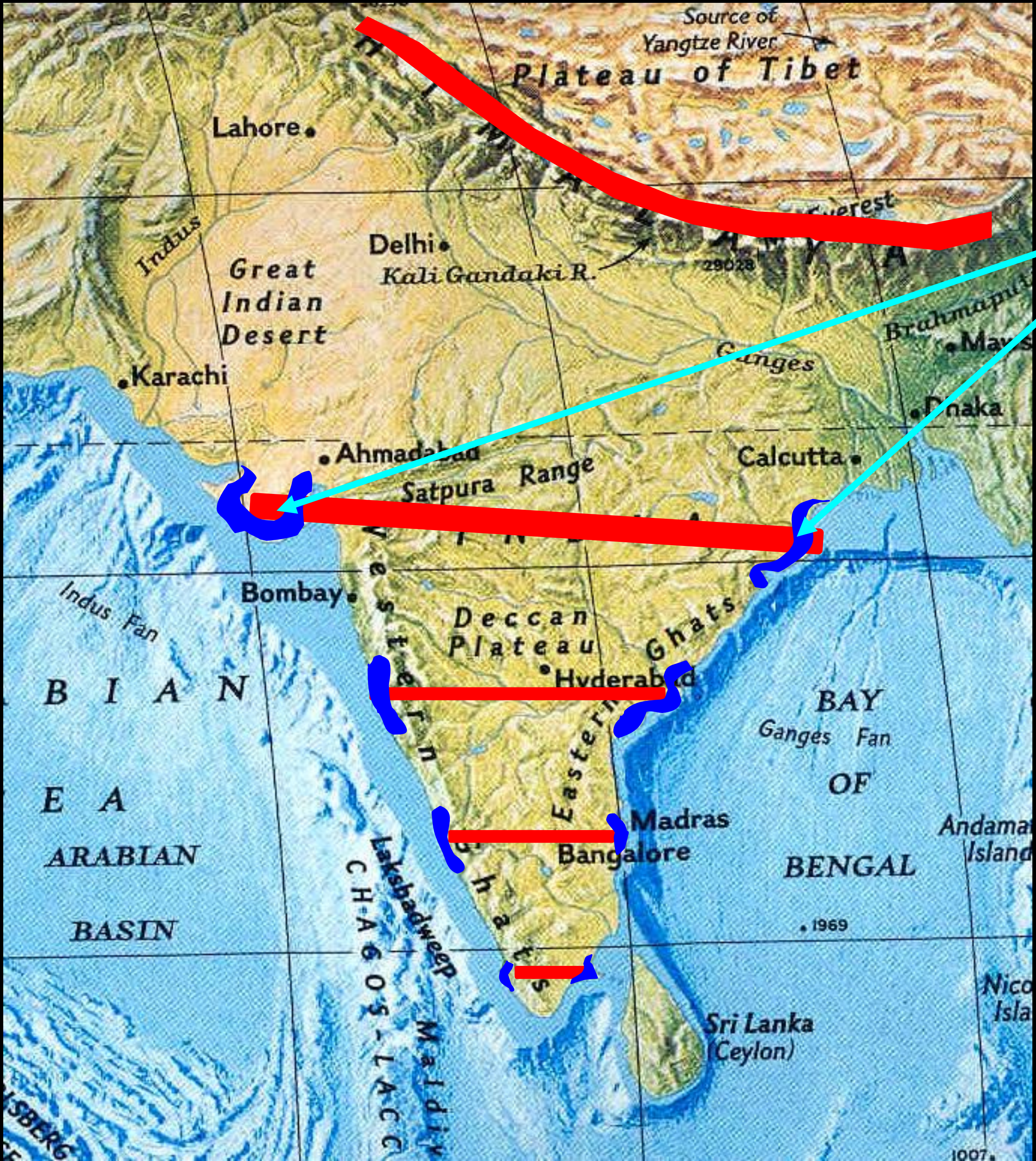
Source of Yangtze River
Plateau of Tibet
Qin Ling
HIMALAYA
Lahore
Chengdu
Wuhan
Shanghai
Chongqing
Yangtze
Mt. Everest
Hengduan Shan
Delhi
Indus
Great Indian Desert
Kali Gandaki R.
Brahmaputra
Mawsynram
Ganges
Karachi
Nan Ling
Dhaka
Salween
Guangzhou
Hong Kong
Ahmadabad
Calcutta
Satpura Range
Irrawaddy
INDIA
Gulf of Tonkin
Hainan
Bombay
Indus Fan
Western Ghats
Deccan Plateau
Eastern Ghats
Mekong
Hyderabad
Yangon (Rangoon)
ARABIAN SEA
BAY OF BENGAL
Ganges Fan
Indochina Peninsula
SOUTH CHINA SEA
Bangkok
Madras
Bangalore
Andaman Islands
Andaman Sea
ARABIAN BASIN
ANDAMAN BASIN
Ho Chi Minh City
Gulf of Thailand
Palawan
Lakshadweep
CHAGOS-LACCADIVE PLATEAU
Maldive Islands
1969
Nicobar Islands
Sri Lanka (Ceylon)
CARLSBERG RIDGE
Malay Pen.
Str. of Malacca
CONTINENTAL SHELF
Kinabalu
1007
Singapore
Sumatra
Borneo
CEYLON PLAIN
COCOS BASIN
INDONESIA
Kerinci
Nikitin Seamount
Greater Java Islands
Jakarta
Chagos Archipelago
Diego Garcia
CHAGOS TRENCH
Java
Surabaya
VEMA FRACTURE ZONE
MID-INDIAN BASIN
JAVA TRENCH
Bali
Saya de Malha Bank
829
Christmas I.
Cocos Islands
NINETYEAST RIDGE
INVESTIGATOR RIDGE



Arching & Fracture Swarms



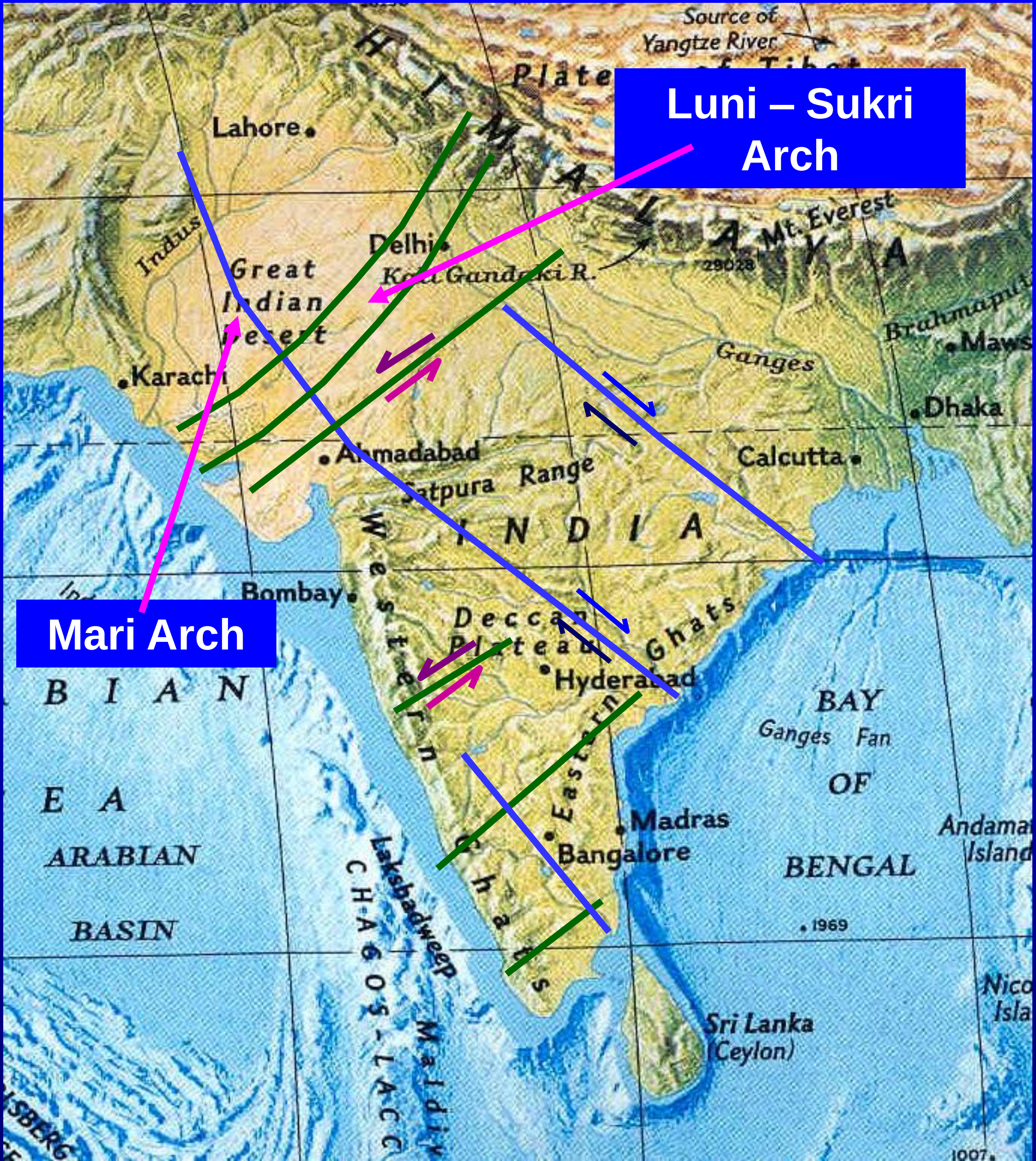
Arching & River Migration



Arching

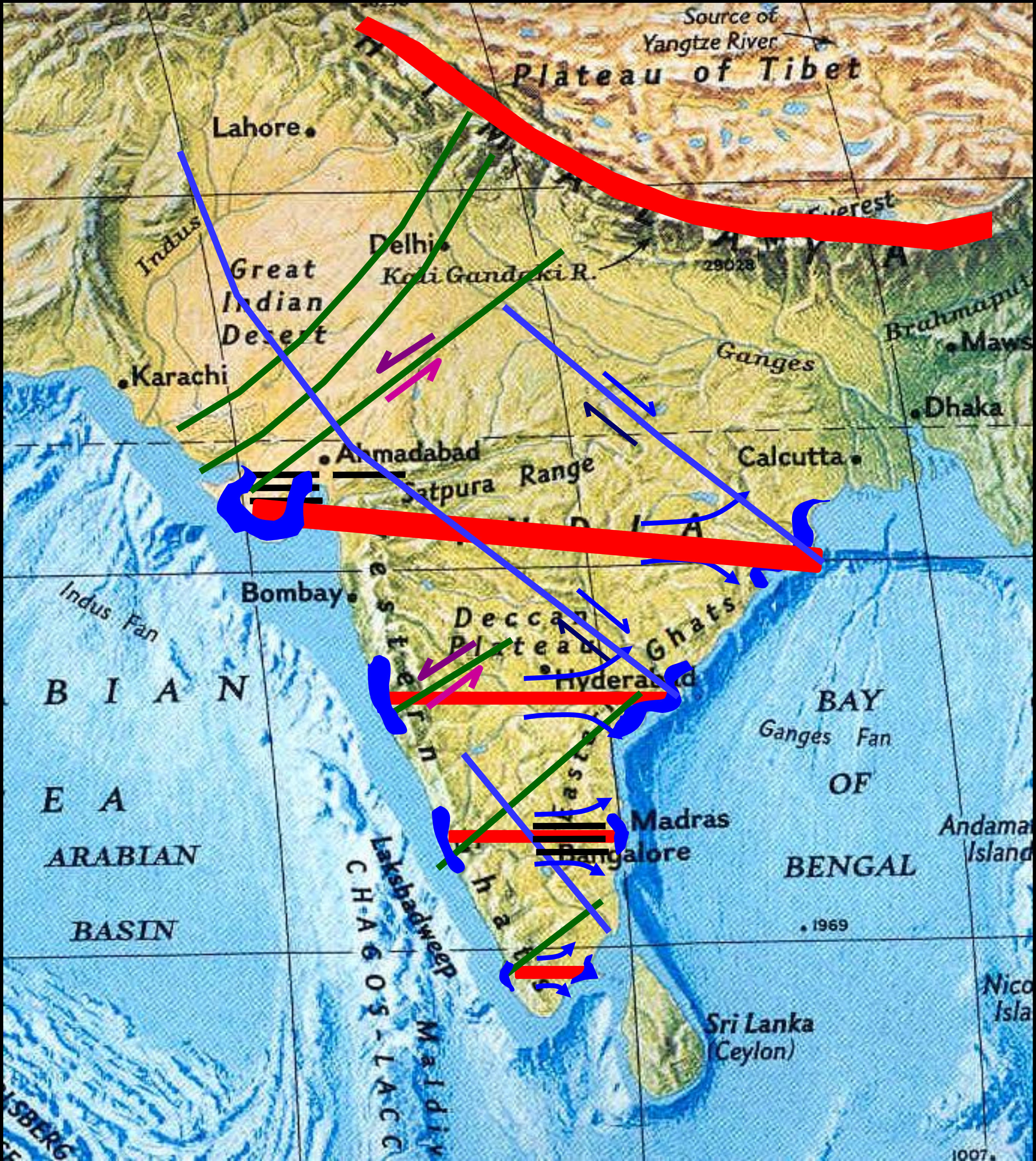
Convex Coast

Restricted Marine Regression



Faults Movements

Cenozoic Tectonic of Peninsular India



Thank You