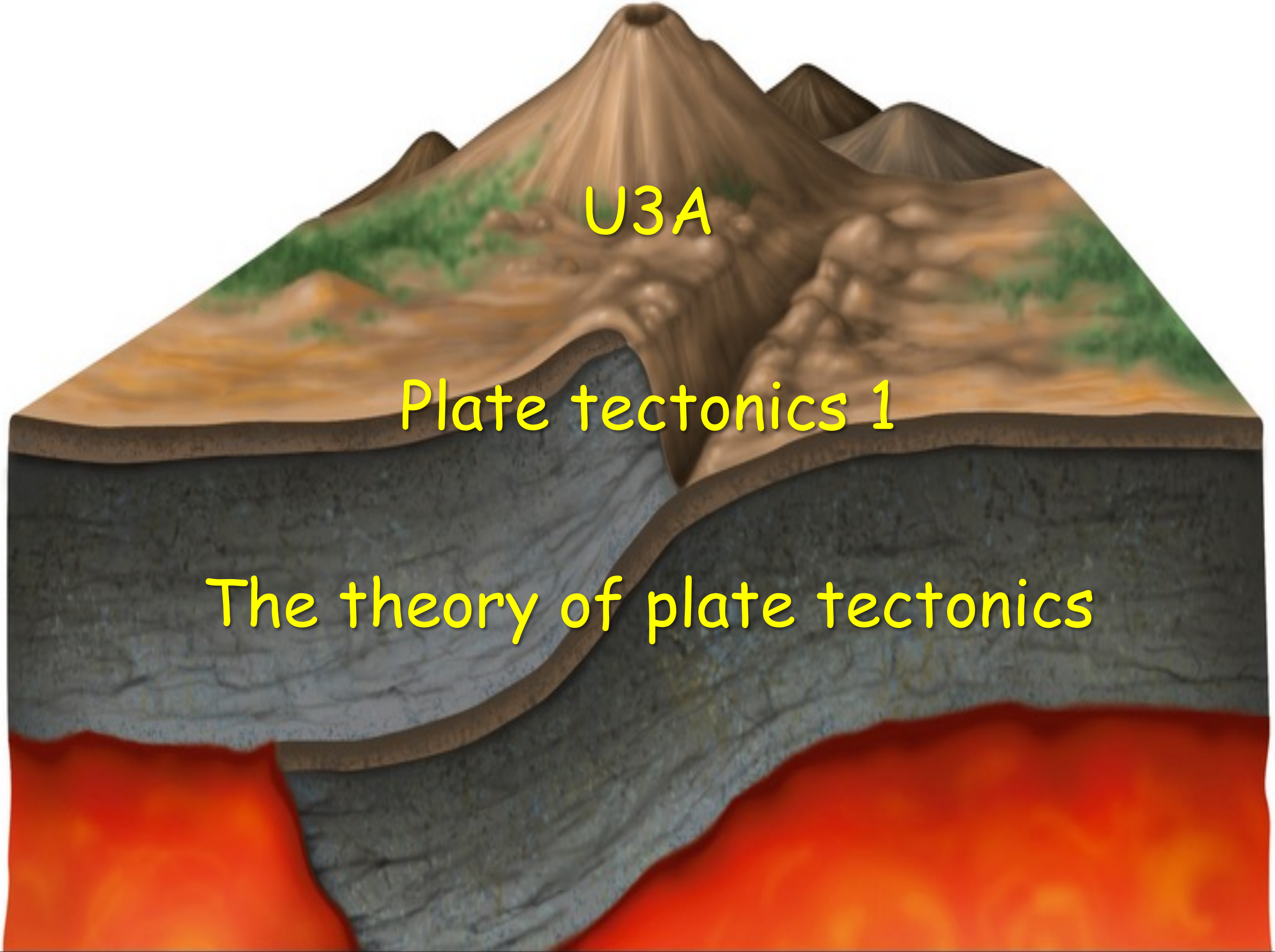


U3A

Plate tectonics 1

The theory of plate tectonics

Introduction

- Theory of Plate Tectonics → largely developed since 1967
- only since WWII that sufficient data has been obtained from 60% of the Earth's surface covered in deep water → providing evidence to support the theory
- much of the early data was obtained through research on submarine detection during WWII
- Plate tectonics research has provided an understanding of the origin and history of the ocean basins
- it has shown that the ocean areas are young geologically (<200Ma) and that oceanic crust is dissimilar to continental crust

Theory of plate tectonics

- Founded on basis → outer shell of Earth (lithosphere) is composed of rigid plates that slide over the underlying mantle
- supporting theory → evidence of large scale movements in Earth's crust resulting in intense deformation in mountain belts
- theory evolved over time, particularly in the 1950s – 1970s from a variety of different contributors
- WWII techniques developed to locate submarines at sea, were adapted to study sea floor
- the theory can account for deformation, earthquakes, volcanoes

Folded sedimentary rocks, Swiss Alps

Nappes, Bernese Alps, Switzerland

Tectonics

- Tectonics – the study of Earth's crustal movements on large scale
- involves study of the large scale structures on Earth and the large movements of the Earth's crust that produced them
- primary features → bimodal distribution of elevations → oceans and continents (land above sea level and land 5-6km below sea level)
- secondary features

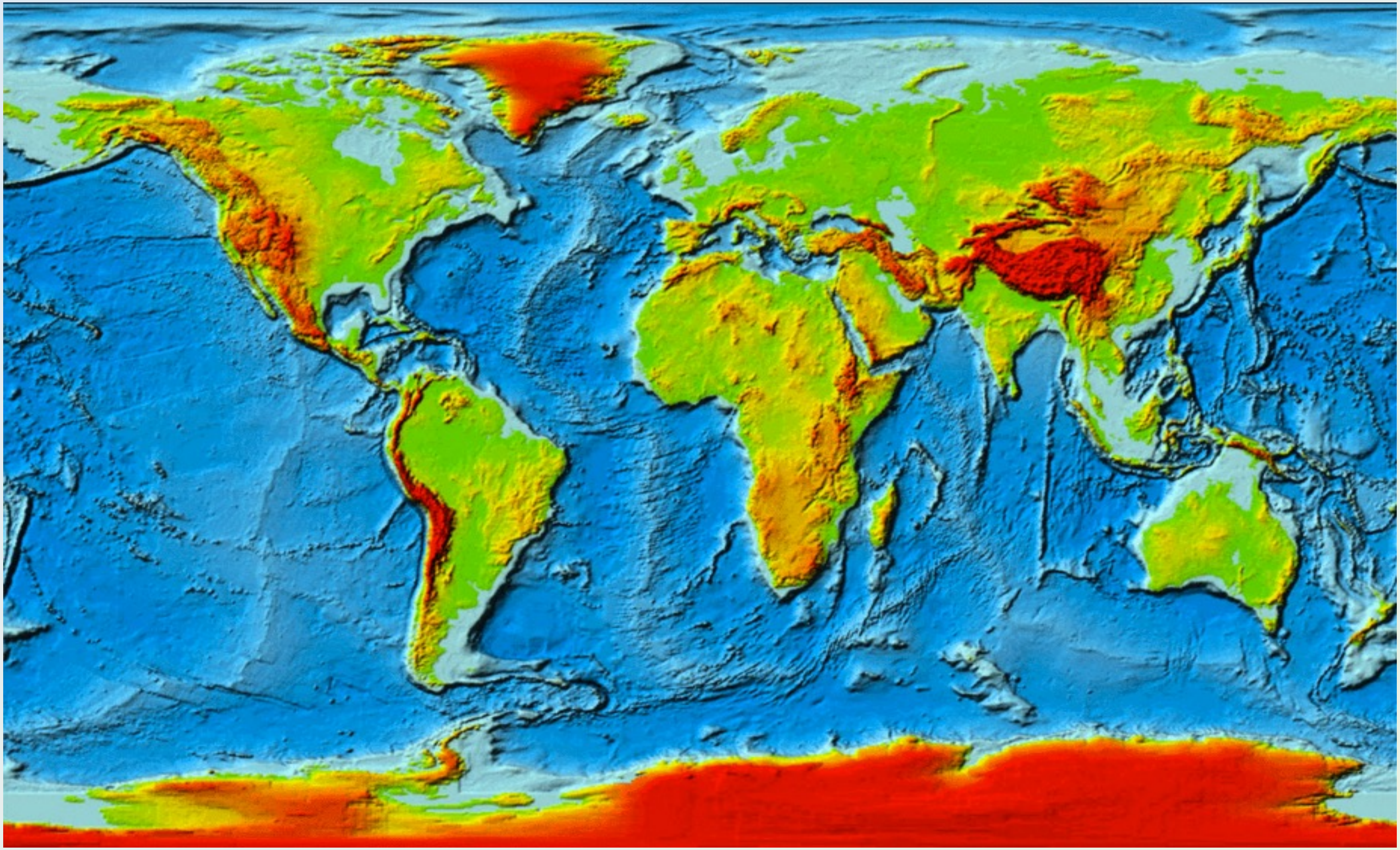
  continental mountain ranges (Andes, Himalayas, Rockies)

  submarine mid-ocean ridge systems

  linear island chains

  island arcs

Topography of Earth's surface

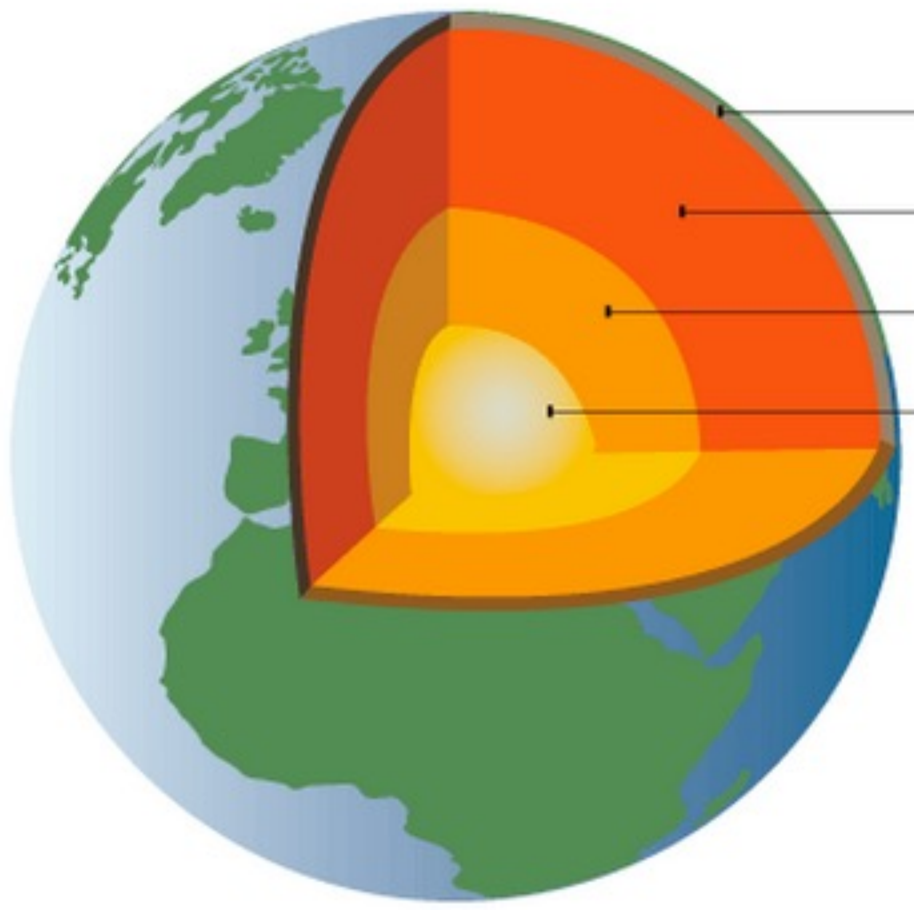


Large scale features on the Earth's surface

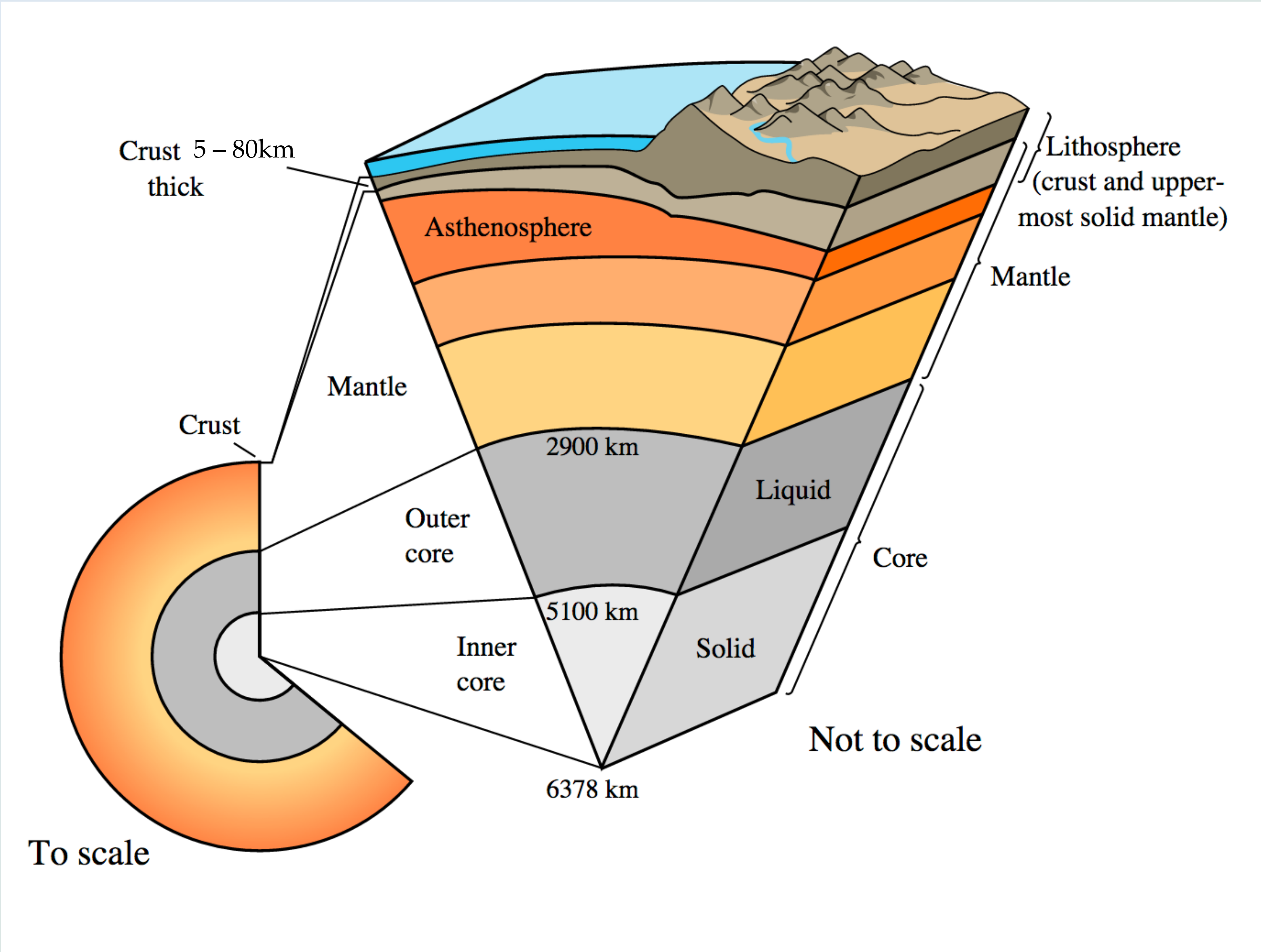
- The largest single tectonic feature on Earth is the ridge system → runs right across all of the oceans
- another major feature is the island arc system → arcuate chains with volcanic and earthquake activity e.g. Indonesian arc, Mariannas arc, Aleutian Island arc
- linear, narrow, high ridges → run more or less as straight lines across the ocean e.g. Ninety East Ridge, Maldives Chagos Ridge

Internal structure of the Earth

- Internal structure of Earth → characterised by concentric layers
- layers are defined by their chemical composition or rheology



Earth's interior

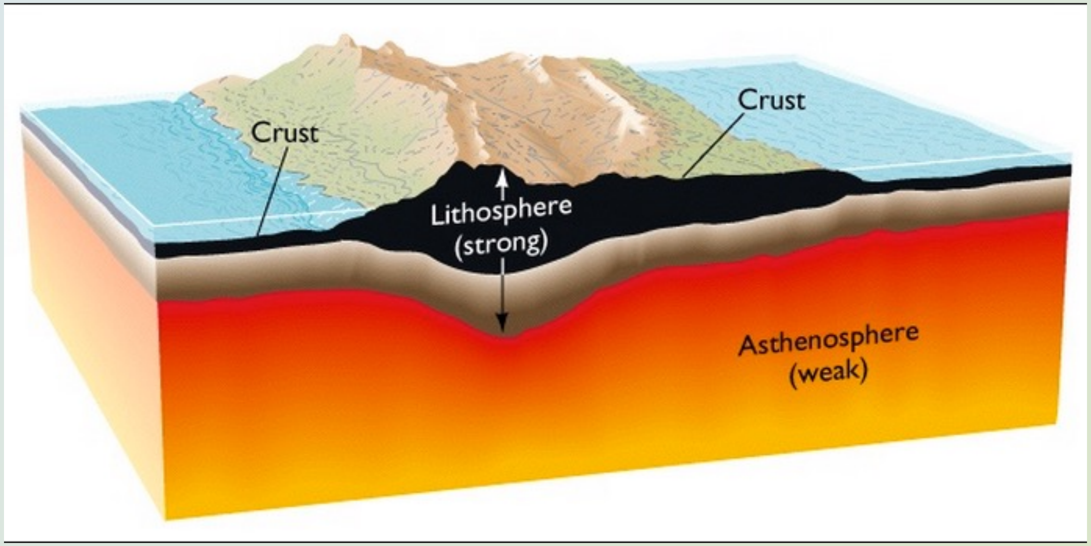


Lithosphere

- Rigid outermost shell of the Earth → includes crust and uppermost mantle
- underlain by asthenosphere (hotter, deeper, structurally weaker)
- lithosphere deforms elastically and through brittle fracture
- asthenosphere deforms viscously, plastic deformation
- two types of lithosphere:

  (1) oceanic lithosphere (mean density 2.9gm/cm^3)

  (2) continental lithosphere (mean density 2.7gm/cm^3)

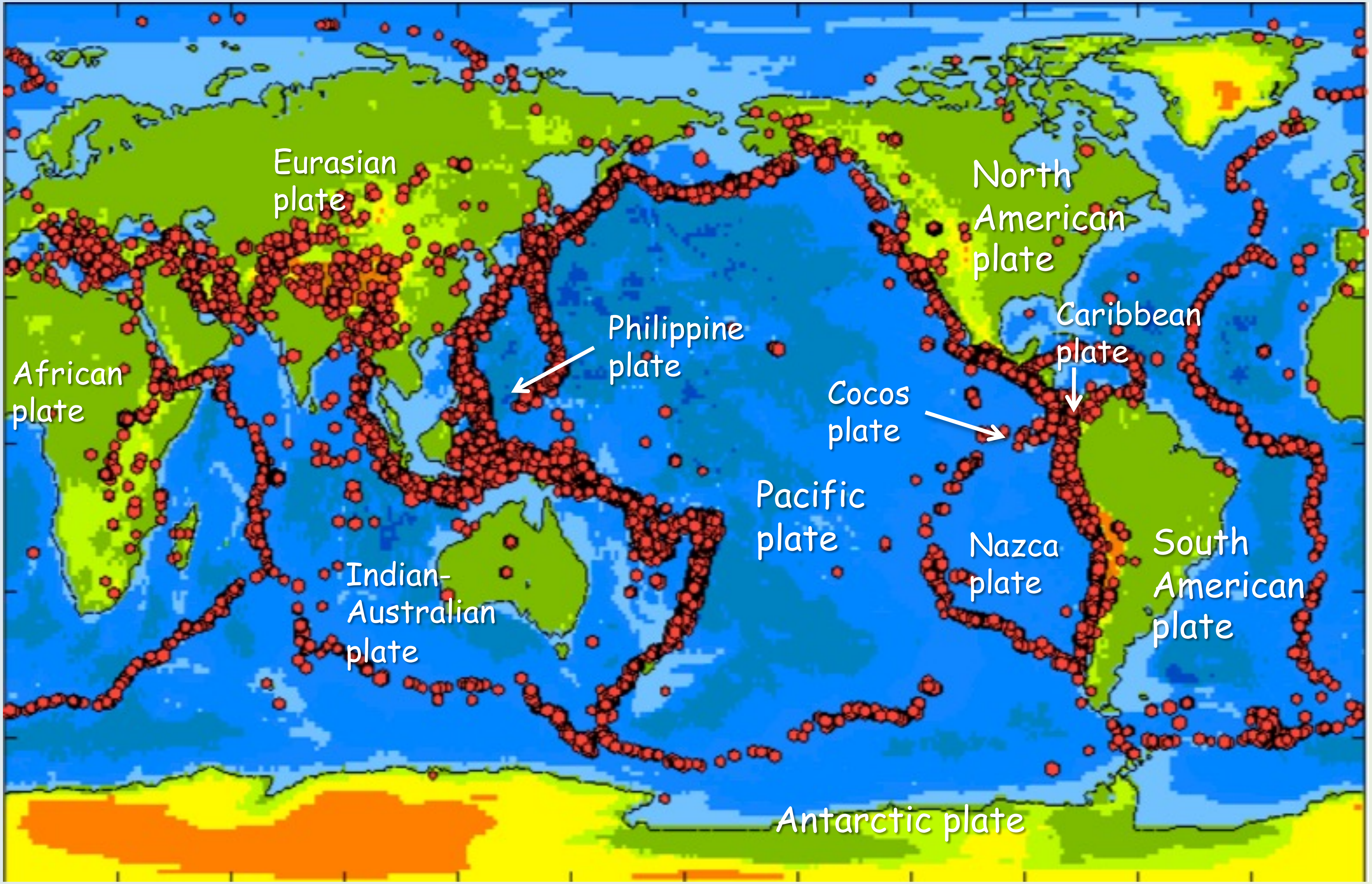


Theory of Plate Tectonics

Plate tectonics is a unified theory of the Earth that is based on three major concepts:

1. The Earth's lithosphere is divided into a mosaic of rigid segments called plates
2. The rigid plates are in motion relative to each other
3. Major structural features of the Earth form at plate boundaries (spreading ridges, island arcs, orogenic mountain belts)

Tectonic plates

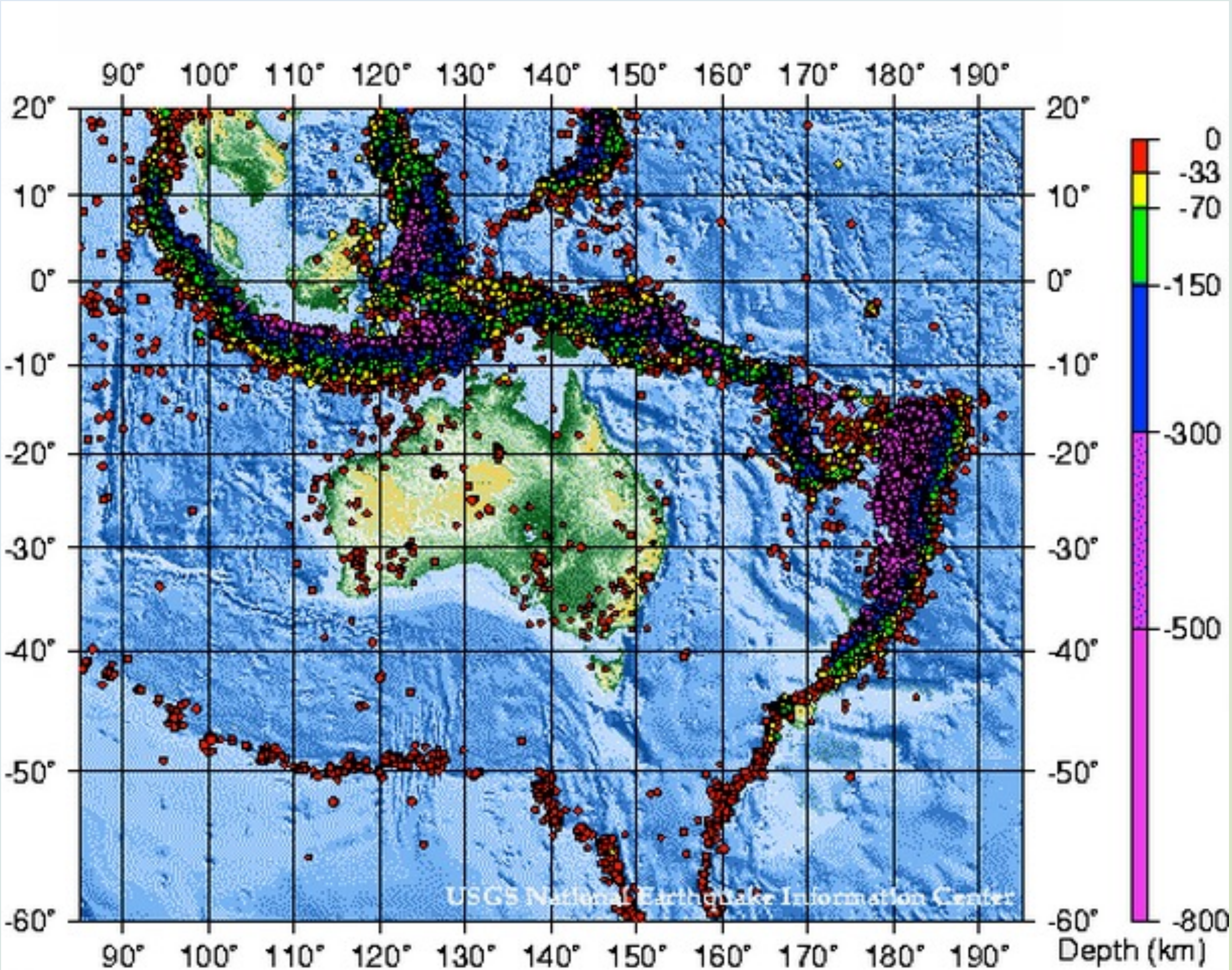


● Earthquake foci

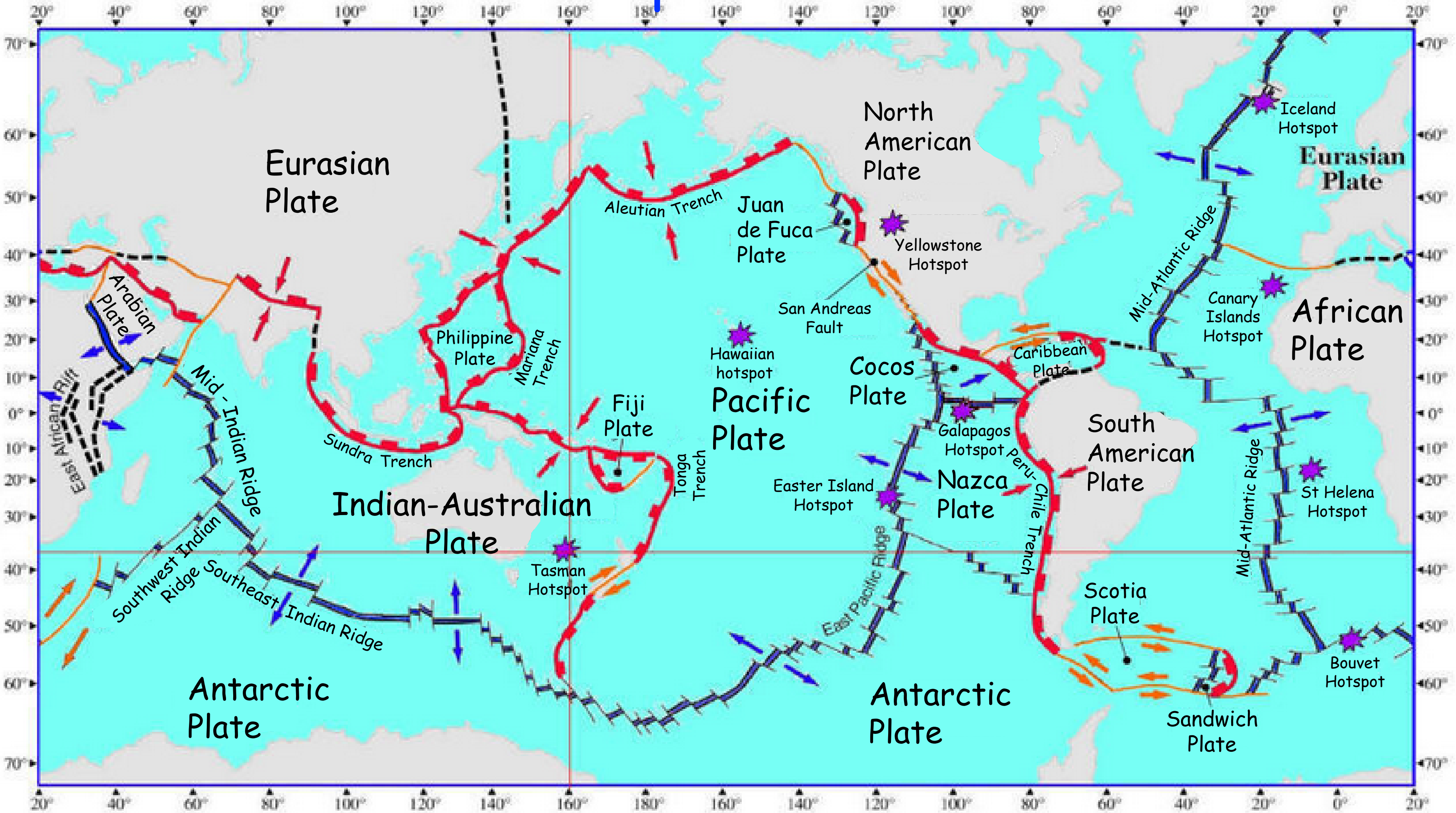
Plate boundaries and interiors

- Major geological processes (orogenesis, earthquakes, volcanoes) principally occur at plate boundaries
- plate interiors are relatively quiet geologically (except where underlain by mantle hotspots and where internal stresses produce fault movement)
- plate boundaries move towards each other, away from each other or past each other → produce major surface features
- earthquake epicentres are highly concentrated along convergent plate boundaries

Seismicity of Australia, NZ and Indonesia 1977-1997



Tectonic plate boundaries



Key

- Relative motion at plate boundary
- Transform plate boundary (transform fault)
- Divergent plate boundary (usually broken by transform faults along mid-ocean ridges)
- Convergent plate boundary (subduction zone)
- Complete or uncertain plate boundary
- Mantle Hotspot

Motion of plates

- Motions of tectonic plates are relative motions of segments of the surface of a sphere
- the motion of a plate across the surface of a sphere can be described as a rotation about one pole that passes through the centre of a sphere

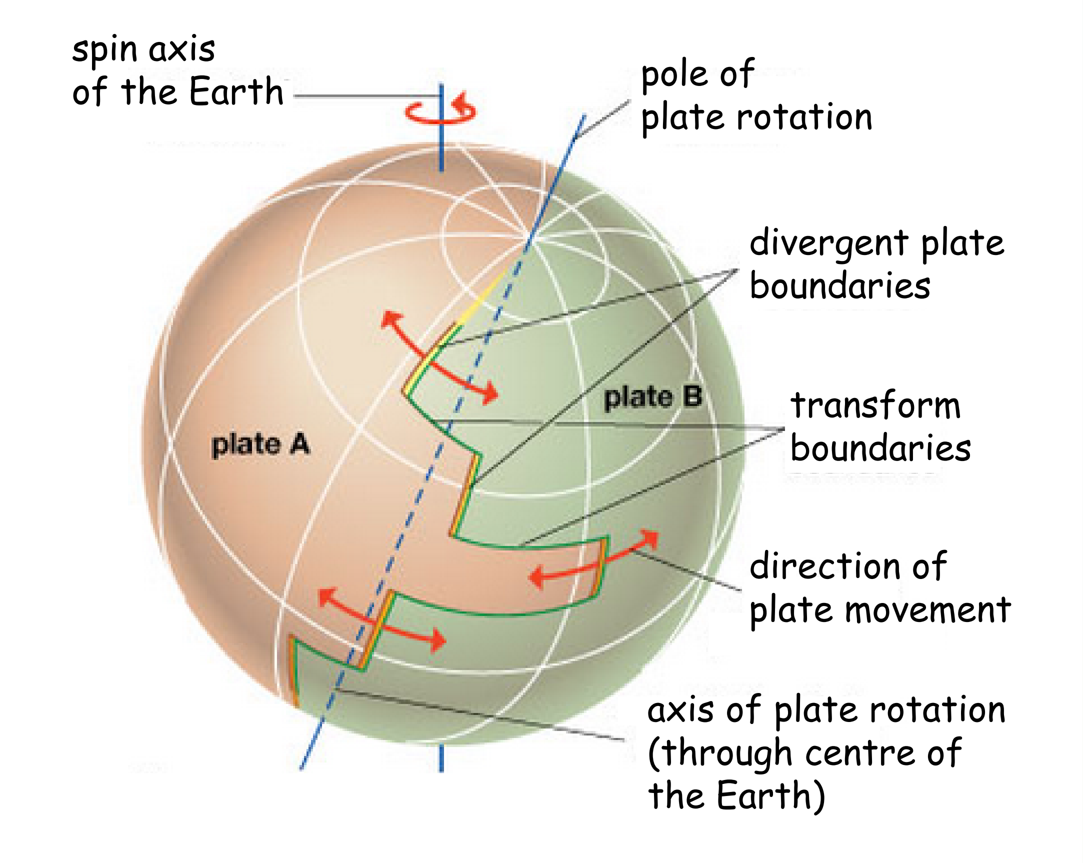


Plate motions - fundamentals

- Assume a pie shaped wedge plate B, rotating about a rotation pole with respect to a fixed plate A

  linear velocity of B w.r.t A

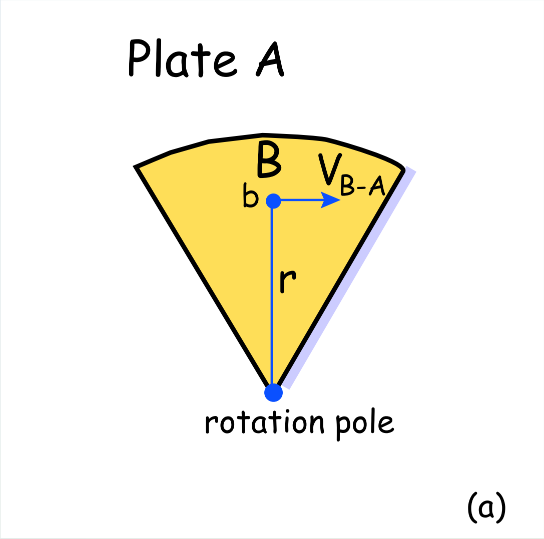
  $V_B = r \times \omega_{(B-A)}$

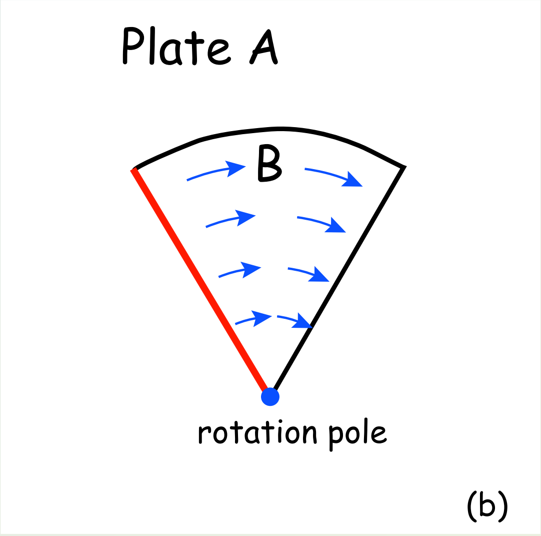
V_B = linear velocity

r = radius

ω = angular velocity

- velocities (linear) on plate B increase with distance from rotation pole





Motion of plates

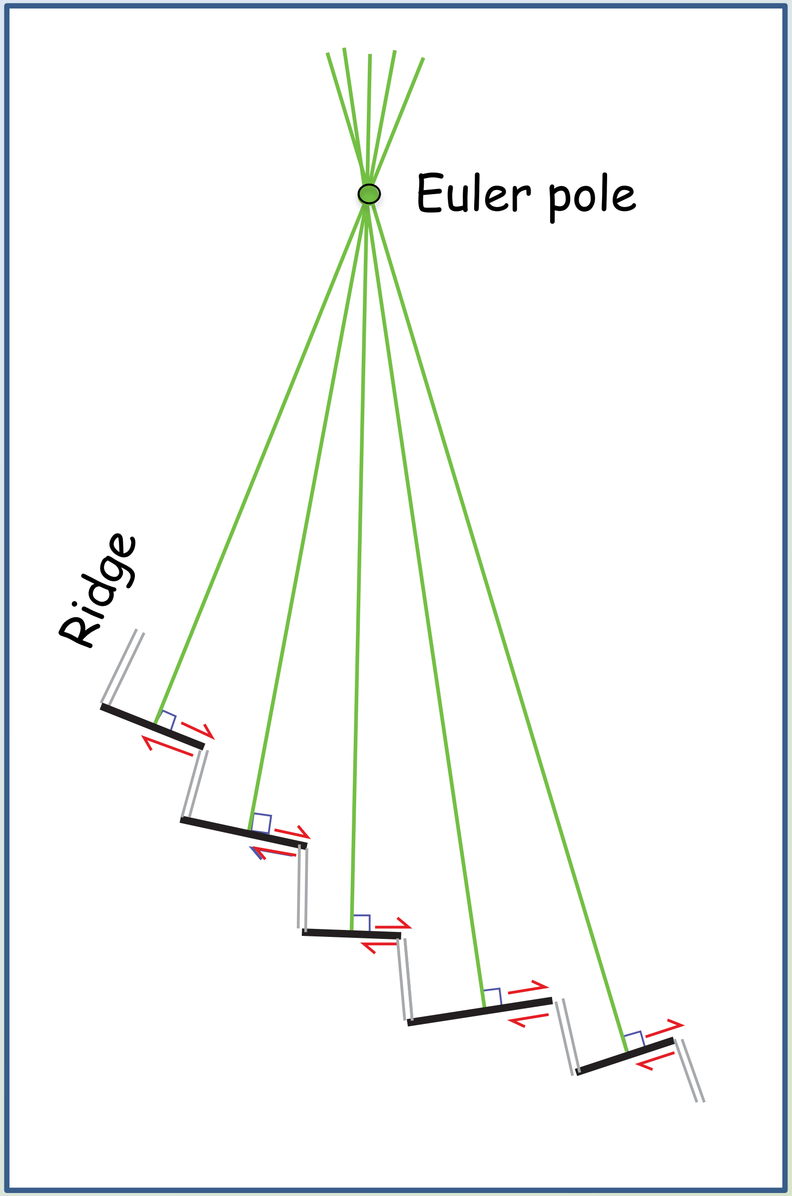
- Tectonic plates are able to move because Earth's lithosphere → stronger than underlying asthenosphere
- since plates are spherical segments moving on weak, plastic asthenosphere, the plates will creep laterally
- different parts of tectonic plate will move at different velocities → depending on their relationship to the pole of rotation
- to describe the motion → ignore geometry that works on flat plane → consider geometry of movement on surface of a sphere
- all movements of plates on surface of sphere can be described as angular movements around some pole of rotation

Euler theorem

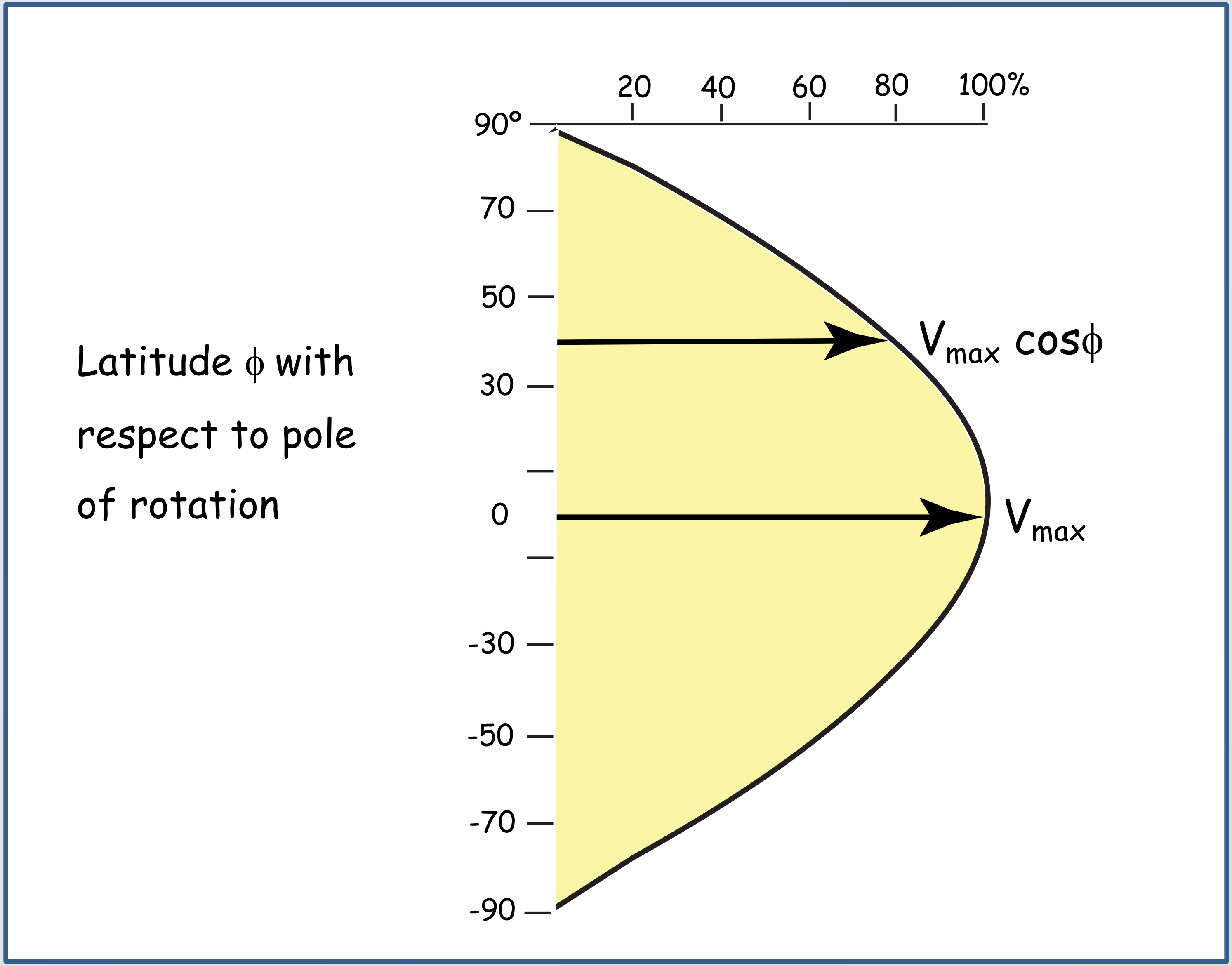
- Motion of plates over the Earth's surface is described by Euler's theorem
- " the relative motion between two plates is uniquely defined by an angular separation about a pole of relative motion → Euler pole"
- the pole is a unique point on Earth's surface → does not move relative to either of the two plates → remains fixed for long time
- position of pole can be determined by constructing great circles perpendicular to transform faults affecting common plate margin and noting their point of intersection

Determination of the Euler pole for spreading ridge

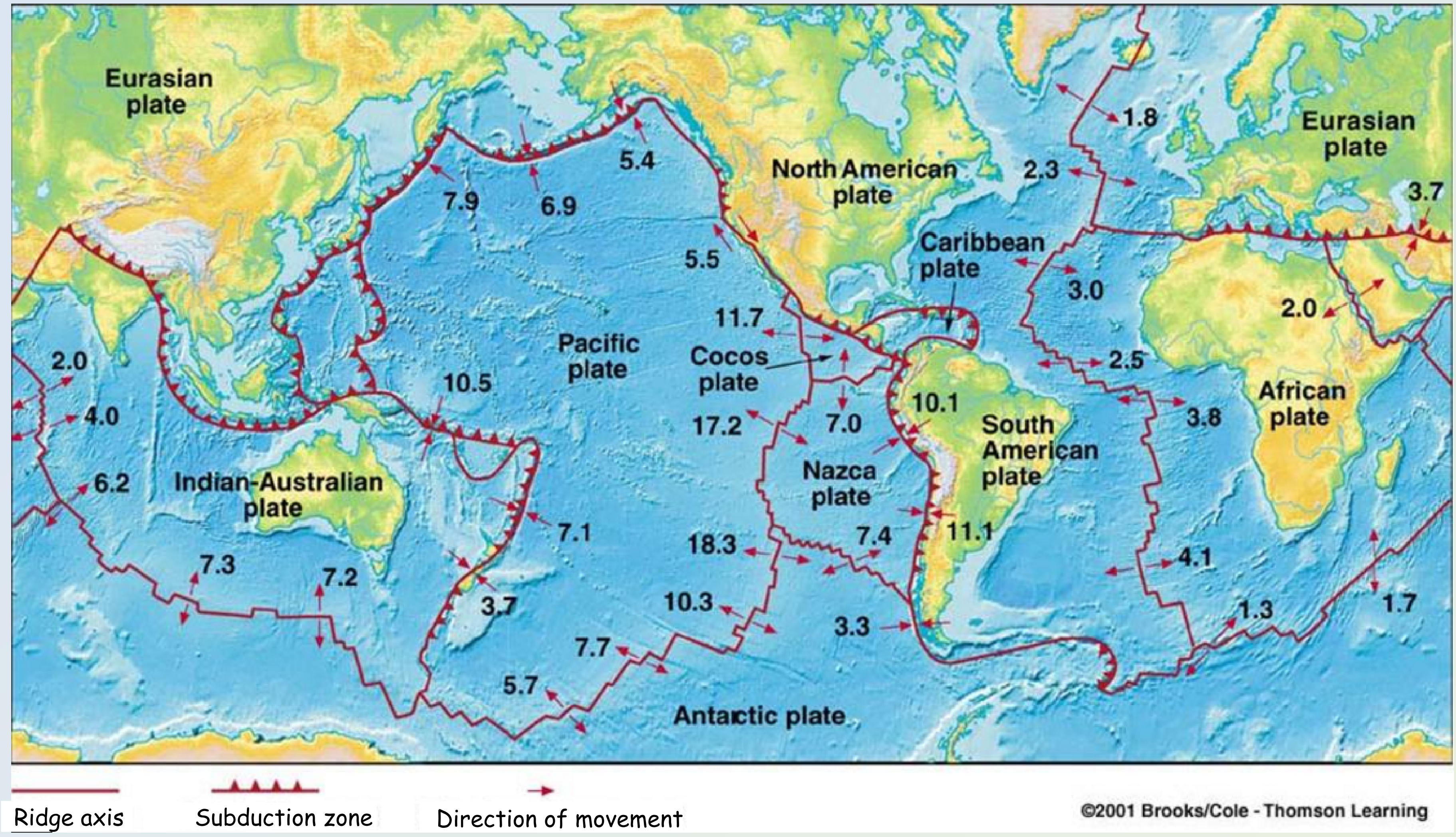
(Kearey et al. 2015)



Variation of spreading rate with latitudinal distance from Euler pole of rotation (Kearey et al. 2015)



Variations of plate movement at plate boundaries (cm/yr)



Motion of plates

Movement of plate B with respect to plate A

Transforms

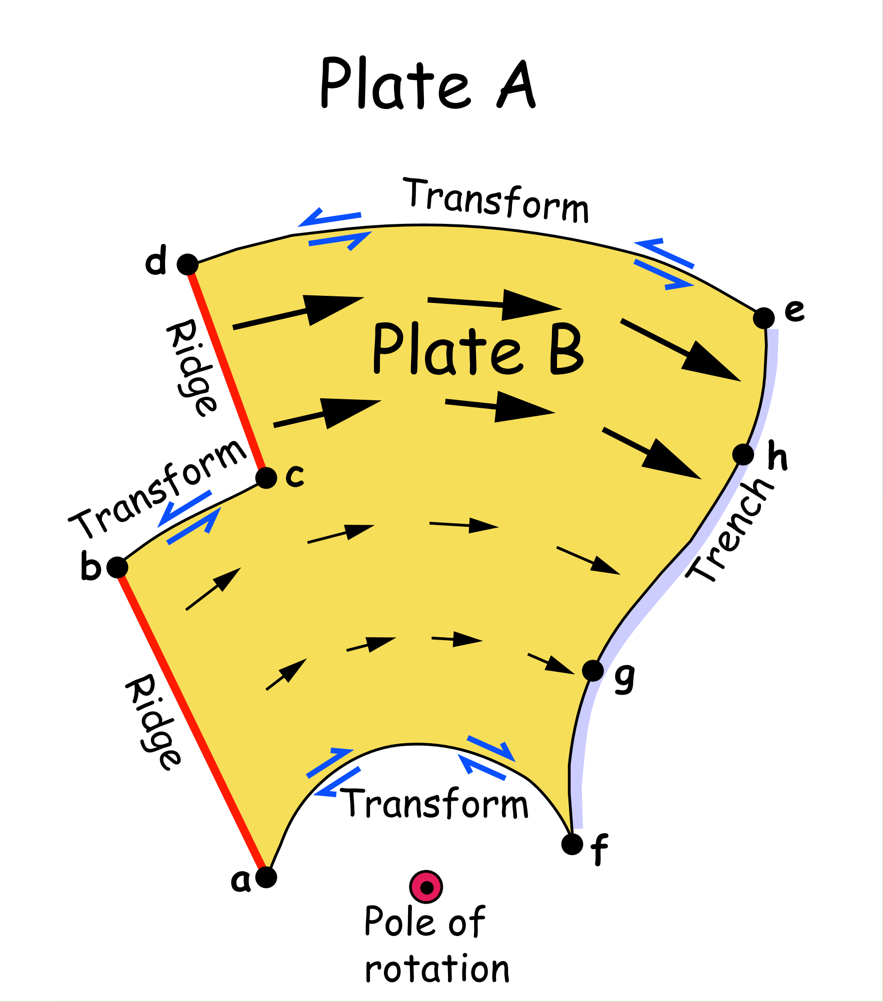
- parallel to linear velocity vectors near them

Ridges

- usually linear
- usually perpendicular to transform faults
- usually perpendicular to linear velocity vectors near them

Trenches

- usually not linear
- usually perpendicular to linear velocity vectors near them



Expanding Earth theory

- To maintain a constant-sized Earth, for every increment of plate separation, there must be compensatory convergence and subduction somewhere
- movements must sum to zero to maintain a planet of constant size
- a group of scientists supported expanding Earth theory → proposed size of Earth has increased since the Palaeozoic i.e. no convergence
- the idea of an expanding Earth has been disproven by accurate measurements using satellite positioning systems
- however, a few geoscientists still support 'expanding Earth theory'

Types of plate boundaries

Three types of relative plate motions can occur:

1. Plate edges move towards each other

   → convergent plate boundaries

2. plate edges move away from each other

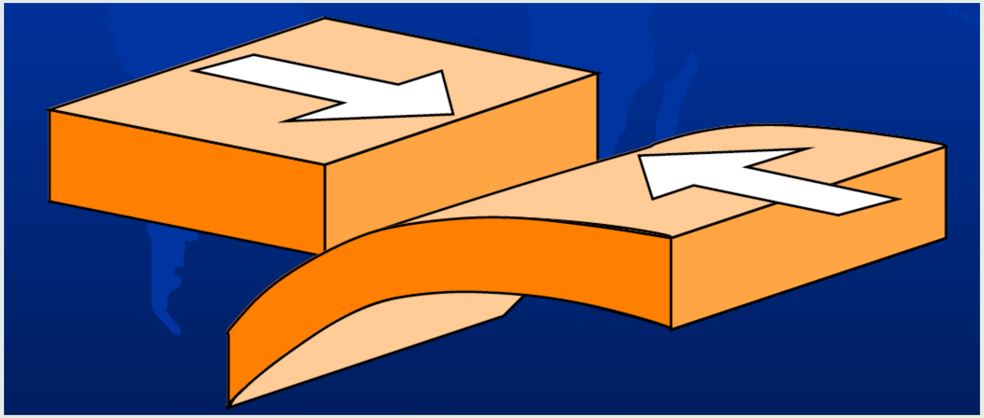
   → divergent plate boundaries

3. plate edges move past each other

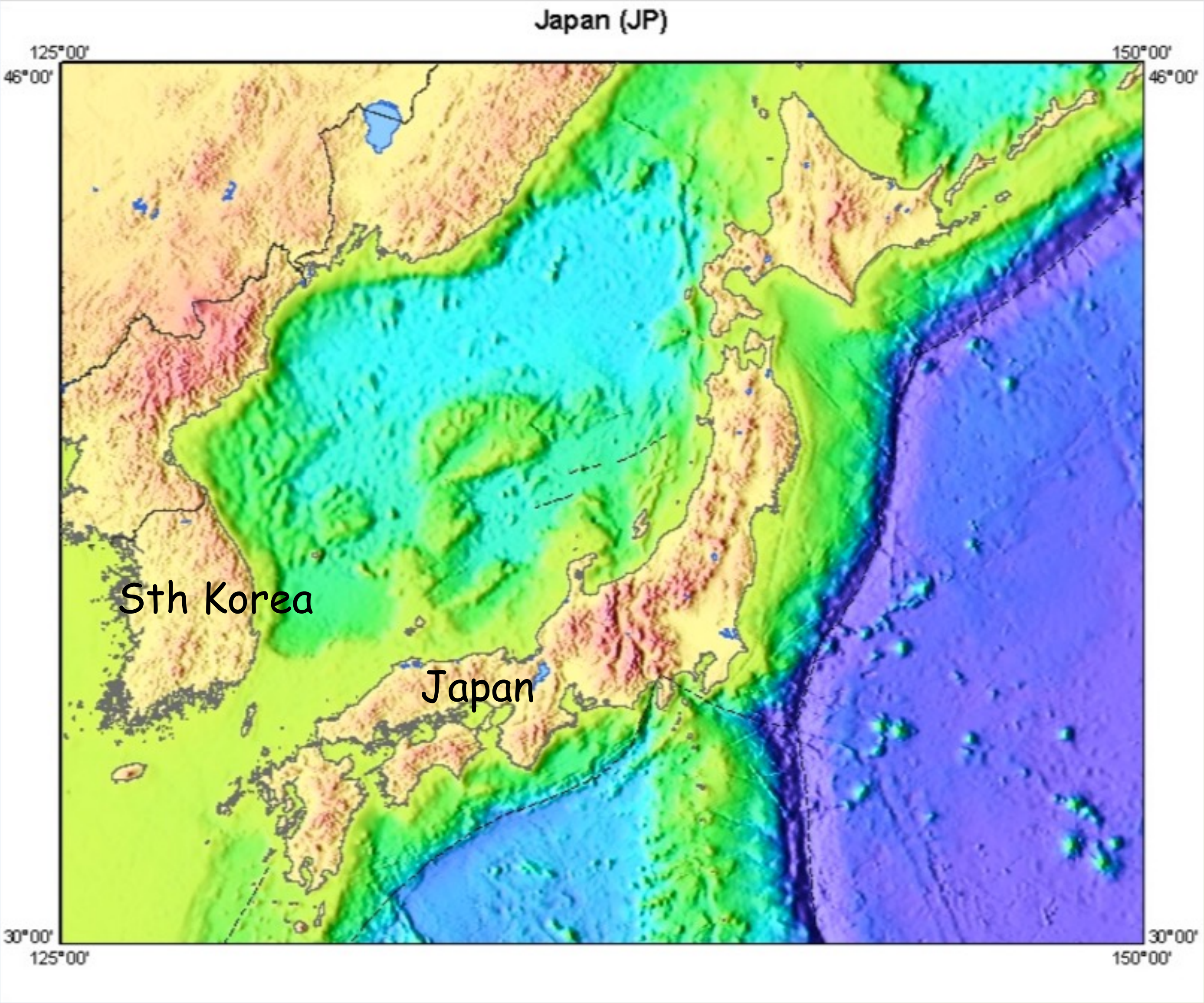
   → transform plate boundaries

Convergent plate boundaries

- Also called compressional or destructive boundaries
- plate margins move towards each other
- old lithosphere on one plate is consumed at convergent plate boundary as oceanic crust dives down into the mantle
- this process is called subduction → always involves oceanic lithosphere (denser than continental crust)
- examples of convergent plate boundaries are island arcs and continental collision zones



Convergent plate boundaries

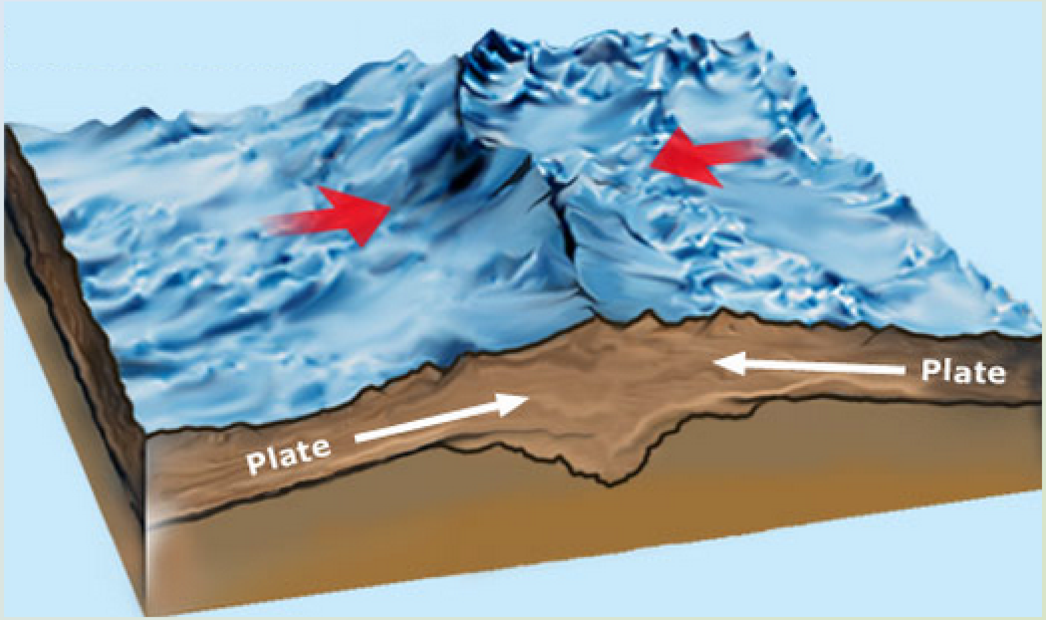


Topographic map of part of western Pacific

Convergent plate boundaries

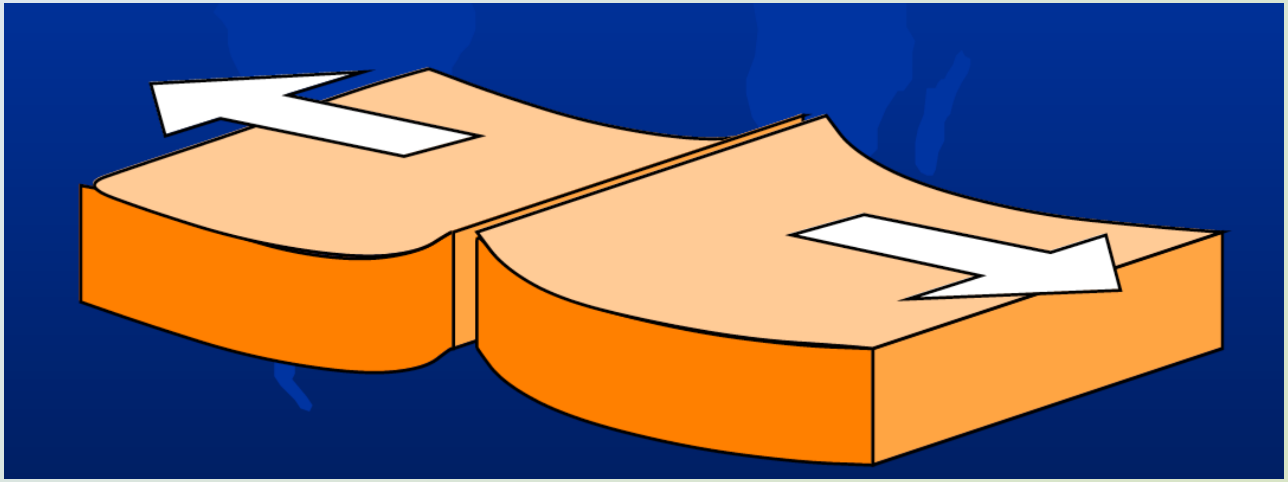
- Where continental plates converge without subduction there is tremendous compression forming mountain belts e.g. Himalayas, European Alps

- these are zones of frequent earthquake activity, thickening of the continental crust



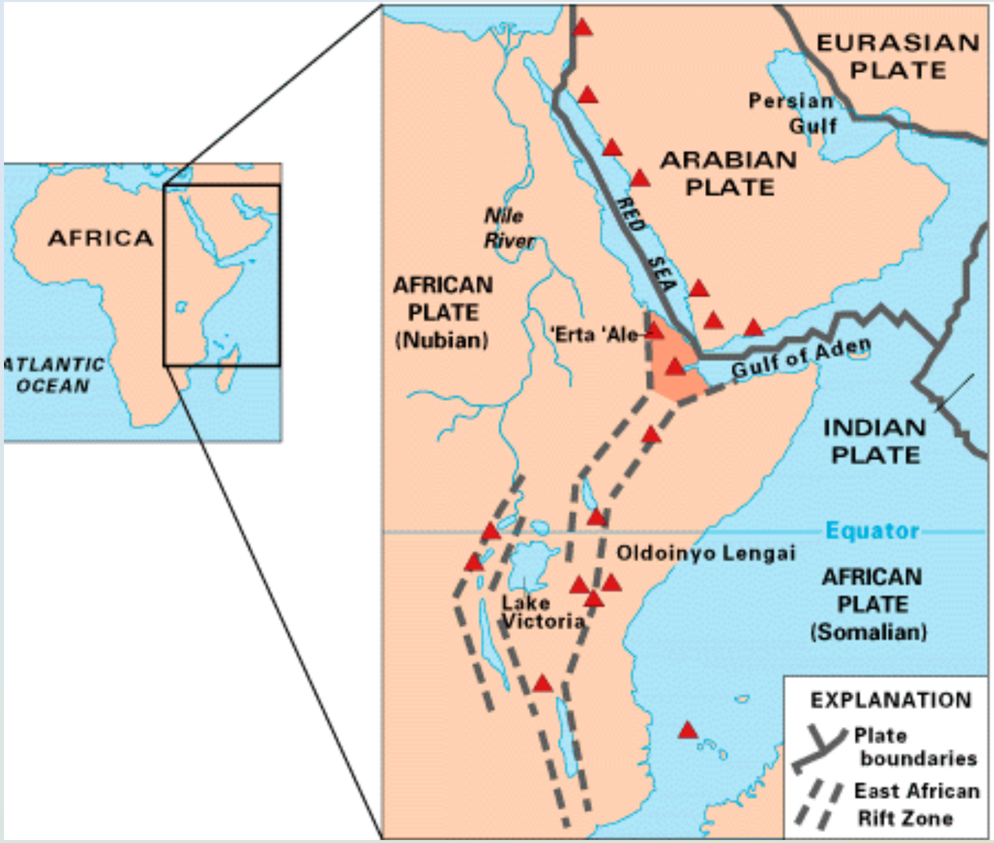
Divergent plate boundaries

- Also called extensional or constructive plate boundaries
- plate boundaries pull apart from each other
- new crust is generated by magmas flowing upwards from the asthenosphere to fill the gap



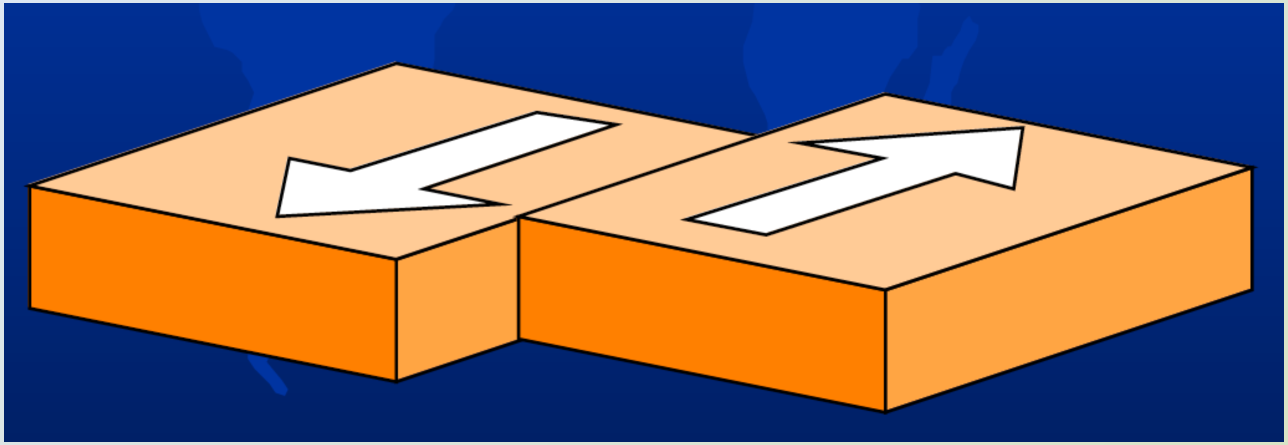
Afro-Arabian triple junction

- Triple junction → location where 3 tectonic plates intersect
- plate boundaries are all rift boundaries
- Afro-Arabian triple junction is the only R-R-R triple junction above sea level where all three plate boundaries are rifts
- volcanic activity in Red Sea and East African rift



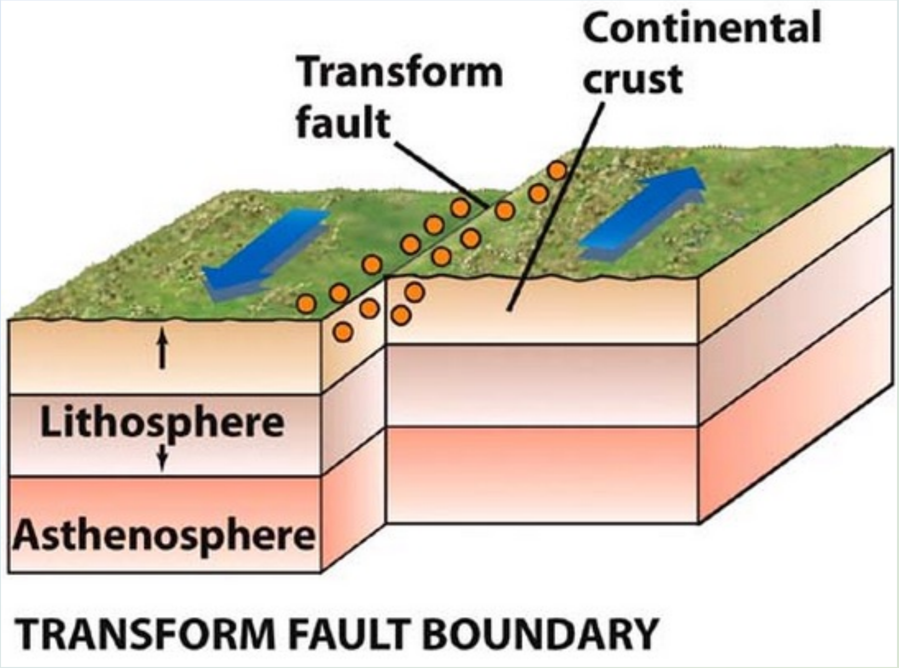
Transform plate boundaries

- Also called transcurrent conservative plate boundaries
- plates move sideways past one another e.g. San Andreas fault
- lithosphere is neither destroyed nor generated



Transform plate boundaries

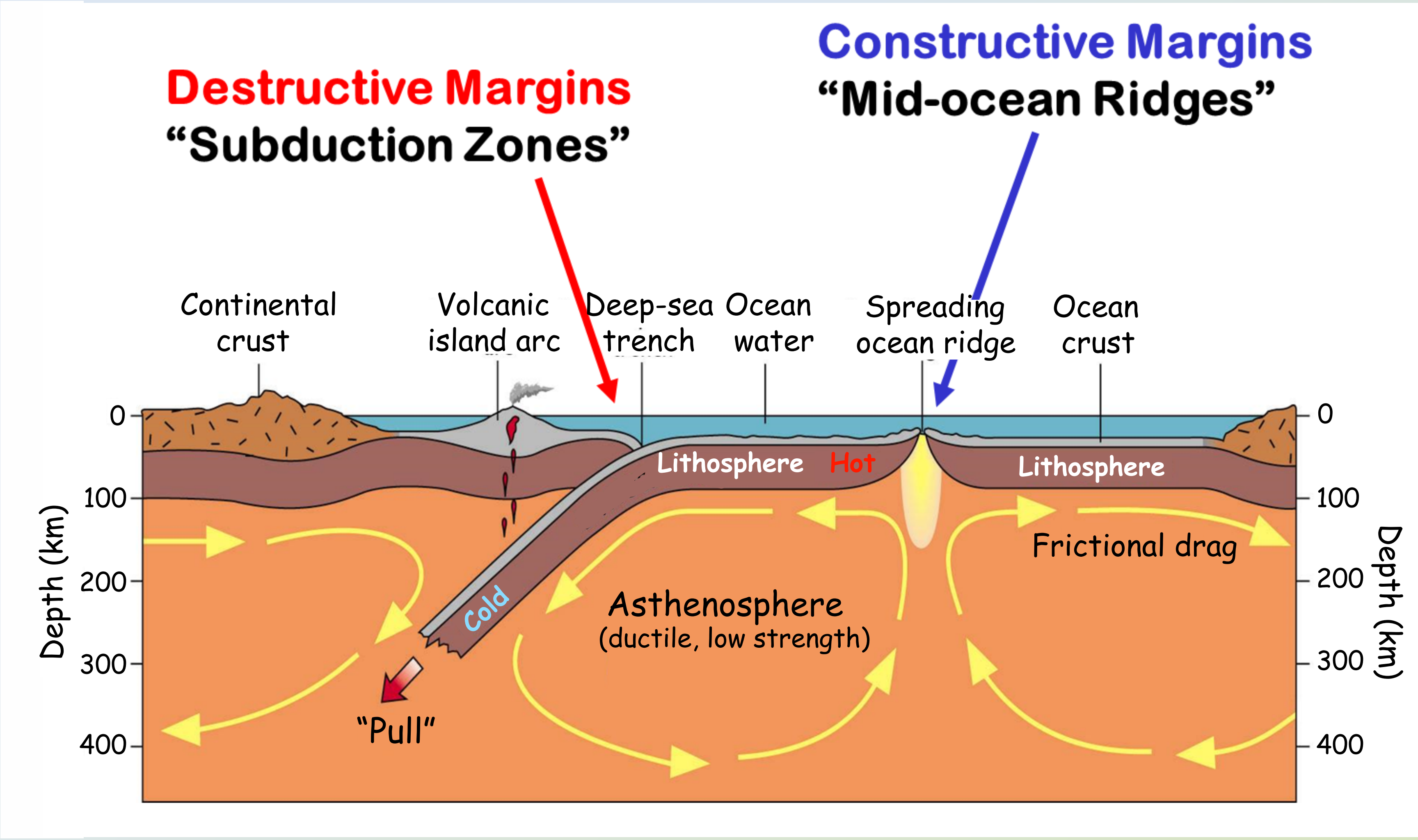
Examples of transform faults include the San Andreas Fault and the Great Alpine Fault of New Zealand



San Andreas Fault

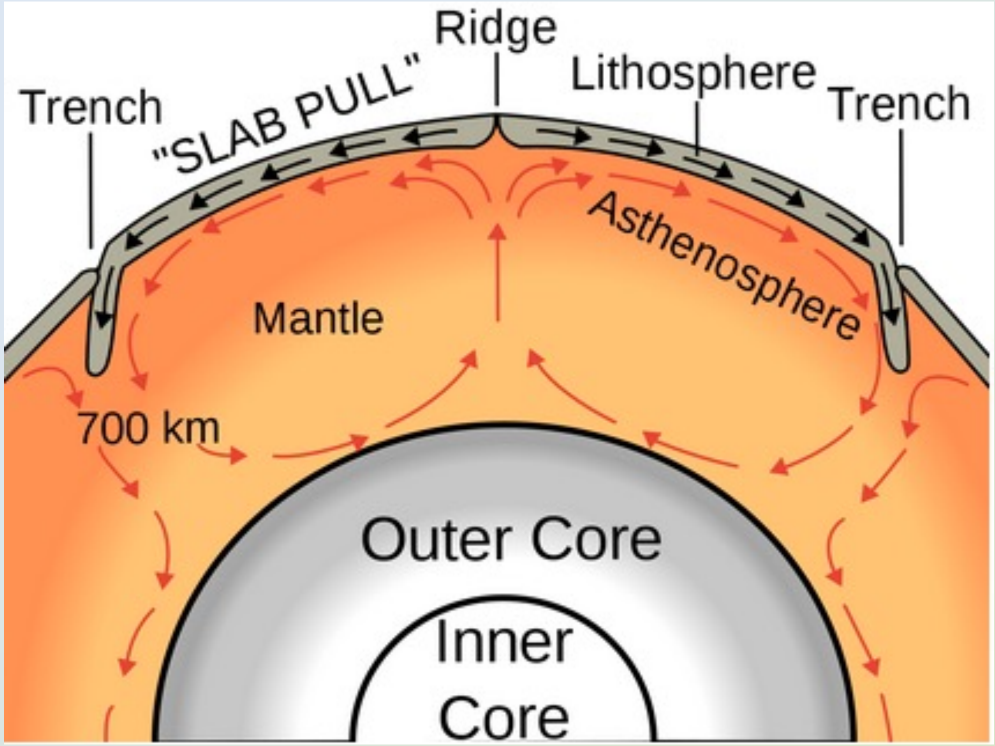
Driving mechanism of plate tectonics

- Driving mechanisms of plate tectonics → not fully understood
- plate motions → consequence of convection in the mantle



Convection in the mantle

- Convection in the mantle → driving mechanism of plate tectonics
- in mantle → hotter areas rising, colder areas descending
- rising convection currents → crustal extension
- descending cold convection currents → plate convergence
- mantle and lithosphere are decoupled by weak asthenosphere



Motion transfer mechanisms

- Convective motion in the mantle can be transferred to the lithospheric plates → ridge push force and slab pull

Ridge push force

- at spreading ridge → new crust generated → crust thin and hot
- magma is injected into gaps at extensional plate boundaries → pushes plates apart
- ridge push force → relatively weak

Slab pull force

- leading edge of cold, dense slab → descends into warm dense mantle
- exerts pull force on lithospheric plate
- aided by suction of descending mantle
- where it descends, plate is thicker, older and very cold and dense

Transfer mechanisms