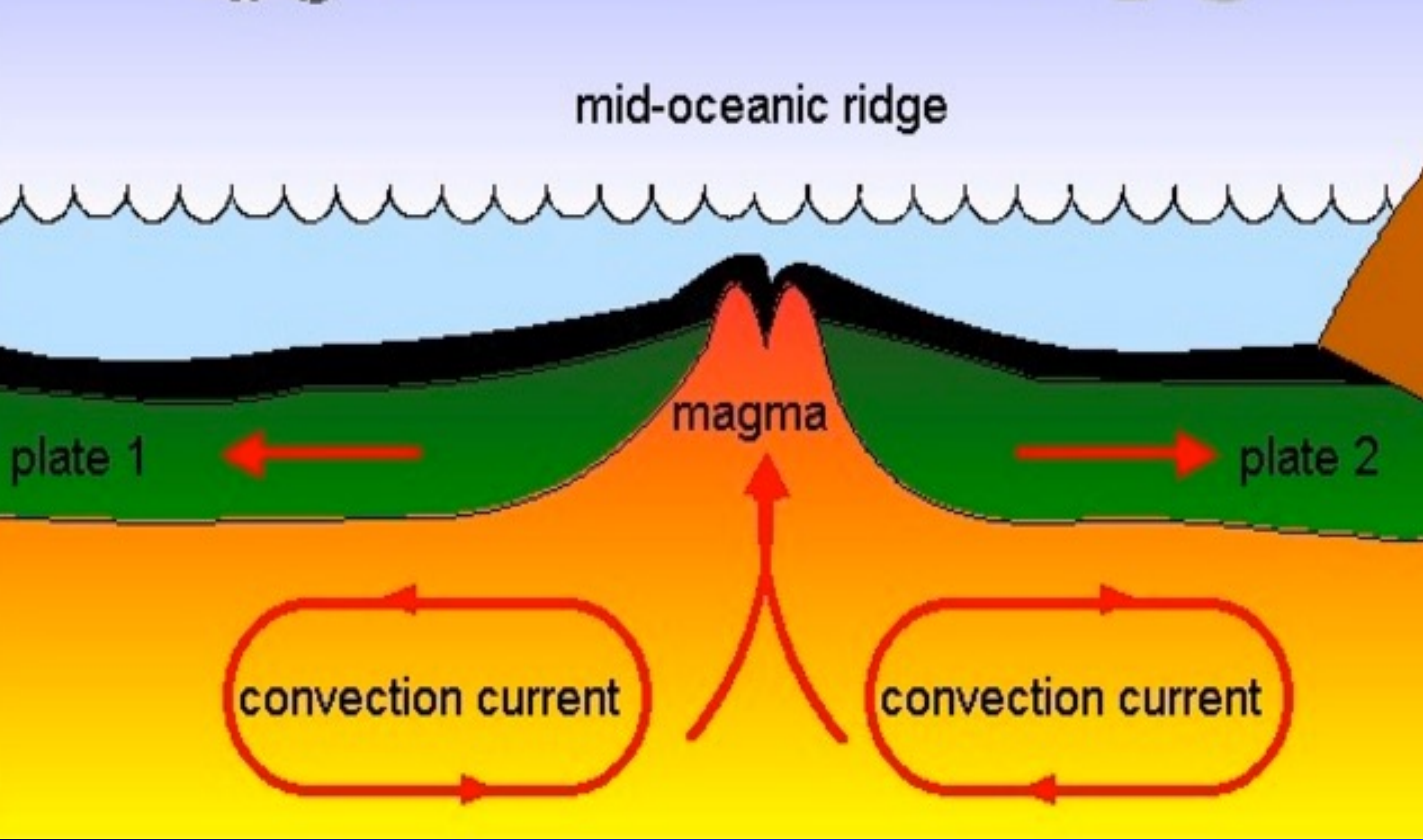
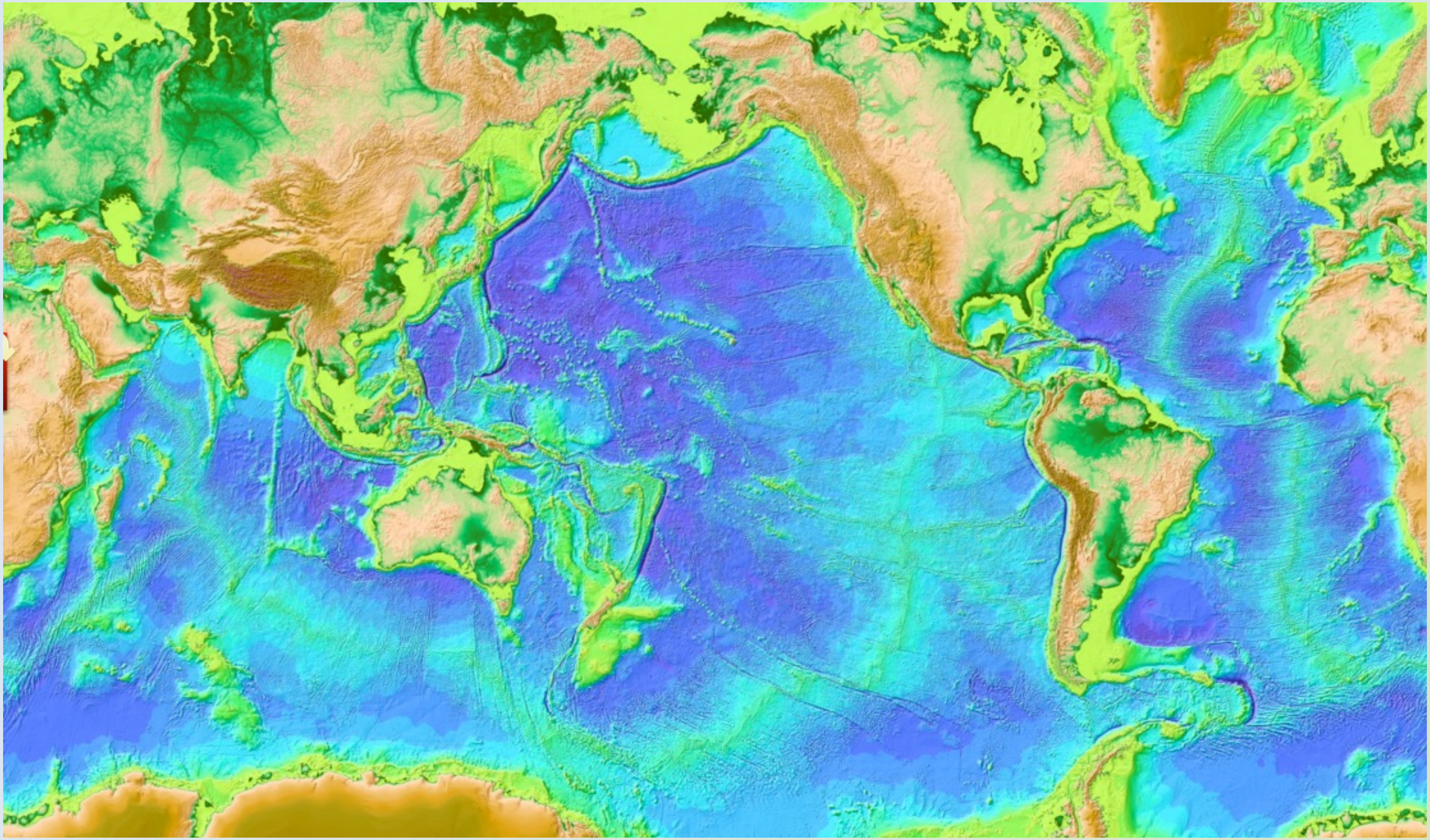
U3A Plate Tectonics 5
Sea floor spreading



Introduction

- By the end of the 1950s much evidence was appearing about the sea floor
- new technologies developed during WWII provided much information
- techniques enhanced and developed post war
- the world-circling ocean ridge had been identified

Seafloor topography



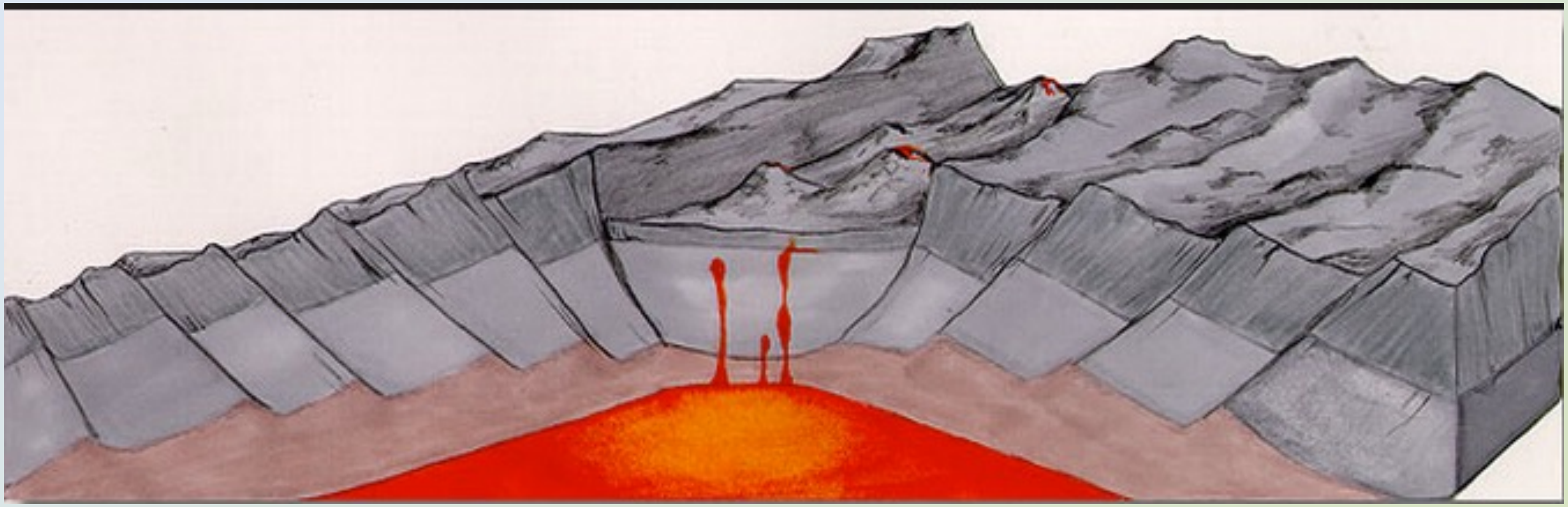
Global seafloor topography from gravity data derived from satellite altimetry

Understanding the ocean ridge system

- Every part of the 64,000km ridge system is connected
- understanding of ridge system → fundamental to understanding the way the Earth works
- it was recognised that the central rift valley along the ocean ridges was an extensional feature due to tension in the rocks
- it became clear from coring and dredging that the oceanic rocks are much younger than the continents (oldest 180myr)
- heat flow was known to be higher along the ridges

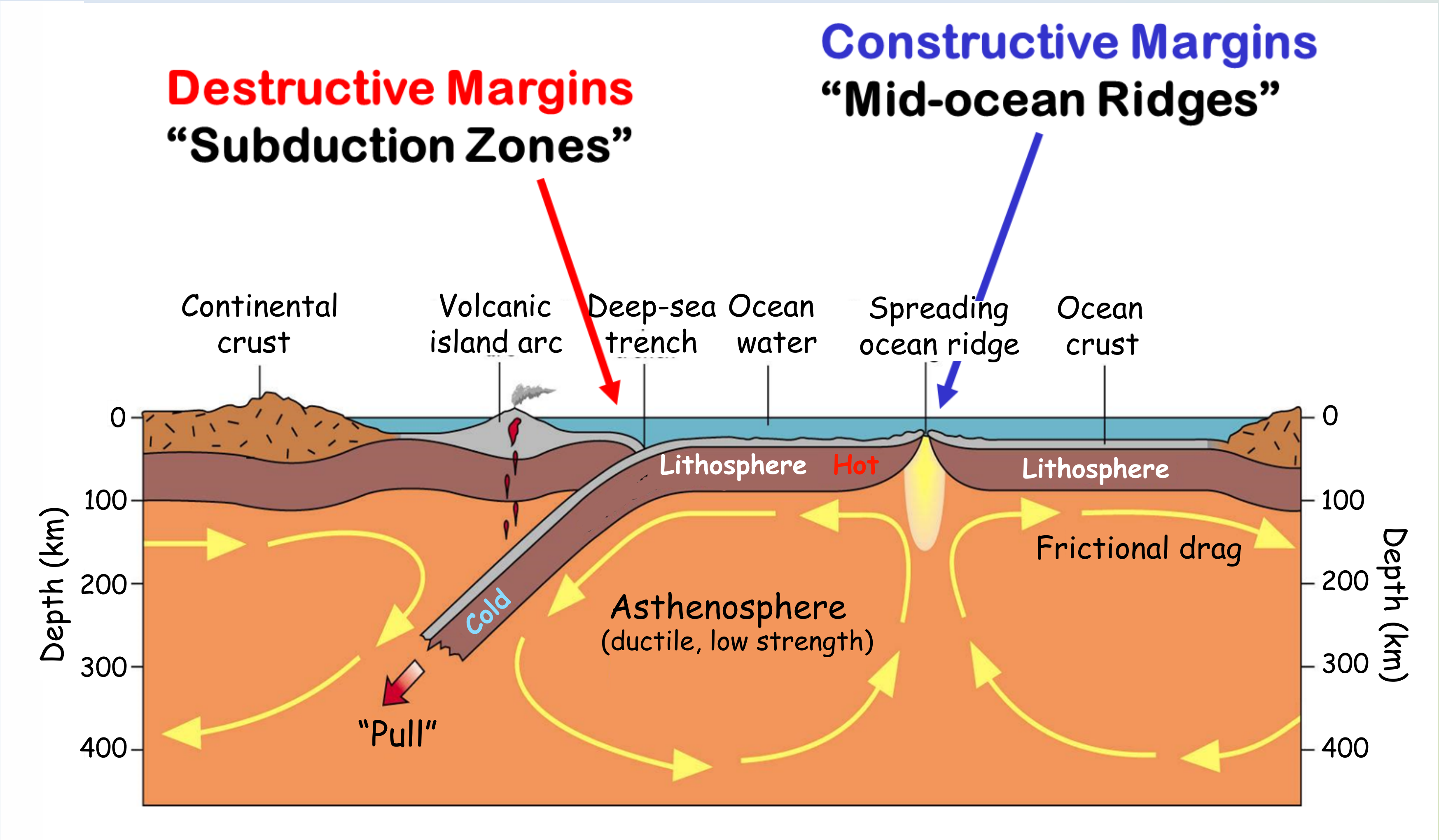
Mid ocean ridges

- Rise 3000m above ocean floor, more than 1500km wide
- ridge length bisected by deep trough (up to 2000m deep)
- they are zones of high heat flow, elevated earthquake activity and submarine volcanism



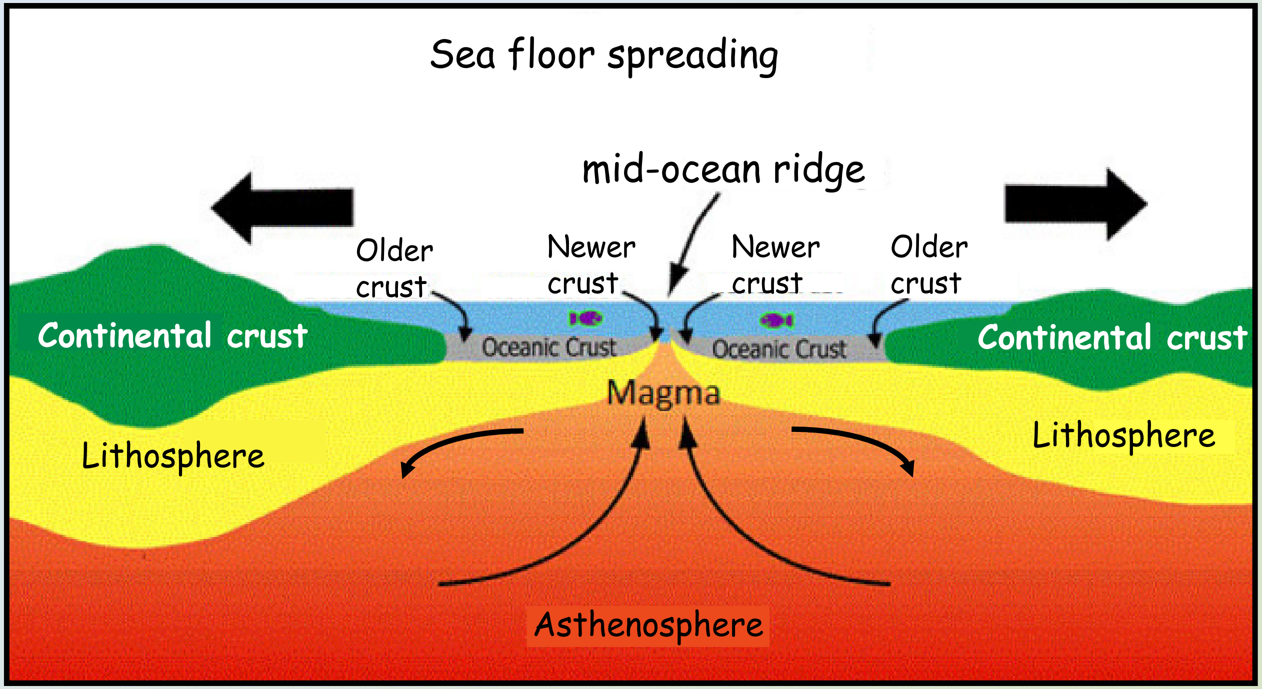
Driving mechanism of plate tectonics

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



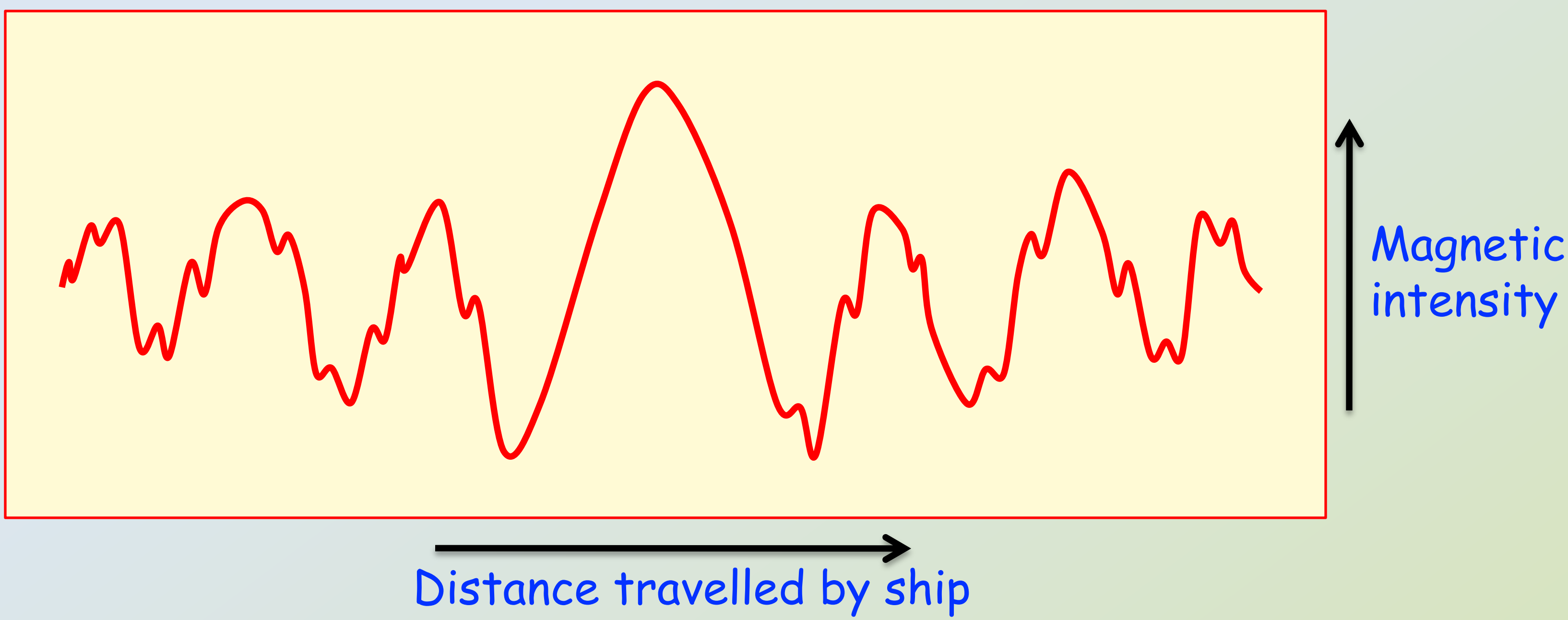
Sea floor spreading

- In 1962, Harry Hess from Princeton University wrote an essay to explain observations of sea floor → "Exercise in geopoetry"
- Hess proposed → major structures of the sea floor resulted from convection in the mantle → tension below mid-ocean ridges
- he called the concept "sea floor spreading"



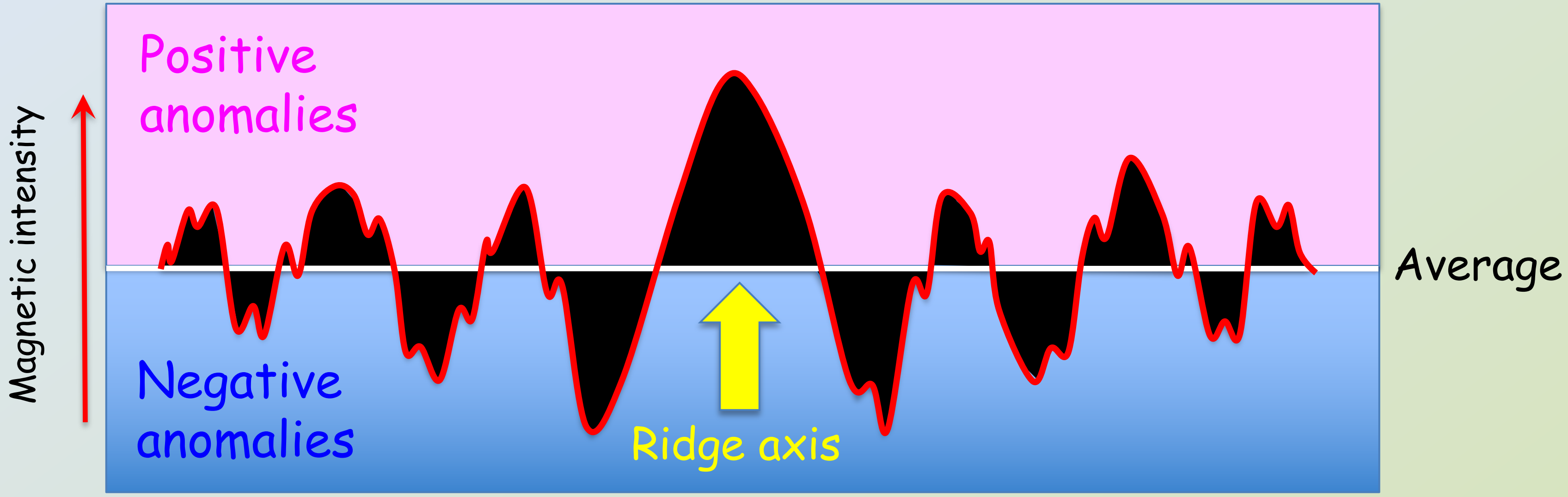
Magnetic measurements at sea

- Between 1955 and 1960, the first detailed magnetic surveys of the oceans were made using sensitive magnetometers
- these showed that the magnetic field had small but very regular variations called anomalies caused by rocks in the ocean crust
- these variations alternated between higher (positive) and lower values (negative anomalies) in a regular, systematic way



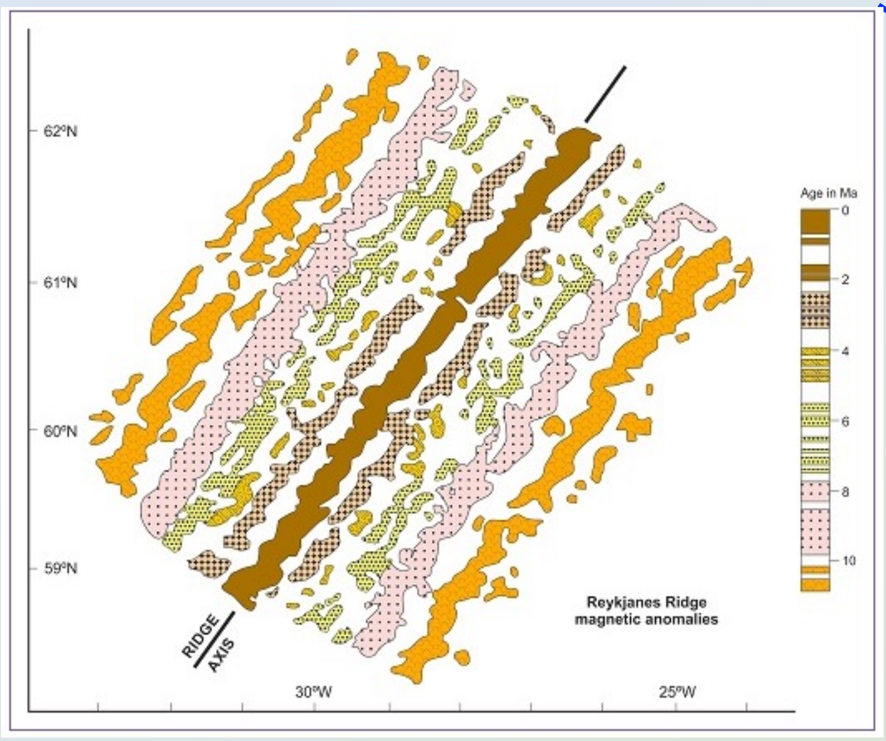
Magnetic anomalies on the sea floor

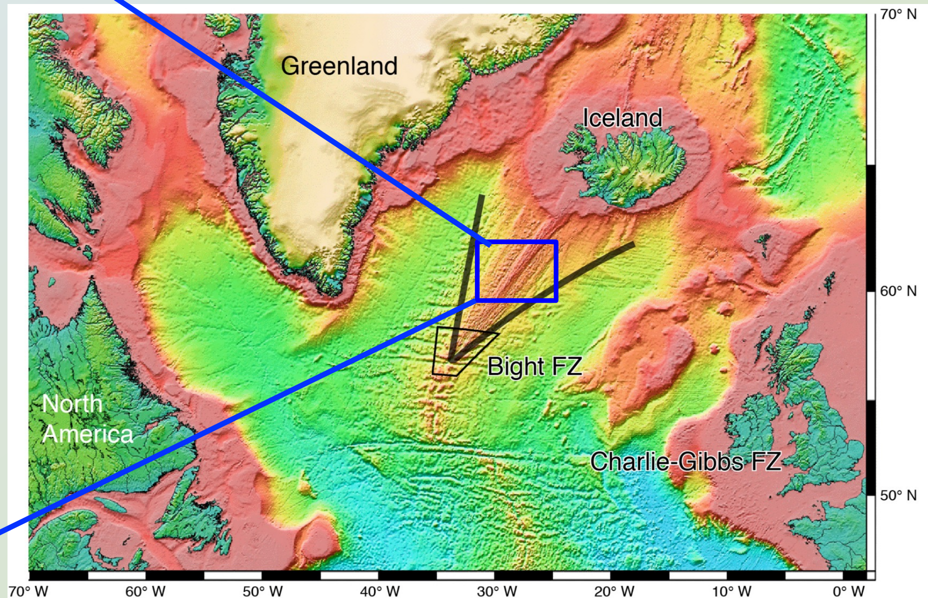
- When plotted on a map, the anomalies were found in long parallel stripes about 10-20km wide
- pattern of stripes are symmetrical about the central axis of the oceanic ridge
- patterns of stripes can be traced over thousands of kms
- the anomaly over the ridge axis is always positive



Magnetic anomalies, Reykjanes Ridge

- Simplified maps show the positive anomalies in coloured bands and negative anomalies in transparent bands
- the patterns are unique to the ocean floor (not observed on land)
- similar patterns are found in all of the oceans

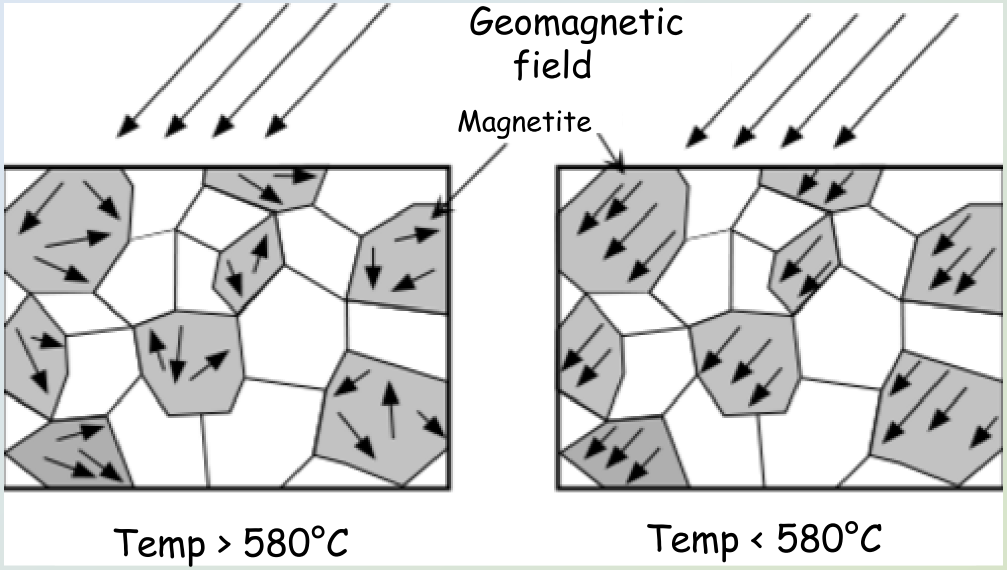




Central rift, þingvellir Iceland

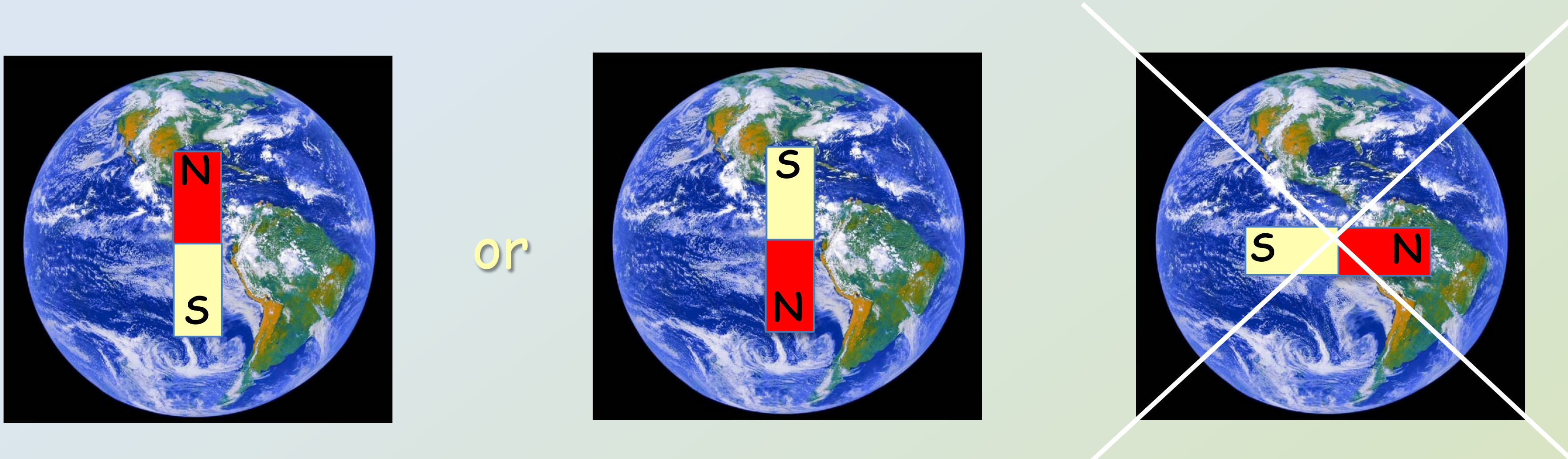
Ferro/ferrimagnetic minerals

- Ferrimagnetic minerals are magnetic in absence of a magnetic field e.g. magnetite, pyrrhotite, some garnets
- materials only ferro/ferrimagnetic below their Curie temperature
- Curie temperatures → critical temperatures at which ferrimagnetic minerals lose their magnetic properties
- at temperatures below Curie temperature → ferro/ferrimagnetic minerals retain their induced magnetism → remanent magnetism



Magnetic field reversal

- Earth's magnetic field periodically reverses polarity
- reversals mostly occur over 1,000 to 10,000yrs (some much quicker)
- duration of reversal <500 to 1,000,000yrs
- last major reversal 780,000yrs ago (brief reversal 41,000yrs ago)



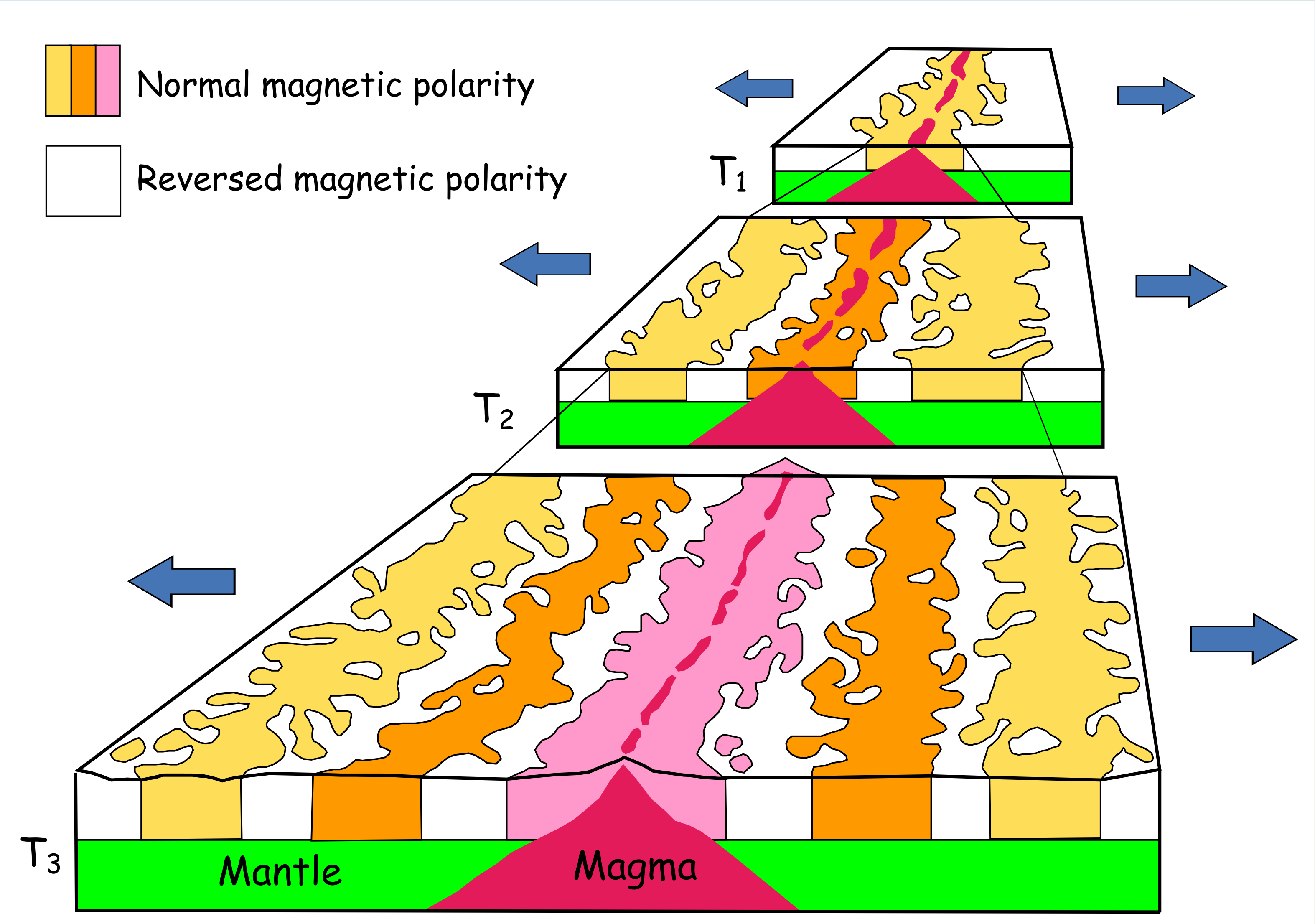
Vine-Matthews-Morley hypothesis

- In 1963, Fred Vine, Drummond Matthews and Lawrence Morley explained magnetic anomalies
- they proposed that magnetic stripes are due to strips of ocean crust being magnetised in different directions at different times
- normally magnetised rocks add background magnetic field at a locality → positive anomaly
- reversed magnetised rocks subtract from it → negative anomalies
- as plates move apart, new basalt is intruded along the ridge axis, recording the magnetic field at the time
- due to sea floor spreading the oceanic crust acts like a giant recorder of the history of the Earth's magnetic field

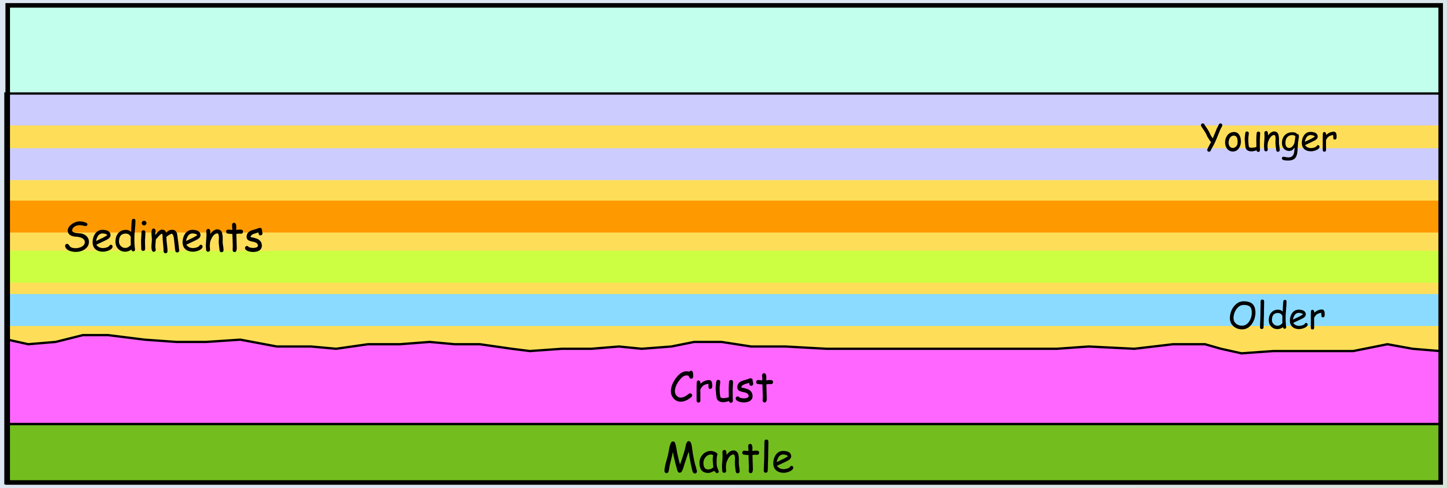
Formation of magnetic stripes on sea floor through sea floor spreading

- Today → positive magnetic anomaly along ridge axis → flanked by alternating negative and positive anomalies
- each stage produces a polarity that is split down the middle and rafted off to each side
- as spreading occurs → produces continuous reading of Earth's magnetic field
- as new basalt is injected along ridge axis and cools → records magnetic field

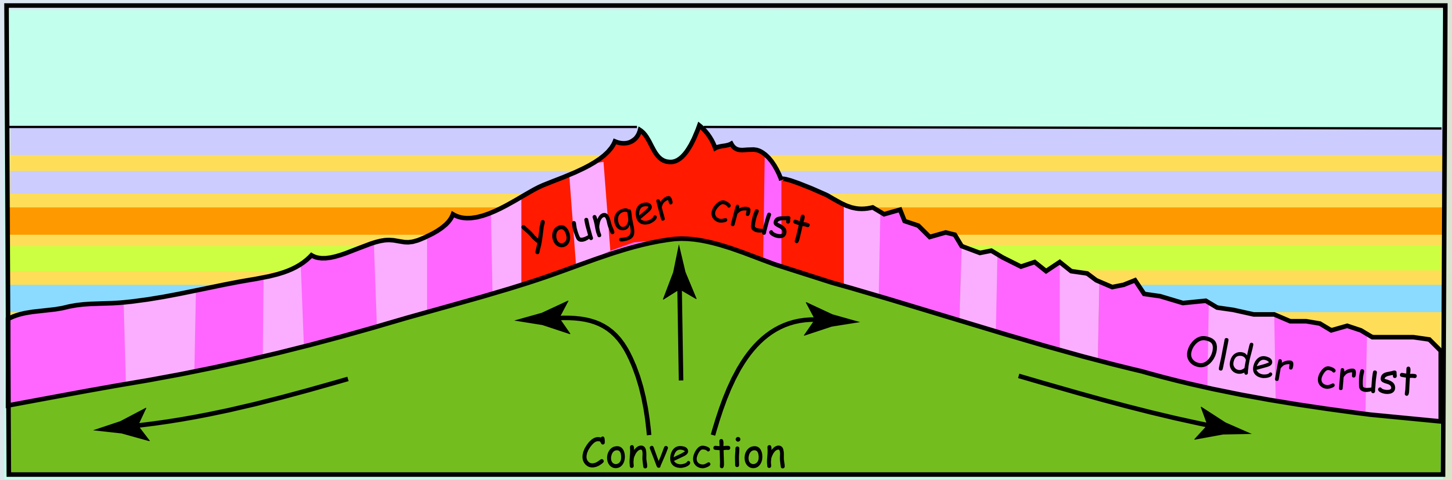
Formation of magnetic stripes on sea floor through sea floor spreading



Seafloor spreading magnetic pattern



Seafloor magnetic pattern expected in an ocean basin without seafloor spreading



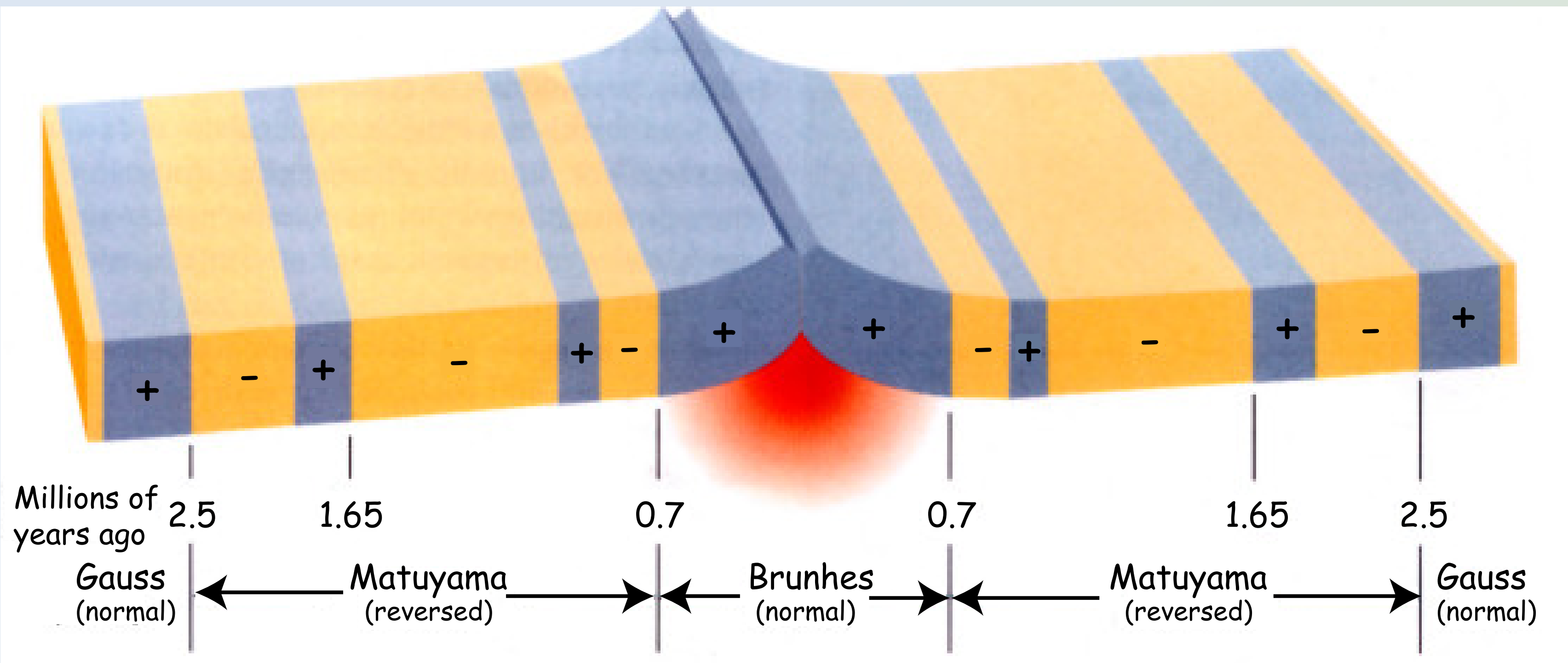
Seafloor magnetic pattern expected in an ocean basin with seafloor spreading

Dating of the sea floor

- The sequence of oceanic crustal magnetic anomalies exactly matches the reversals observed on land
- scientists devised a palaeomagnetic timescale
- particular anomalies can be matched to well-dated reversals on the palaeomagnetic scale
- particular anomalies have a distinctive shape and can be recognised on a global scale
- the age of the oceanic crust and sea floor spreading can therefore be calculated
- spreading rates vary between 1-20cm/year
- oldest oceanic crust is only about 180 Ma old

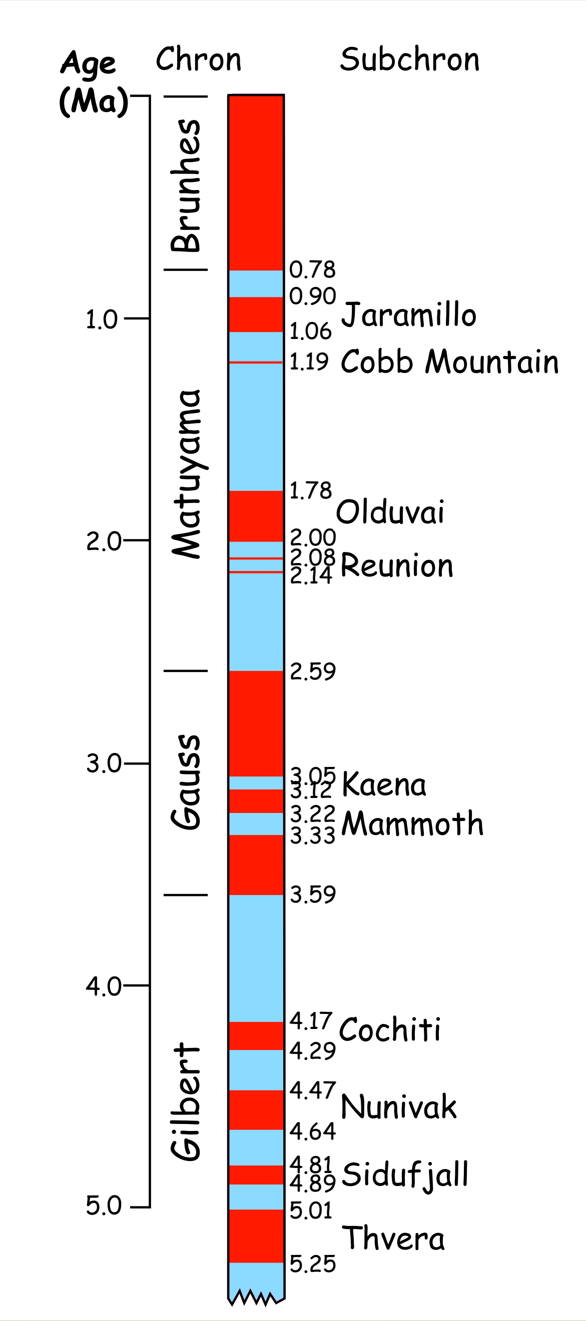
Seafloor magnetic anomalies and Palaeomagnetic time-scale

Palaeomagnetic timescale constructed from K-Ar dating on continental and ocean island lavas



Geomagnetic reversal

- Occurs when magnetic north and magnetic south are interchanged
- large periods are called chrons
- smaller periods are called subchrons
- transition periods → 1,000 – 10,000years but as short as decades
- magnetic fields generated by dynamo action in core
- instability causes magnetic field to flip

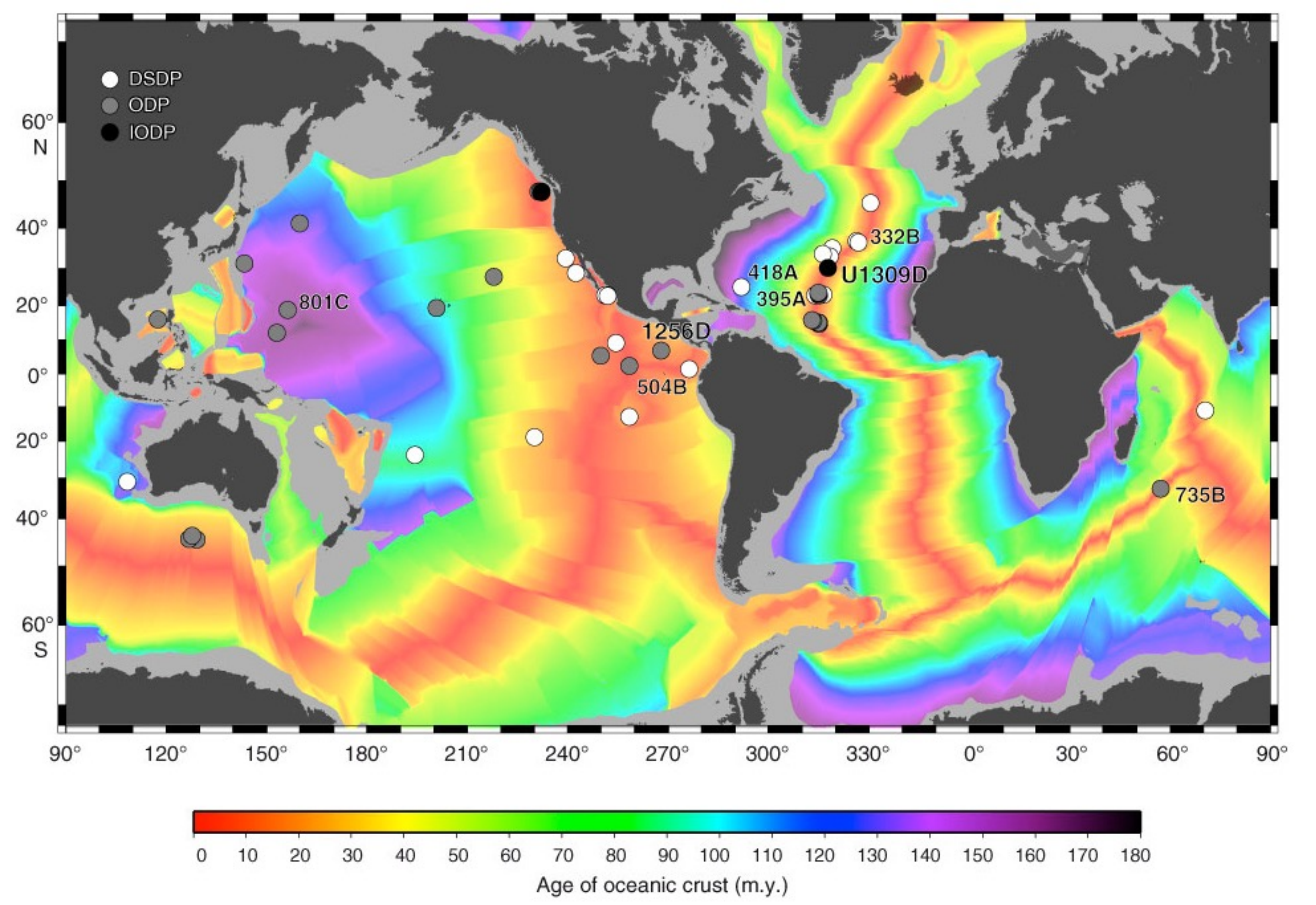


Geomagnetic polarity during the last 5myr

Age of oceanic crust

- Looking at a global image showing distribution of ages of oceanic crust we observe ages from zero up to 180myr
- only places where there are old magnetic anomalies → western Pacific
- magnetometry of the seafloor shows seafloor spreading rates → 1-20cm/yr
- the fastest rate is along the edge of the East Pacific Rise is in between 1-20cm/yr

Age of oceanic crust



Confirmation of sea floor spreading

- Results from the Deep Sea Drilling Project confirm that sea floor spreading is real

- drilling always aimed to drill through the thin layer of sediment to the basaltic crust

- age and thickness of sediments on the sea floor increases away from the ridge crest in a symmetrical fashion

- K-Ar age of the basalts beneath the sediments also increases the same way

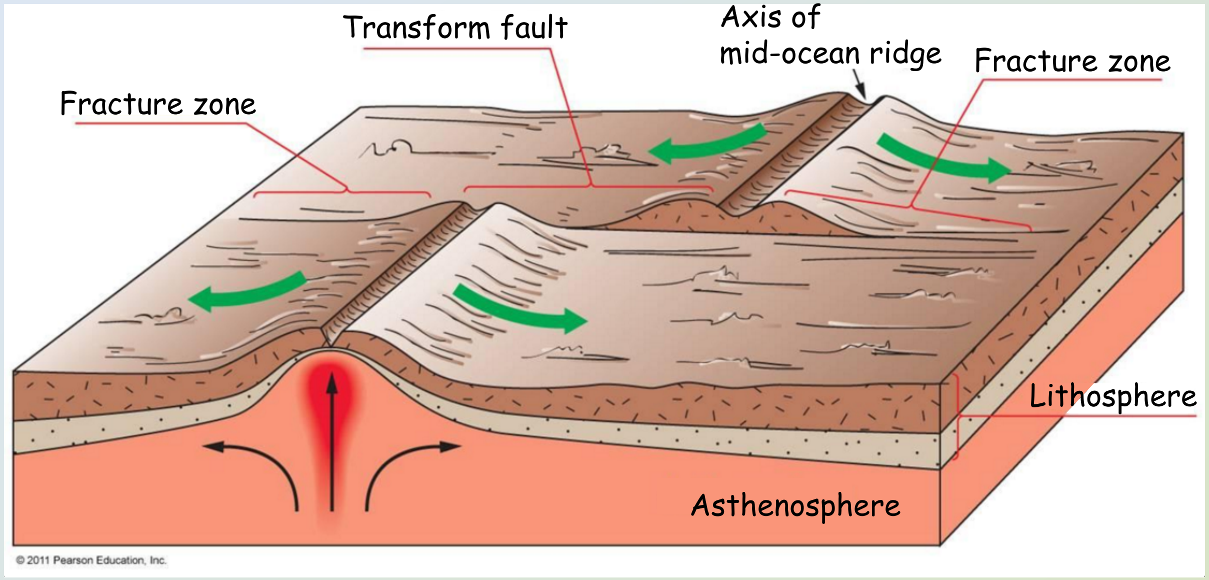
- 3-4km^3 of basalt added to ocean crust annually

Consequence of sea floor spreading

- Seafloor spreading → compelling evidence for continental drift
- if Atlantic is widening → South America and Africa are moving further apart
- knowledge of ages of oceanic crust → enables restoration of continental fit
- compilation of seafloor spreading and continental drift → Theory of Plate Tectonics

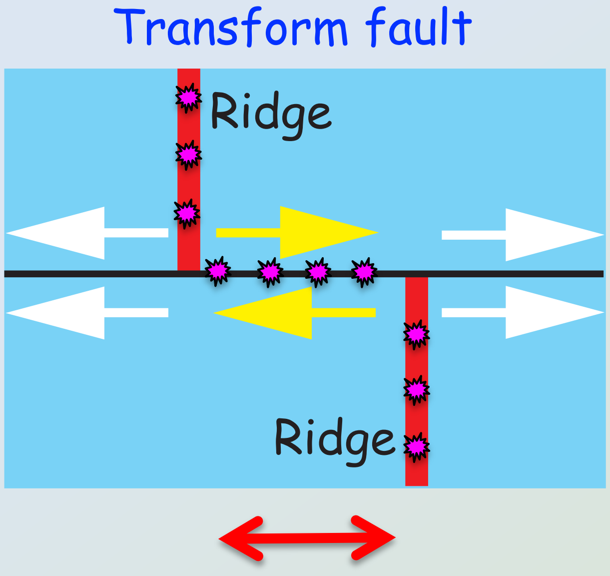
Transform faults

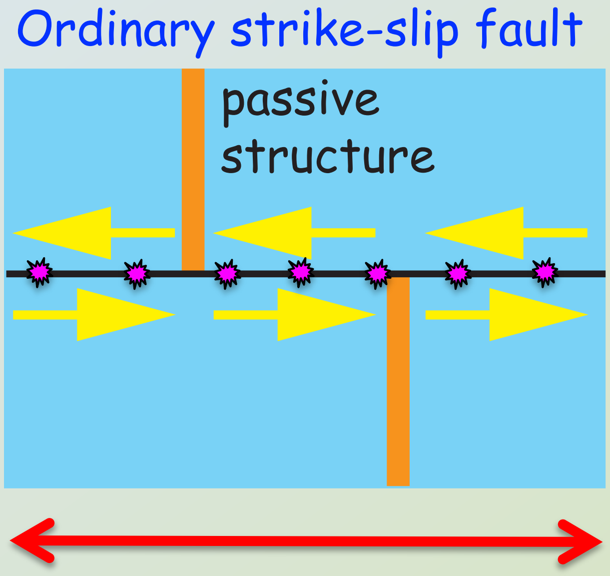
- Transforms → major faults that frequently offset the crests of oceanic ridges to form segments
- movements on transform faults occur only between the segments of the ridge crests
- shallow earthquakes occur along the median rift valleys and along transform faults
- pass laterally into fracture zones that are not seismically active and have no active movement



Movement along transform faults

- Transform faults are a particular type of strike-slip fault i.e. opposing blocks move horizontally parallel to the fault
- distance between offset ridge axis remains constant
- they are only active along part of a fracture zone, relative movement is "transformed" or ceases beyond this zone

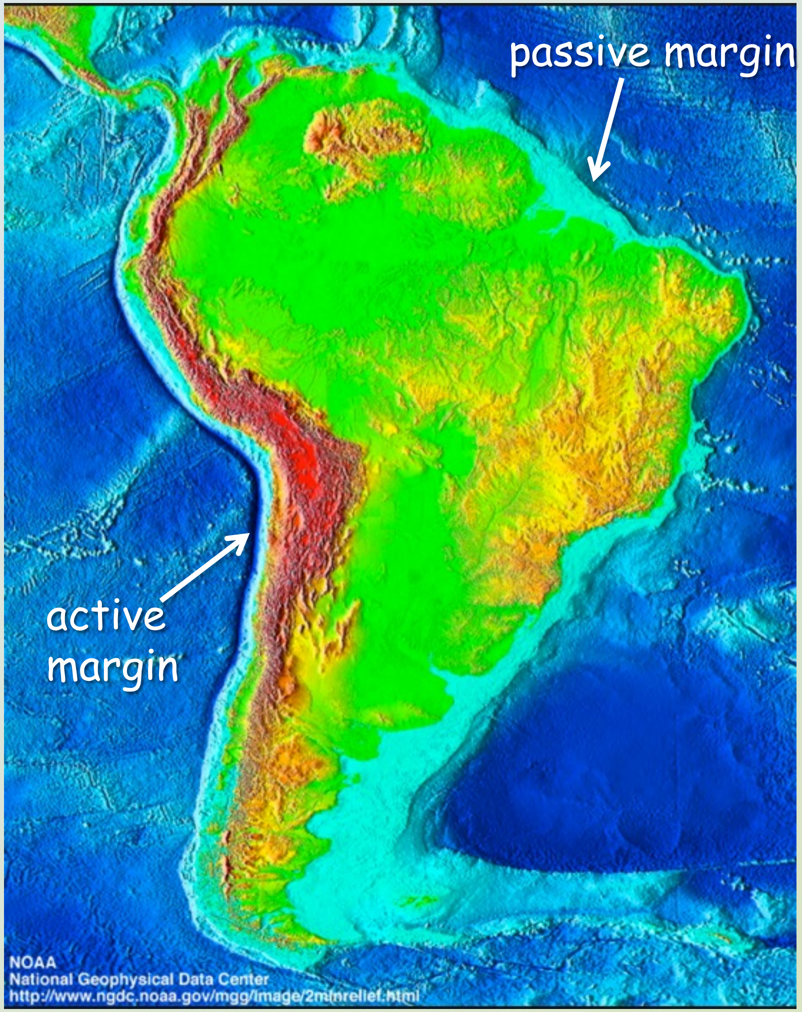




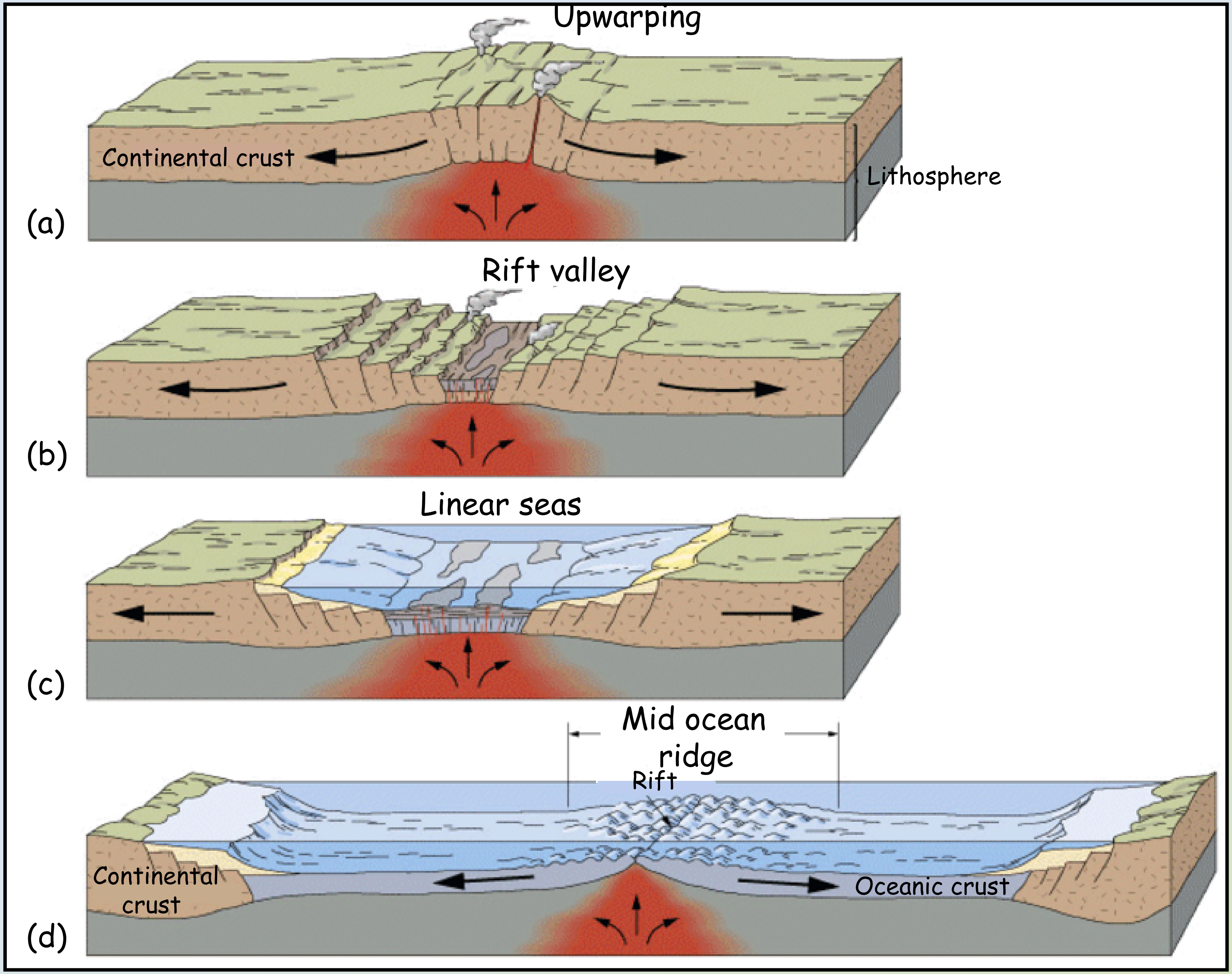
Movement zones

Types of continental margins

- Continental margins formed by rifting at an extensional plate boundary are called passive margins
- passive margins are seismically inactive
- they are no longer plate boundaries
- active continental margins are formed by subduction at convergent plate boundaries
- active plate boundaries are seismically active

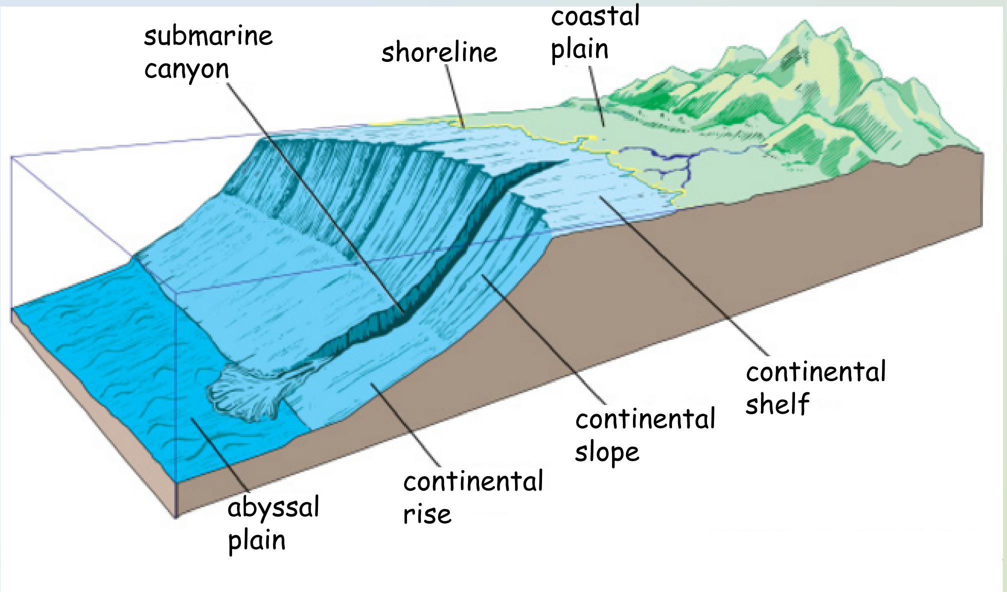


Steps in development of continental margin



Structure of passive continental margin

- Continental shelf is a broad terrace surrounding the continents to a depth of ~200m
- Continental slope is a long continuous slope rising from the ocean floor
- Continental rise is a gentle inclined surface at the foot of the continental slope
- Submarine canyons are deep gorges cut in continental slope and shelf

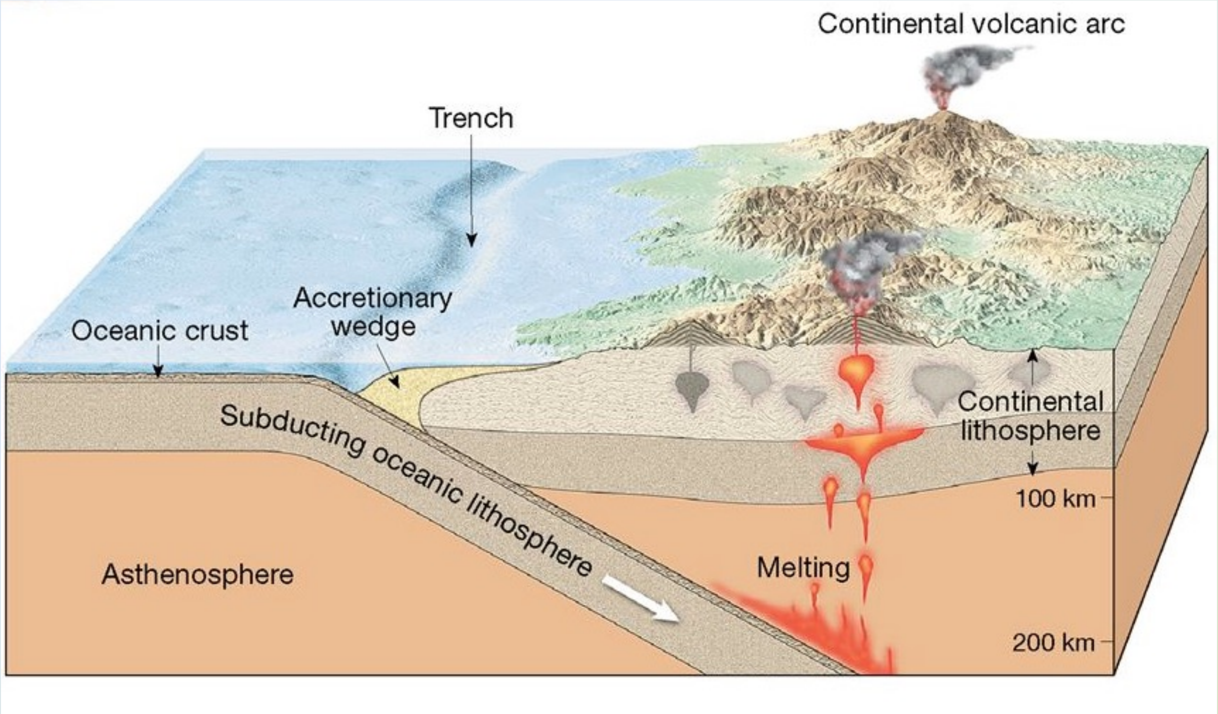


Passive continental margin to active margin

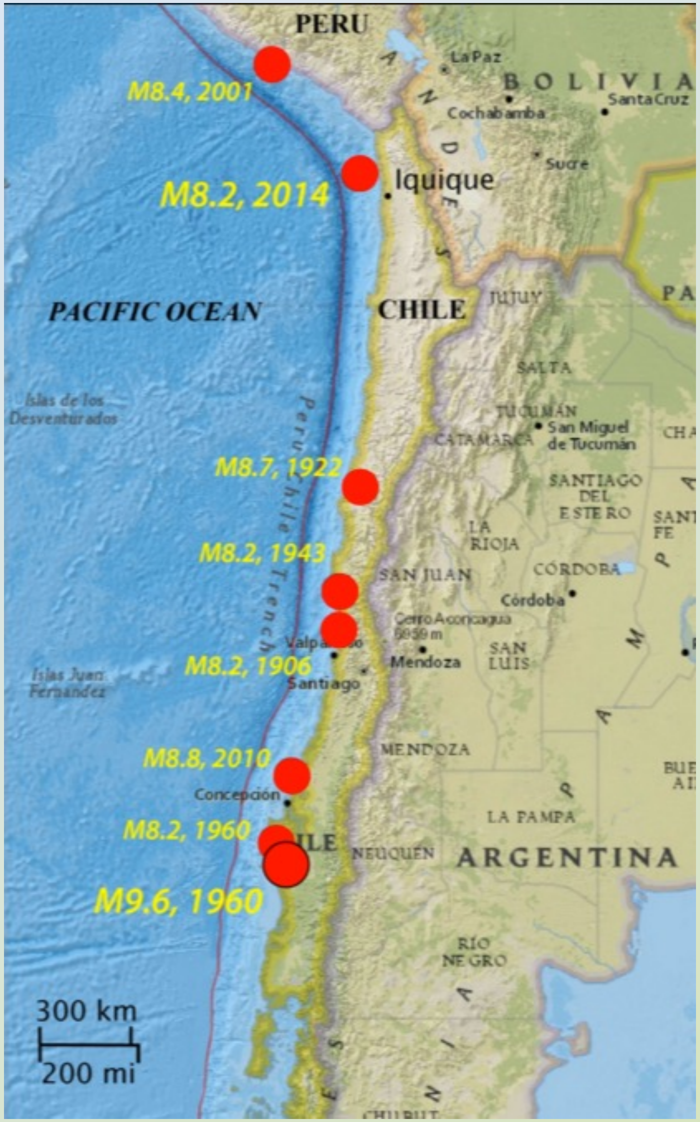
- As passive margin matures → heat source for rifting is way off shore along median valley of ocean ridge
- ocean crust → getting progressively older and colder as it moves away from heat source → becomes buried more and more by sediment
- becomes denser than underlying asthenosphere → sooner or later sinks into mantle → starts to subduct
- forms active continental margin

Active continental margins

- Associated with convergent plate boundaries
- characterised by earthquakes, volcanic activity and building of young mountain belts
- consist of a continental shelf, continental slope, deep sea trench
- occur along eastern Pacific coasts North-western USA, Central America, South America



Active continental margin – South America



Andes

Andean volcanoes

Licancabur, Chile

Cotopaxi, Ecuador

Strike slip fault
(Landsat image of San Andreas Fault)