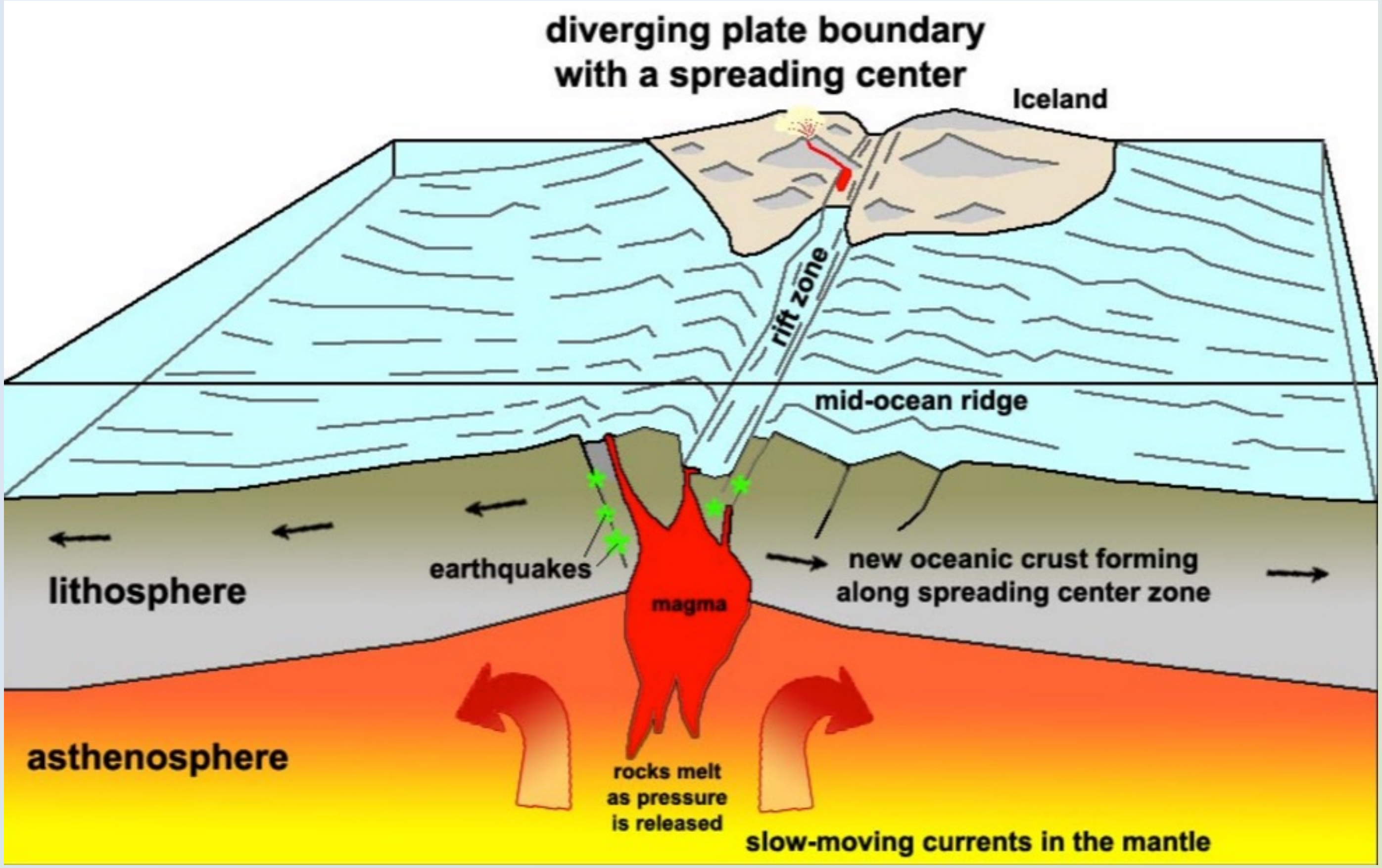
U3A Plate tectonics

Lecture 6

Oceanic volcanism and oceanic crust

Introduction

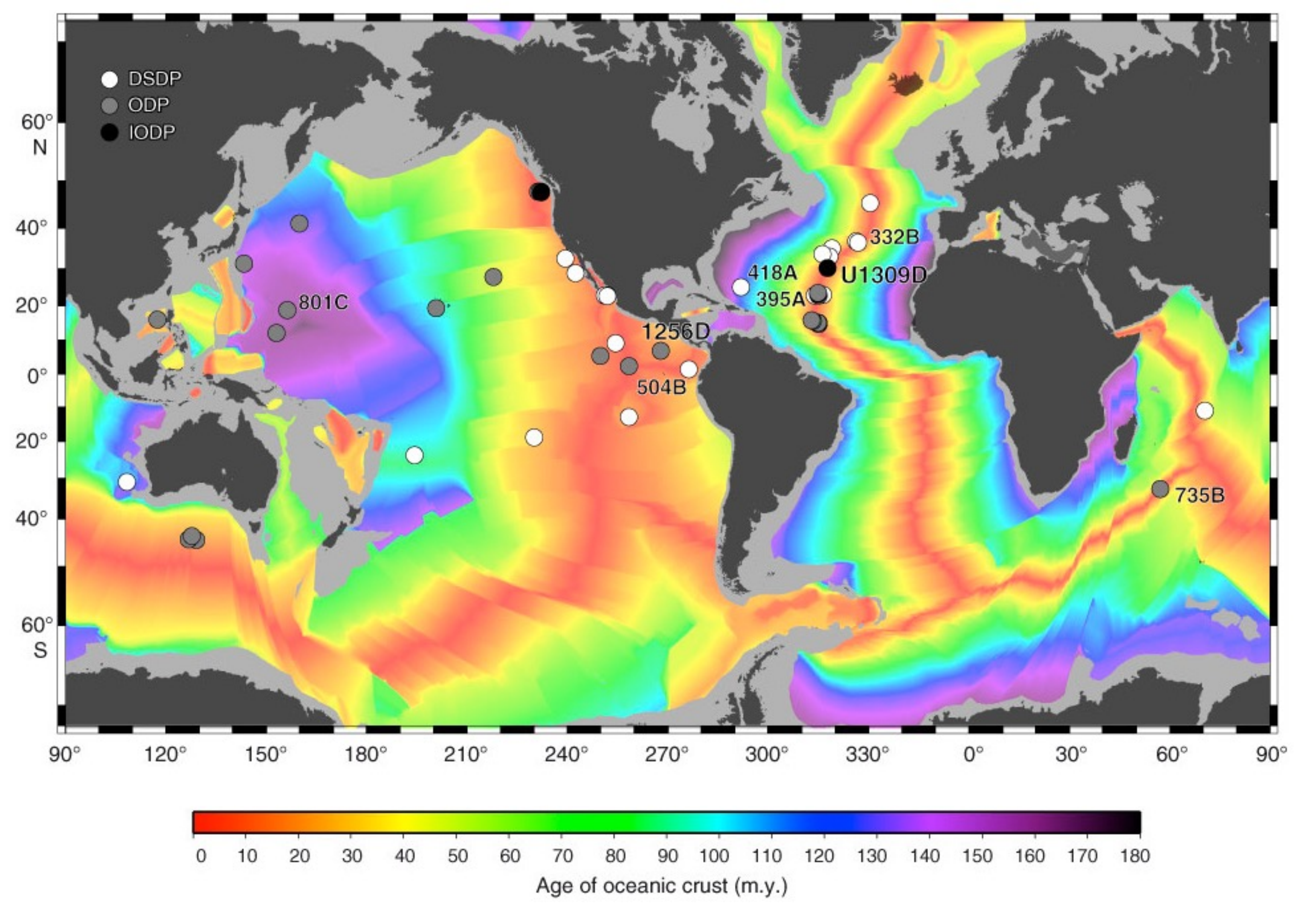
- Volcanic eruptions are frequent along the ocean ridge system
- upwelling magma produces new ocean crust
- volcanoes can also form ocean islands outside the ridge system



Island of Surtsey

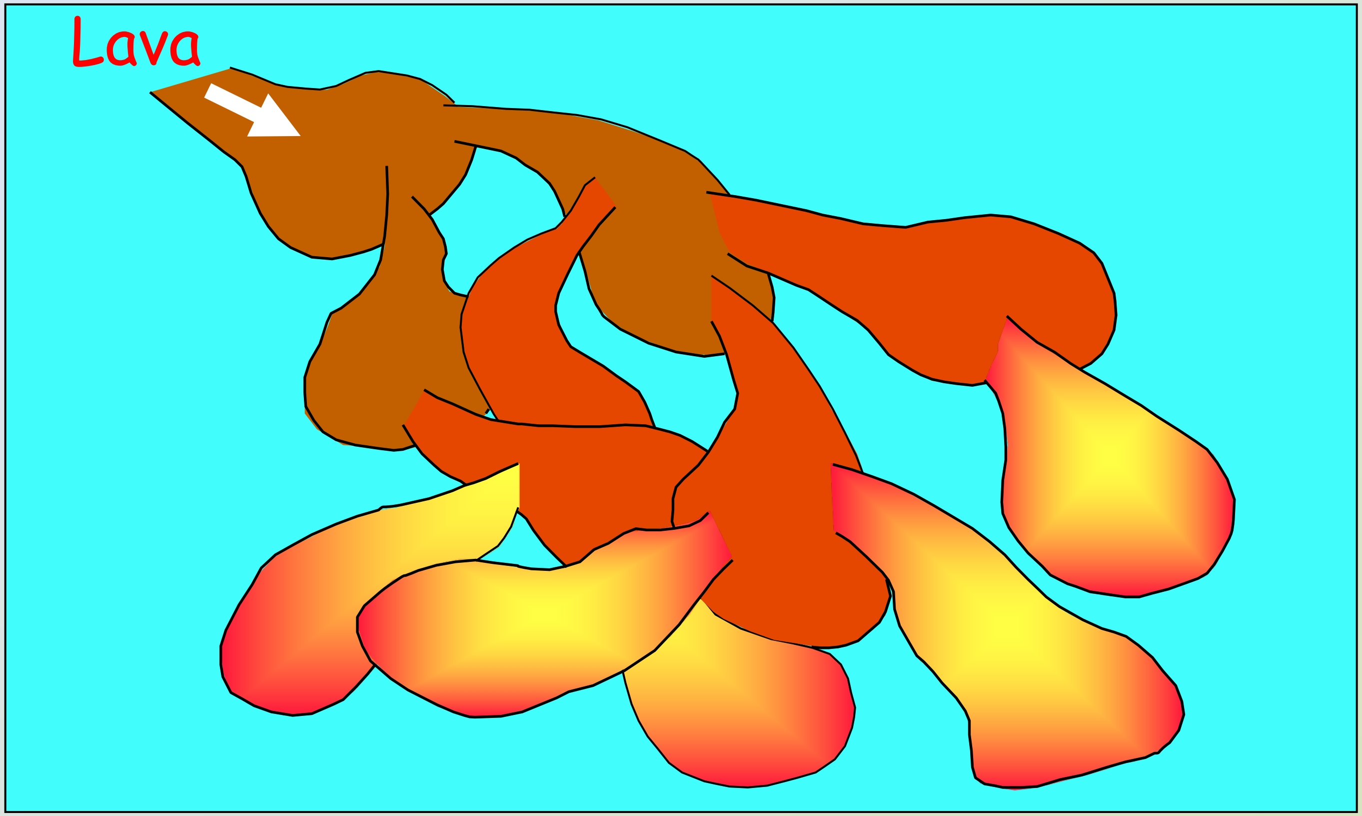
- Formed as a scoria cone on mid-Atlantic ridge in 1963
- volcanism typical of ocean ridge rift zone
- this type of volcanic activity is normally deep submarine

Ages of ocean crust



Pillow Lava Structures

- Bulbous extrusions from fissures → characteristic form of basalt lava that flows under water
- in x-section the flow lobes appear like elliptical pillows



Pillow basalts Gaussberg, Antarctica

Studies of the oceanic ridge axes

- Central axes of ocean ridges (particularly axial rift valley) have been studied using deep-sea submersibles (e.g. Alvin)
- central rift valleys are bounded by steep scarps
- floor of rift composed of small volcanoes, pillow basalts and many open fissures in the sea floor
- hot springs are produced where seawater in the rock is heated above a magma chamber
- Black smokers are mineral-rich hot springs (~350°C) along the ridge axes

Mid oceanic ridge, median rift valley

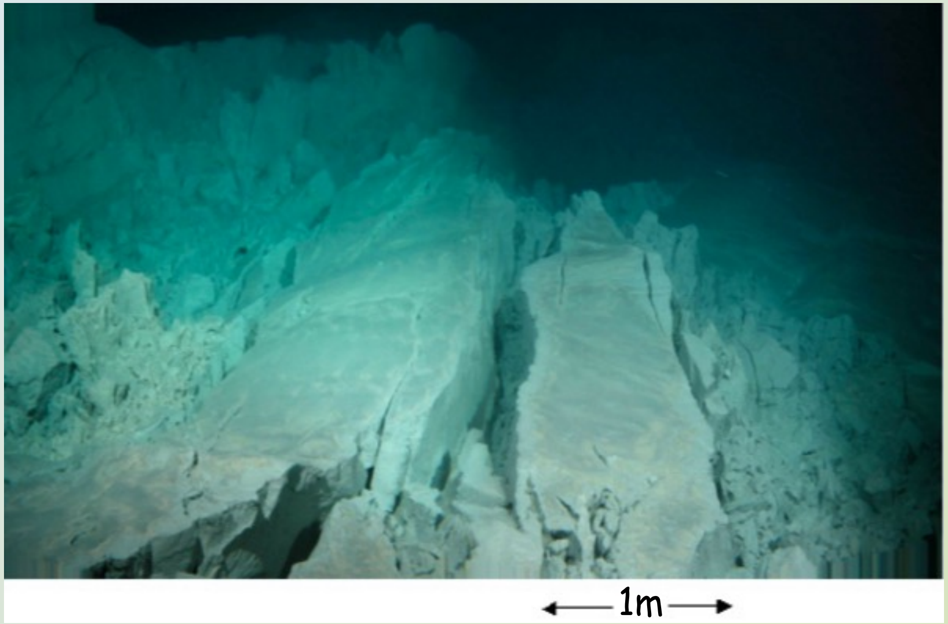
- Ridge rises 3000m above ocean floor, more than 1500km wide
- ridge length bisected by median rift valley (commonly >1000m deep)
- median rift valley bounded by steep fault scarps
- they are zones of high heat flow, elevated earthquake activity, submarine volcanism → lava sheets and mineral-rich hot springs
- fields of pillow basalts form on floor of the median rift
- very low rates of sedimentation (2mm/1000yr) and erosion

Diagram summarises observations made by Alvin scientists

Median rift valley, þingvellir, Iceland

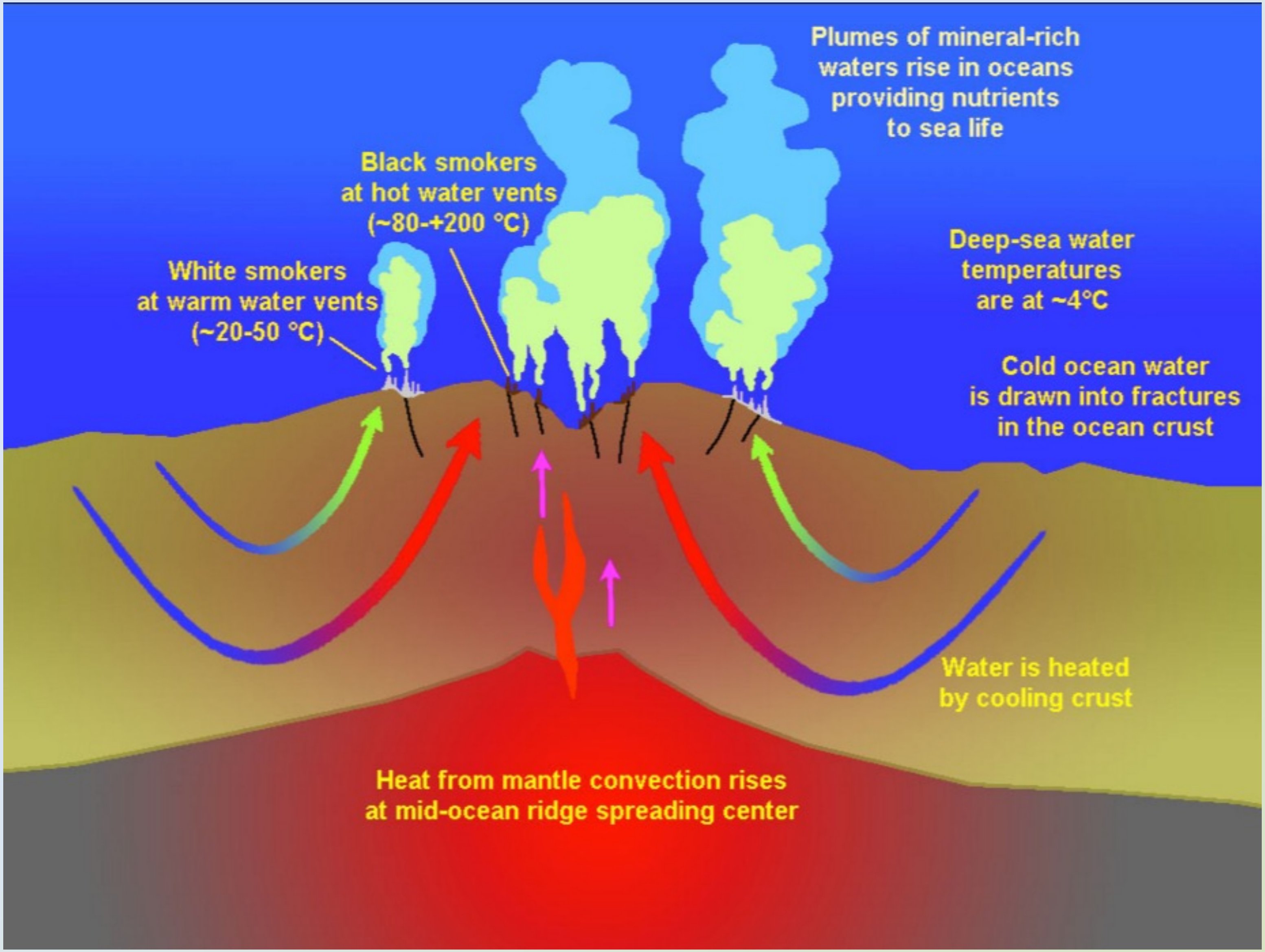
Pillow basalts and open fissures in median rift valley

Pile of pillow lavas



Open fissure along median rift valley

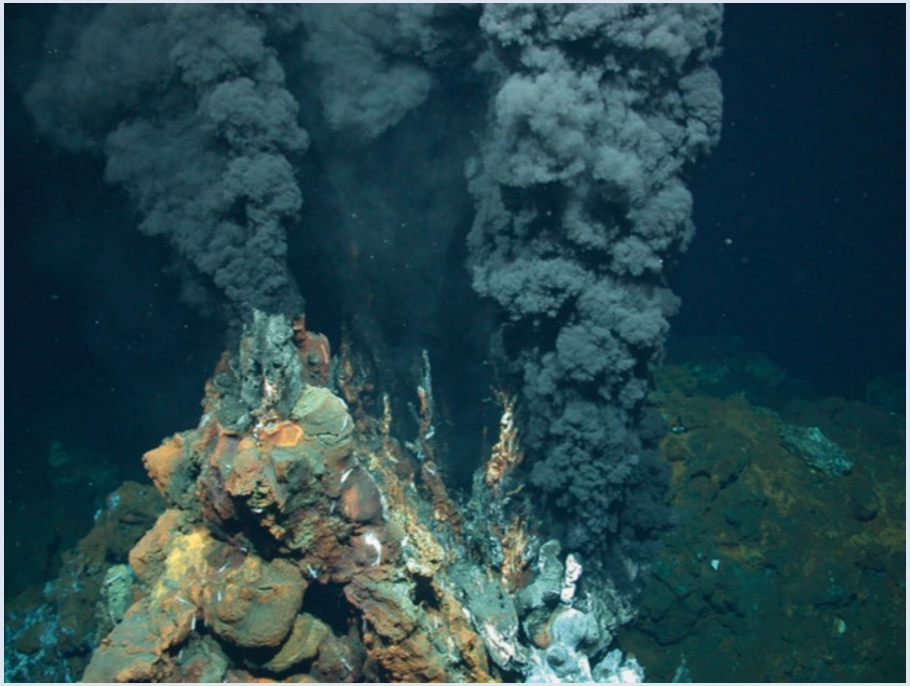
Hydrothermal vents on oceanic ridges



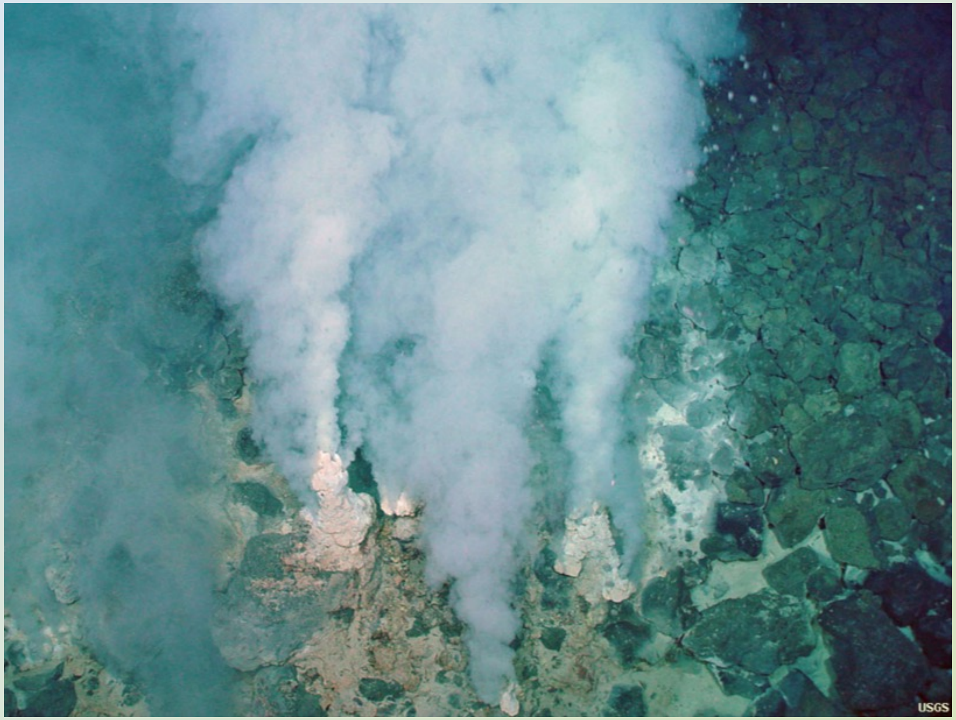
Black and white smokers

- Black smokers → formed when very high temperature, hydrothermal fluids (~350°C) mix with cold sea water and precipitate sulphide particles
- White smokers → precipitate lighter coloured sulphates (barite and anhydrite) and carbonates. These vents are lower temperature dominated by seawater rather than magmatic water

Black and white smokers on mid Atlantic ridge



Black smokers



White smokers

Spreading rate and ridge form

High spreading rate ridges:

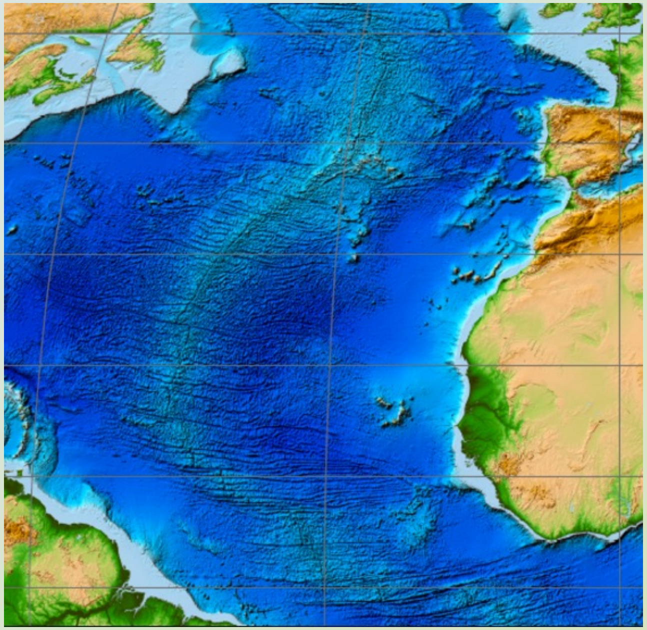
- 10-20cm/year
- produce broad, smooth ridges
- no obvious central rift valley → bulge
- e.g. Pacific rise

East Pacific rise

Low spreading rate ridges

- 1-5cm/year
- produce narrower ridge
- more rugged topography → strongly faulted, blocky
- obvious central rift valley
- e.g. mid-Atlantic ridge

mid-Atlantic ridge



Ocean ridge volcanism in Iceland

- Iceland is part of mid-Atlantic ridge, but above sea level
- 45km wide central rift valley runs NE-SW across the island bifurcates in the south
- built up mostly of superimposed basaltic lavas
- lavas come mostly from fissure eruptions (no pillow lavas)
- there are also stratovolcanoes, shield volcanoes and numerous scoria cones
- dyke emplacement is common
- lavas broken up by numerous parallel faults across the landscape
- hydrothermal fields are found → hot springs and geysers

Dykes intruding basalt flows, Hestgerdi, southern Iceland

Fissure eruptions in Iceland

- Lava fountaining occurs along fissures → lavas move away to form extensive sheet flows
- pillow lava eruptions → not a major feature of Iceland → not under water
- Iceland has a broad central rift valley that splits into two in southern Iceland
- all major ridge features are present except pillow basalts

Fissure eruption, Bardarbunga volcano, Iceland

Fissure eruption, Bardarbunga Iceland

Scoria cone and fissures, Vatnajökull, Iceland

Fissure Mývatn, Iceland

Volcanic features, Iceland

Geothermal activity,

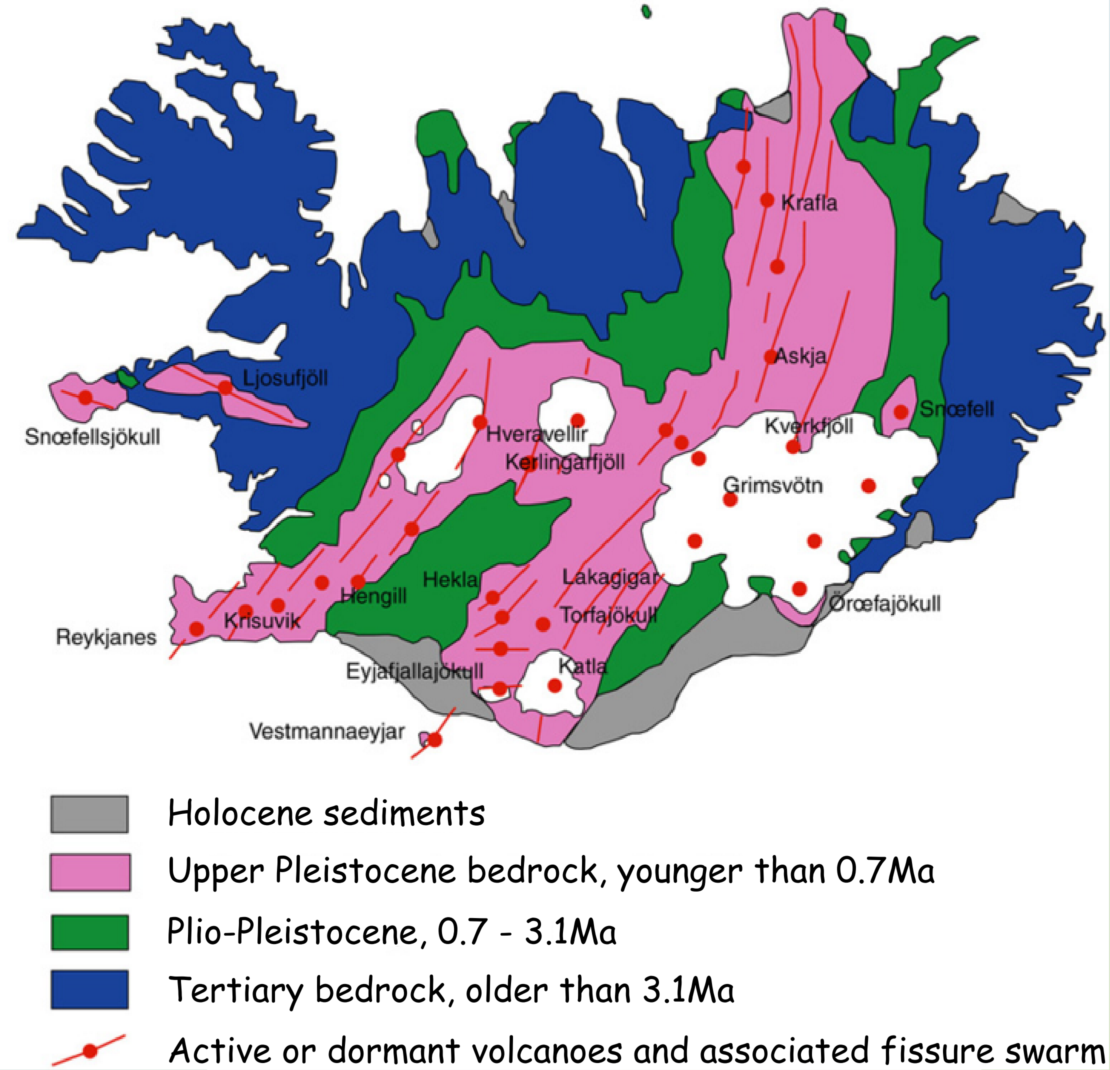
Hverfjall, Iceland

Cinder cone near

Eldborg, Iceland

Age of lavas in Iceland

Age of basalt flows gradually increases away from the central rift valley running across Iceland

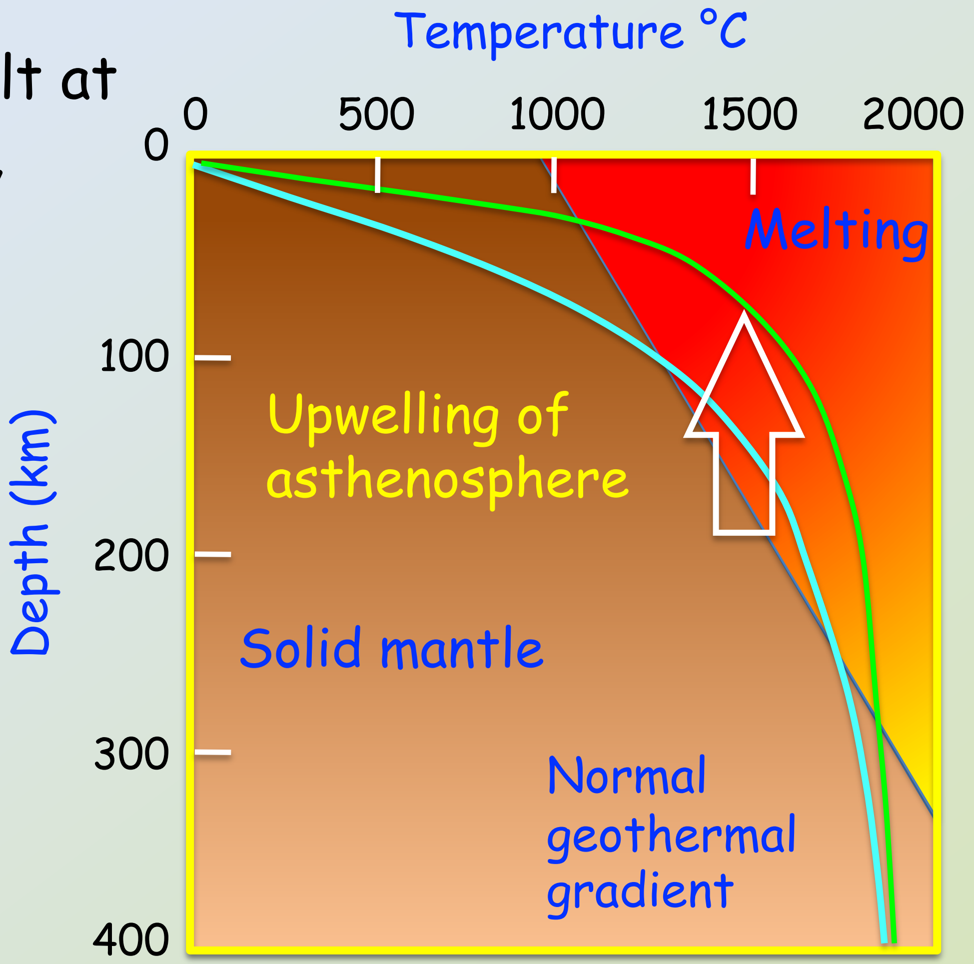


Generation of magma at oceanic ridges

- When lithosphere pulls apart → gap filled by uprise of plastic, soft partially molten asthenosphere beneath ridge axis
- partial melting of mantle peridotite produces basalt lava
- decrease in pressure triggers increase in degree of melting
- magmas produced are less dense and so rise
- degree of melting in asthenosphere typically 2-3% (97% solid)
- upwelling of asthenosphere beneath ridge → ~10% partial melting as high as 15%
- increase degree of melting → mid-ocean ridge basalts (MORBs) low in K and high in Ti

Generation of magma at oceanic ridges

- Asthenosphere → typically 100km to 300km in depth
- if there is upwelling in asthenosphere, rocks at 100km could move up to 30-40km
- rocks that normally begin to melt at 1300°C at 100km, move strongly into melting field → more melting occurs
- generation of mid-ocean ridge basalts with higher degree of partial melting → simply by moving rock up towards the surface in a solid state



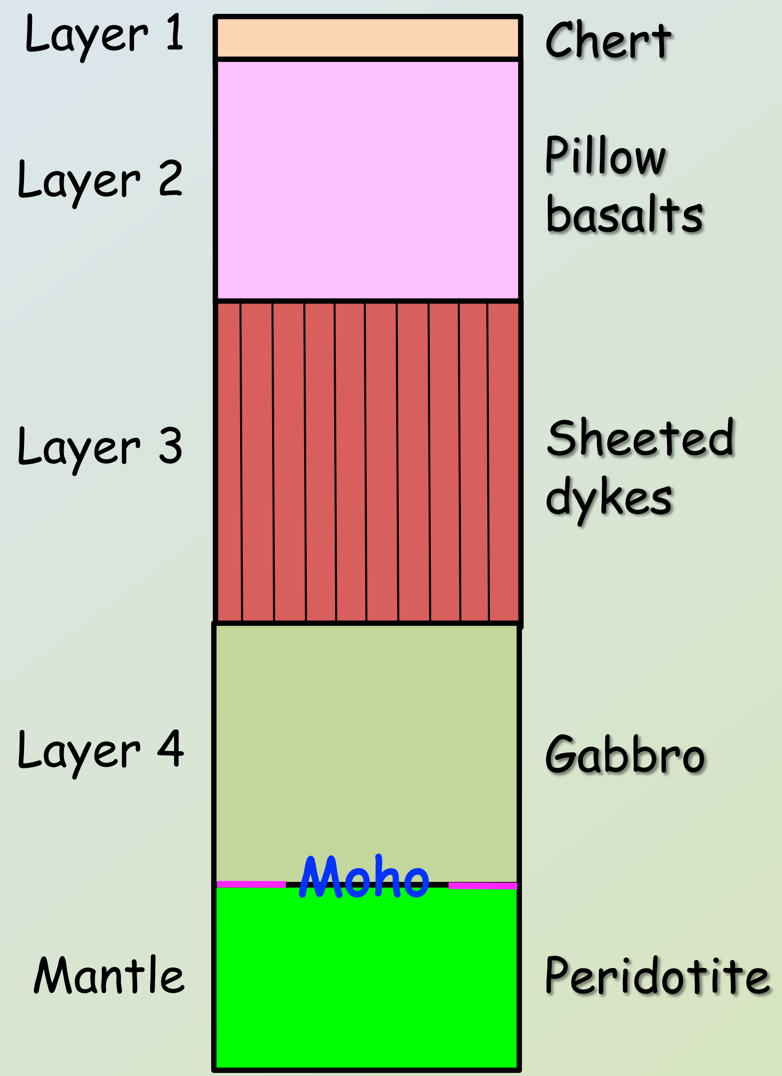
Structure and composition of the oceanic crust

- Magma accumulates in chambers in lower ocean crust (3-4km)
- elongate magma chambers feed magma upwards along fractures
- gabbro crystallises out from walls of magma chamber →

  gabbro layer gradually widens as ocean crust moves apart
- fissures in solid rocks intruded → form dykes (dolerite, basalt)
- magma extruded at surface → pillow basalts
- seismic studies indicate that the ocean crust is strongly layered
- thin layer of siliceous sediment overlies igneous sequence

Structure and composition of the oceanic crust

- The oceanic crust has a layered structure
- studied by drilling and seismic profiling
- four layers are identified
- structure evident in drill cores
- faulted slices of oceanic crust are exposed in ophiolite belts



Volcanism at ocean islands

- Ocean islands are almost all active or extinct basaltic volcanoes or coral atolls built on volcanoes

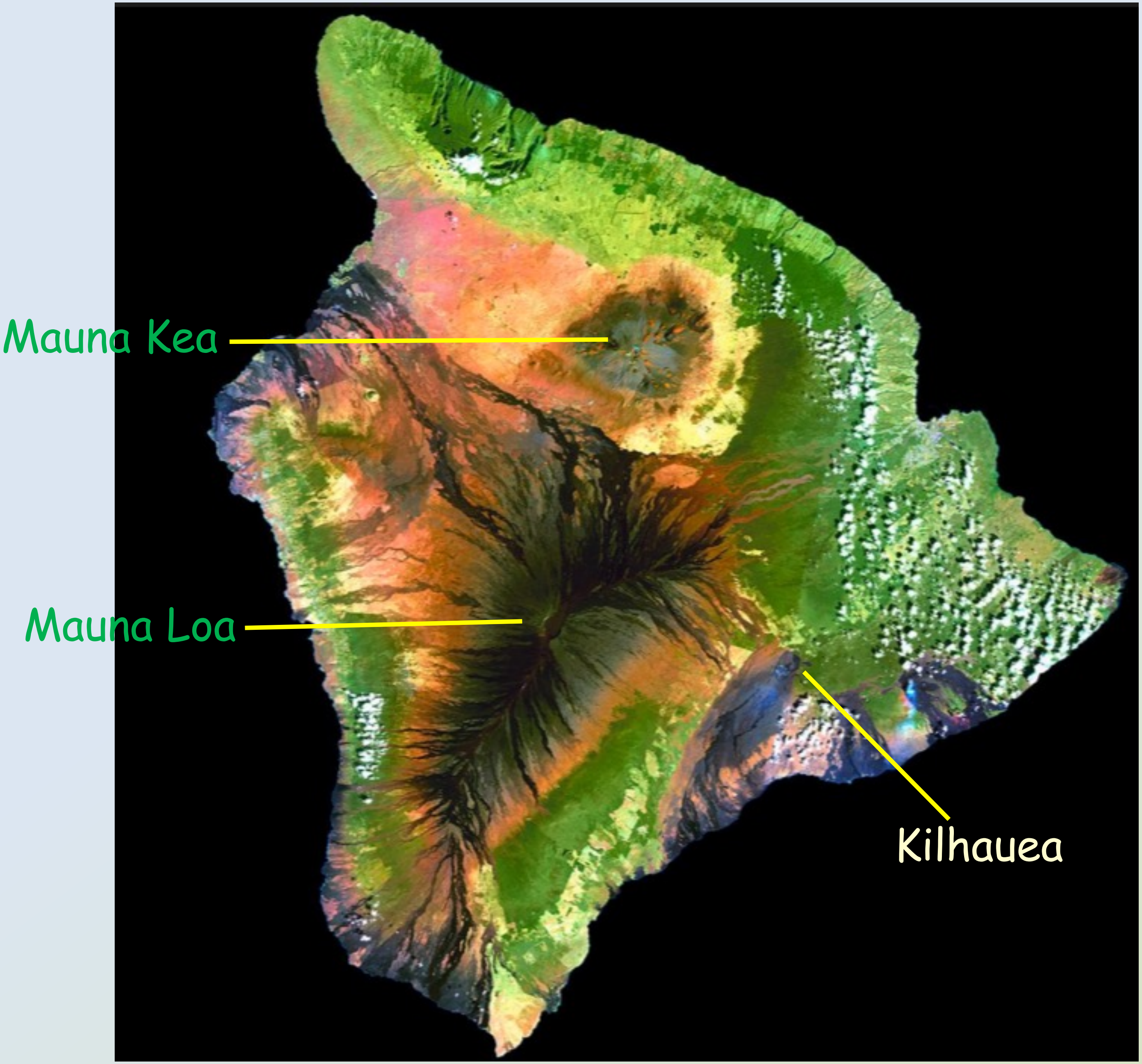
  e.g. Lord Howe Island in Tasman Sea

  Hawaiian Islands, Galapagos Islands in Pacific Ocean

  Mauritius in Indian Ocean

  Heard Island in southern Indian Ocean
- volcanism unrelated to mid oceanic ridge generation of basalt
- these volcanoes can occur anywhere within the ocean crust
- they are often linear chains of islands and seamounts quite distinct from volcanic arcs
- made up of basalts that are relatively higher in alkalis (K, Na) than are MORBs

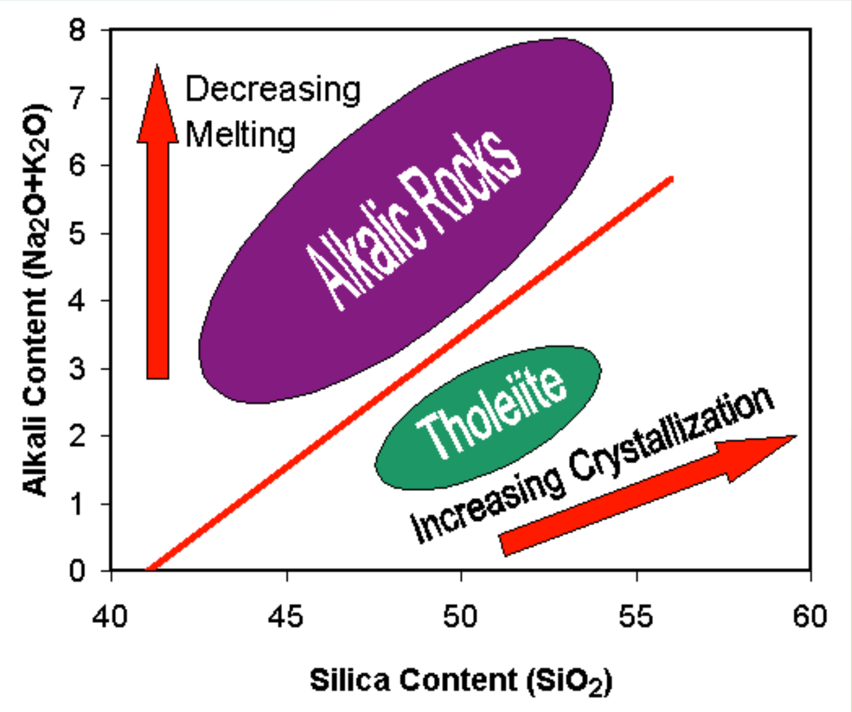
Landsat image of the island of Hawaii



Mauna Loa crater

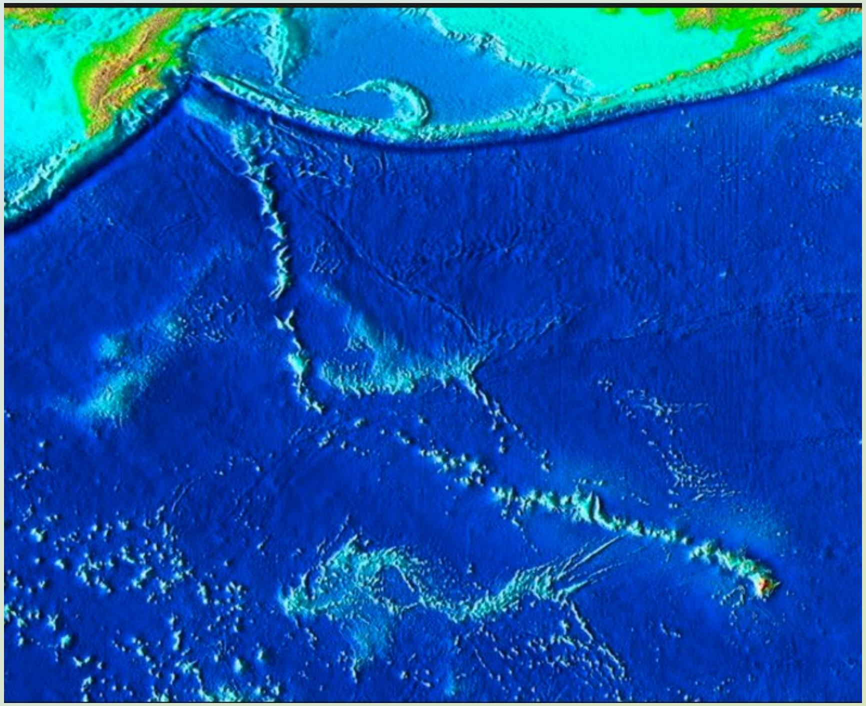
Ocean island basalts

- Ocean island basalts can occur anywhere within oceanic crust
- typically form linear chains of volcanoes on ocean floor
- Ocean island basalts differ from MORBs
- Ocean island basalts → higher in alkalis (K, Na), lower in Ti c.f. MORBs
- result from a lower degree of partial melting (3-4%) c.f. 10-15% for MORBS

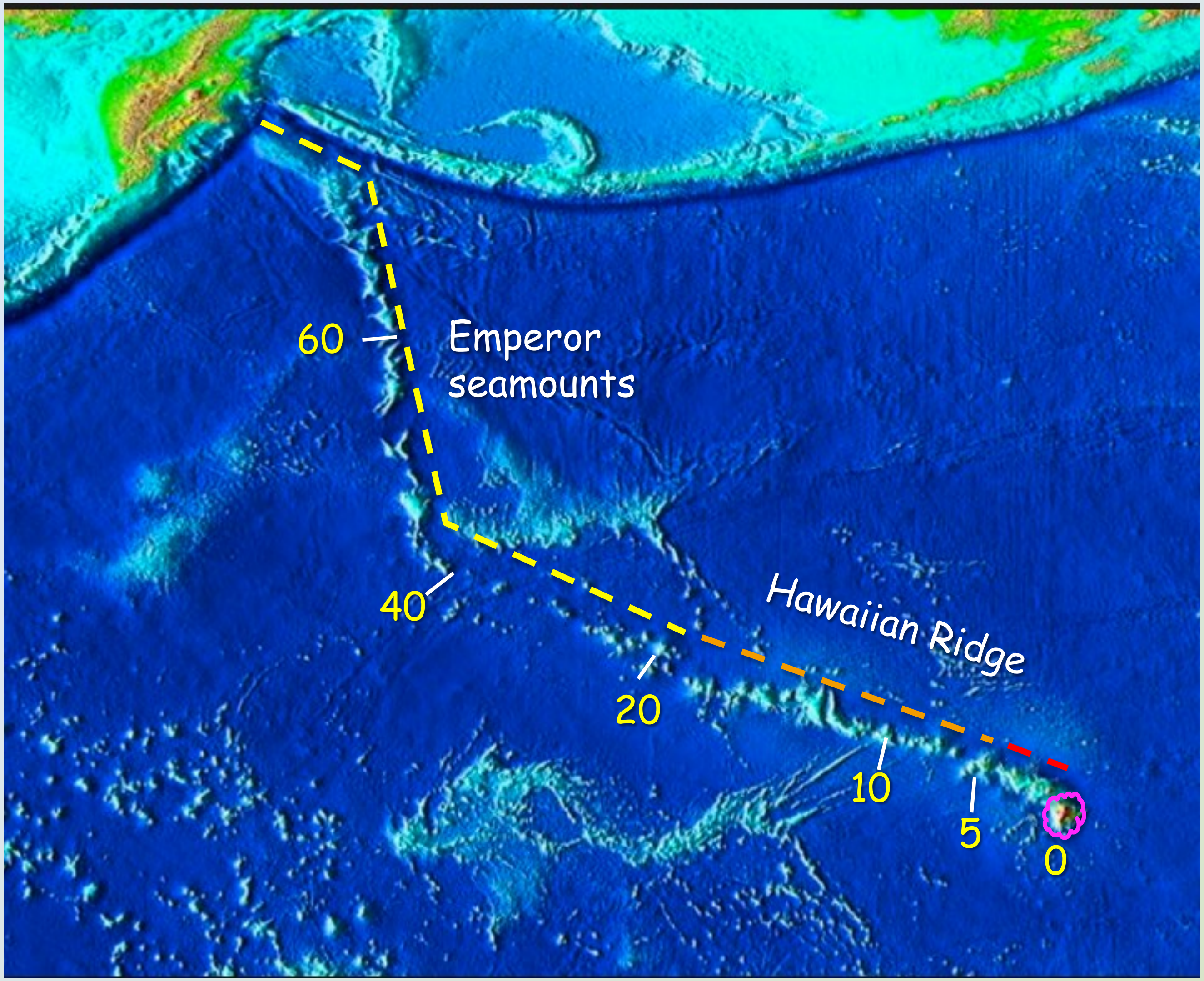


Hawaiian-Emperor chain

- Ocean island volcanoes typically form a linear chain of volcanic islands, coral atolls and seamounts across the floors of the oceans
- active volcanoes only on Hawaii at one end of the chain
- islands slowly subside and are replaced by coral reefs
- coral atolls eventually give way to submerged seamounts
- K-Ar ages of basalts increase along the seamount ridge away from Hawaii



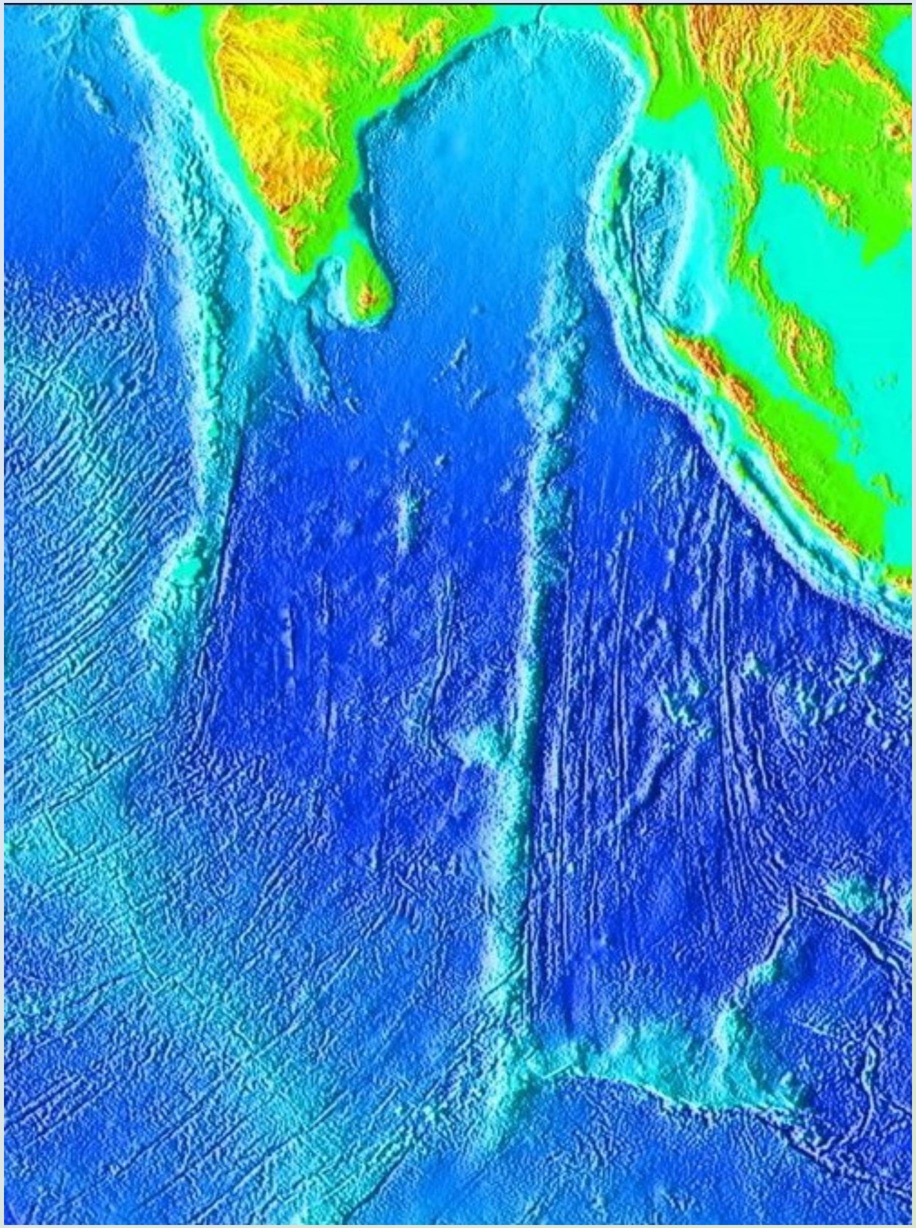
Hawaiian-Emperor chain



seamounts — atolls — islands

40 K-Ar ages (Ma) — active volcanoes

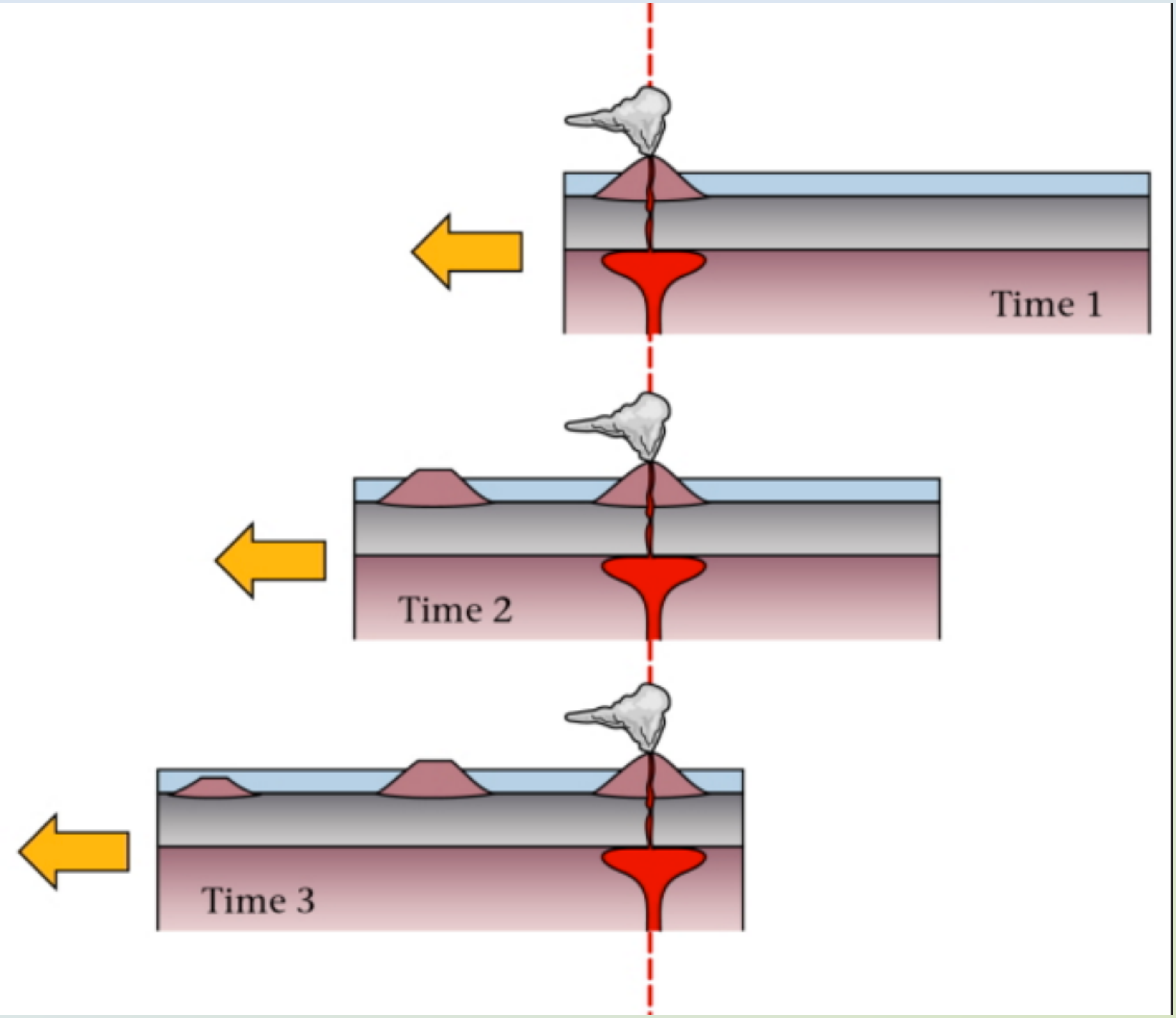
90 east ridge



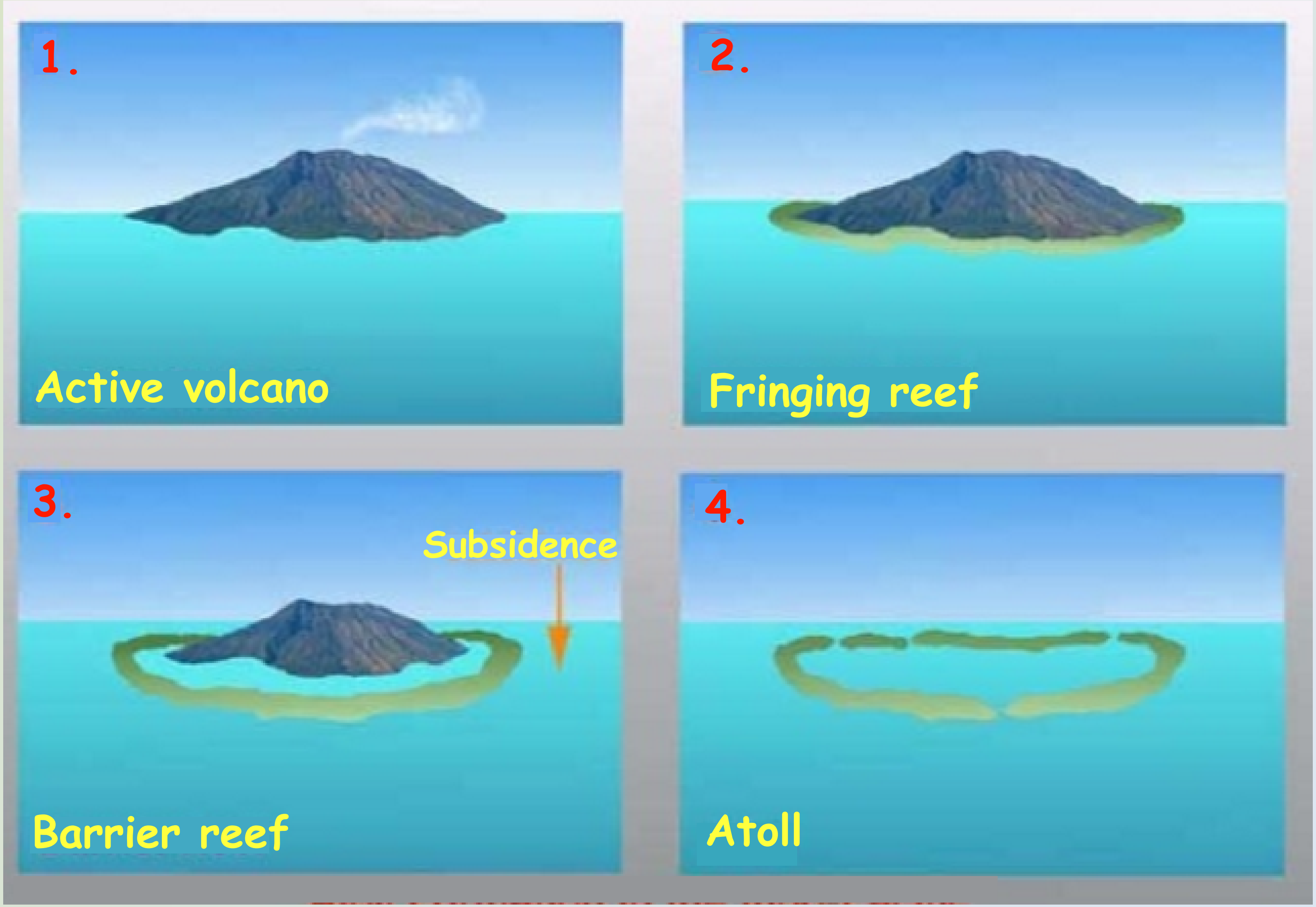
Hotspot trails

- Hotspots are localised regions where plumes of hot mantle material rise from deep beneath the lithosphere → magma generated by decompression produces sites of volcanic activity
- over thirty hotspots are currently recognised within the Earth
- ocean island chains are caused by oceanic crust moving over "hotspot" magma sources in the mantle
- Hotspots also occur beneath continental crust
- Hotspots appear to remain fixed relative to each other through time

Formation of ocean islands by plate movement



Formation of atoll (Darwin)



Bora Bora atoll

Extinct volcano ringed by a coral reef enclosing a lagoon

Measuring plate motions

- Absolute plate movement can be measured from distance and age along hotspot trails
- Hotspot trails give an absolute frame in which to measure plate motions
- this hotspot frame is fixed relative to the deep interior of the Earth
- magnetic anomaly patterns and long distance surveying can only give relative plate motions