U3A Plate Tectonics

Lecture 8

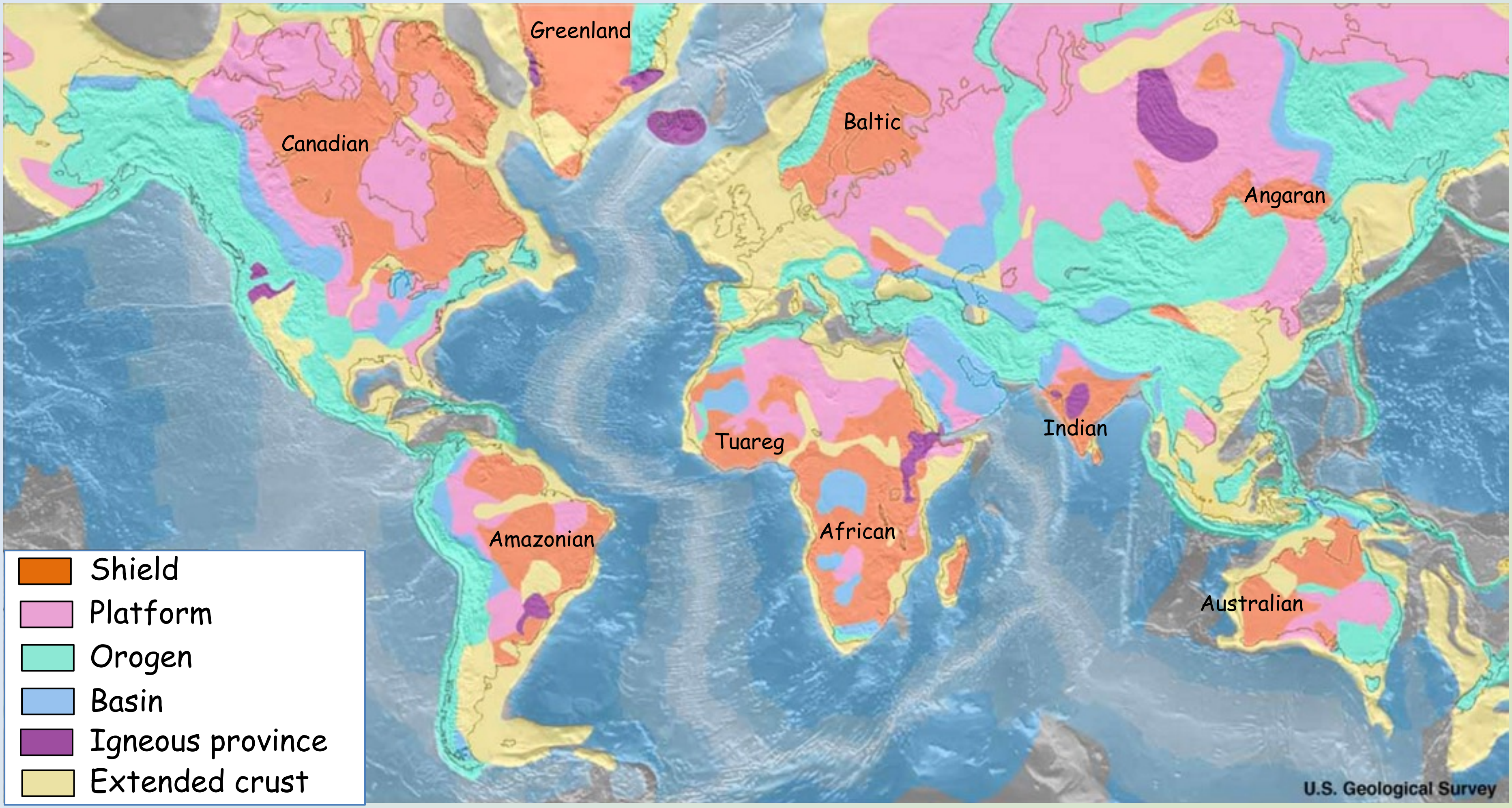
Orogenic belts

Structural features of the continents

All continents are composed of three basic structural components:

- Shields – broad areas of low relief composed of highly deformed ancient metamorphic and igneous rocks e.g. Western Australian shield, Canadian shield
- Stable platforms – shield areas that are covered by a relatively thin covering of undeformed sediments e.g. prairies of North America, Nullarbor Plain, Australia
- Folded Mountain Belts – long, linear zones of high relief and intensely deformed crustal rocks e.g. Himalayan-Alpine Chain, western Cordillera of America

Continental crust components



Shield areas – the Canadian shield

Stable platforms

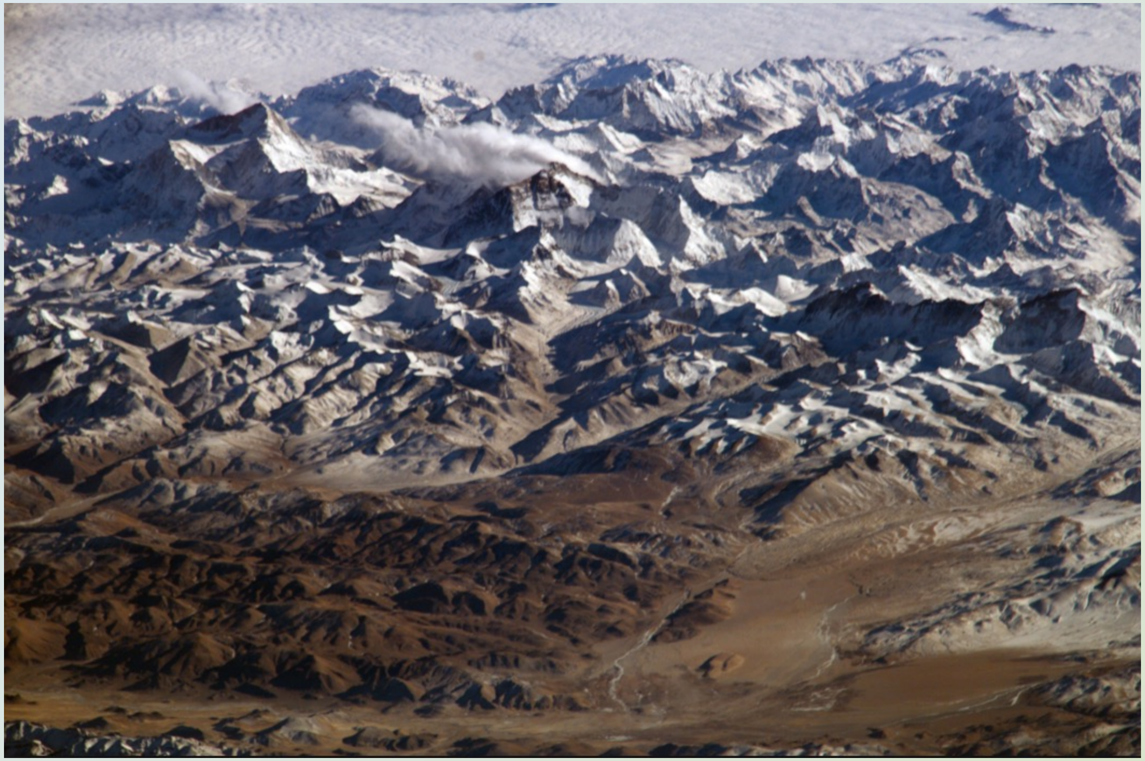
- Stable platforms are very flat e.g. Nullarbor Plain
- form cover over flat-lying sediments of limited thickness over planated shield areas
- sediments undeformed → critical feature
- Grand Canyon sequence exposed down to the underlying shield

North American prairie

Nullarbor Plain, Australia

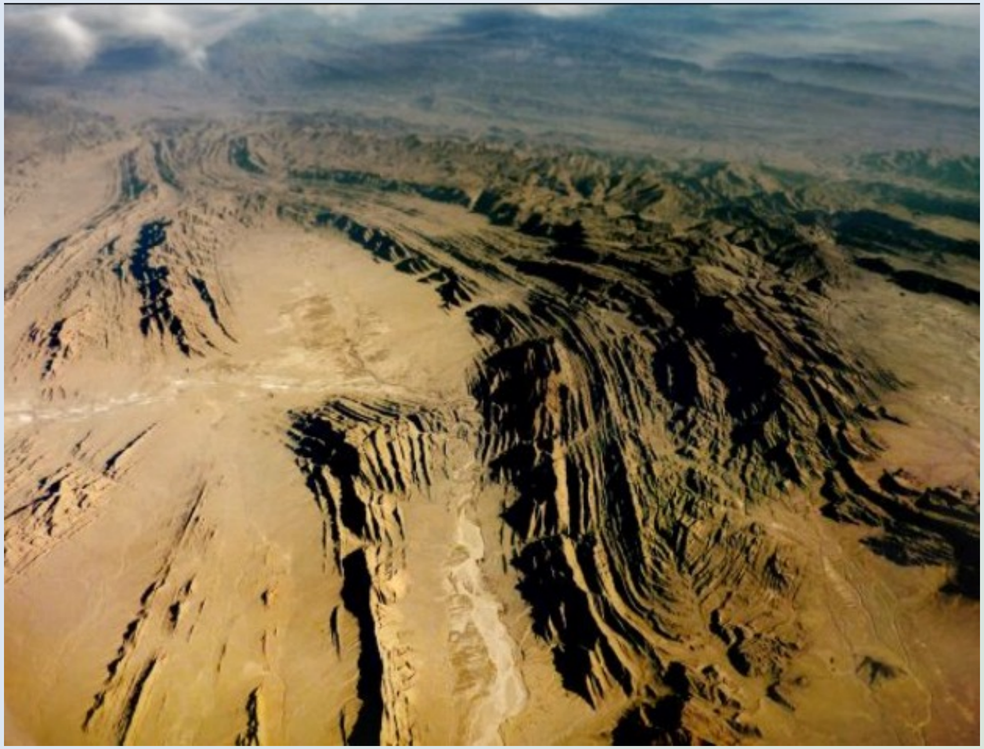
Folded mountain belts

- Most obvious features of the continents
- composed of sedimentary rocks that are intensely deformed
- occur in linear belts hundreds of km wide and thousands of km long
- high elevations up to 8km (Himalayas)



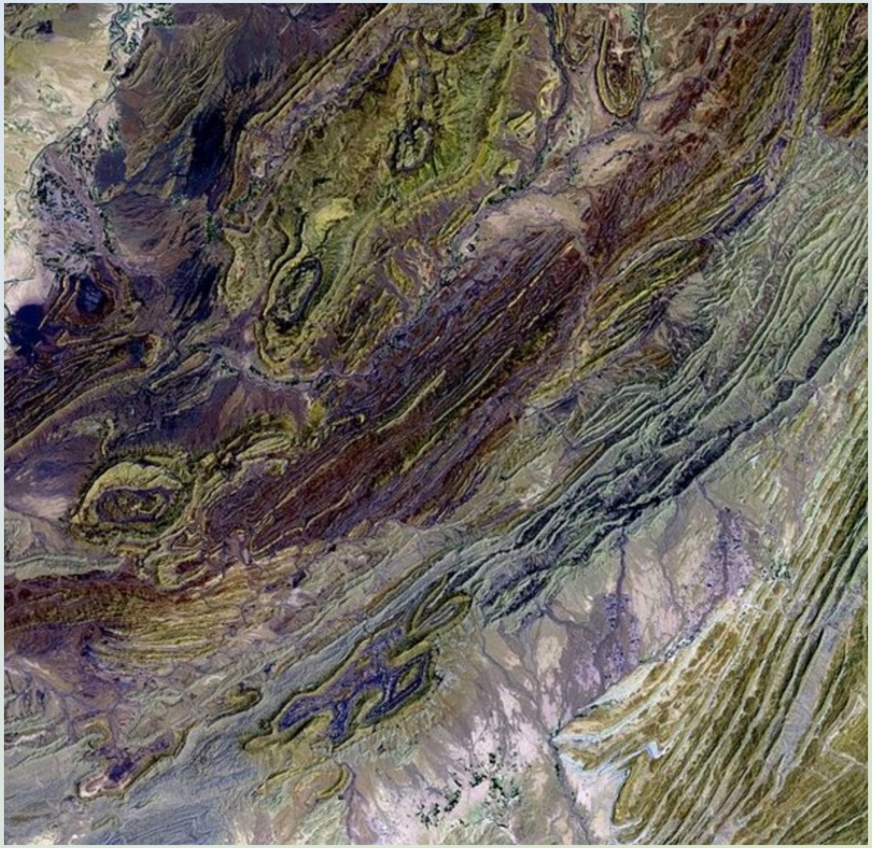
Himalayas

Folded mountain belts



Sulaiman Mountain range, Pakistan

oblique aerial photograph



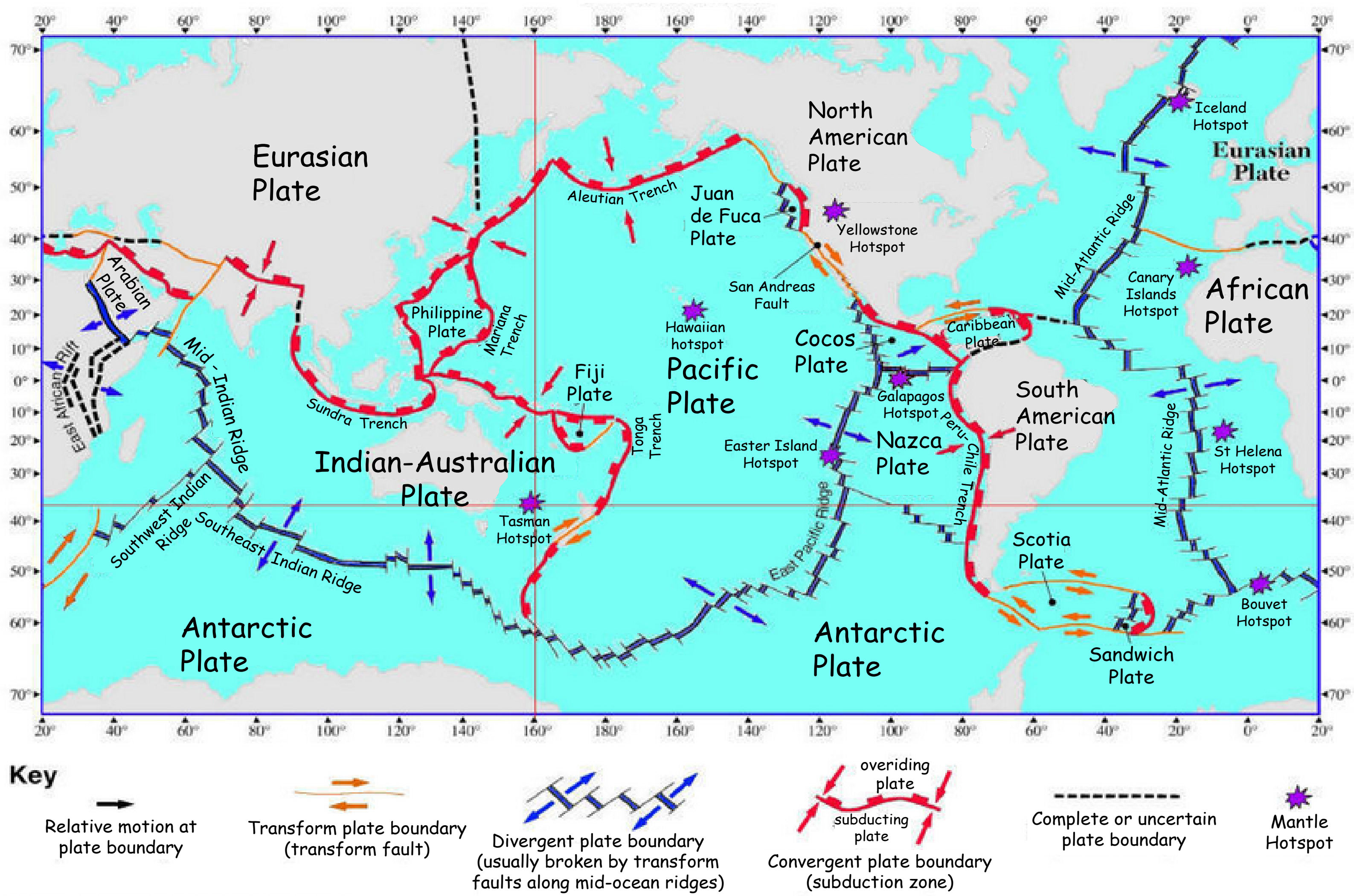
Sulaiman Mountain Range, Pakistan

satellite image

Distribution of mountain belts

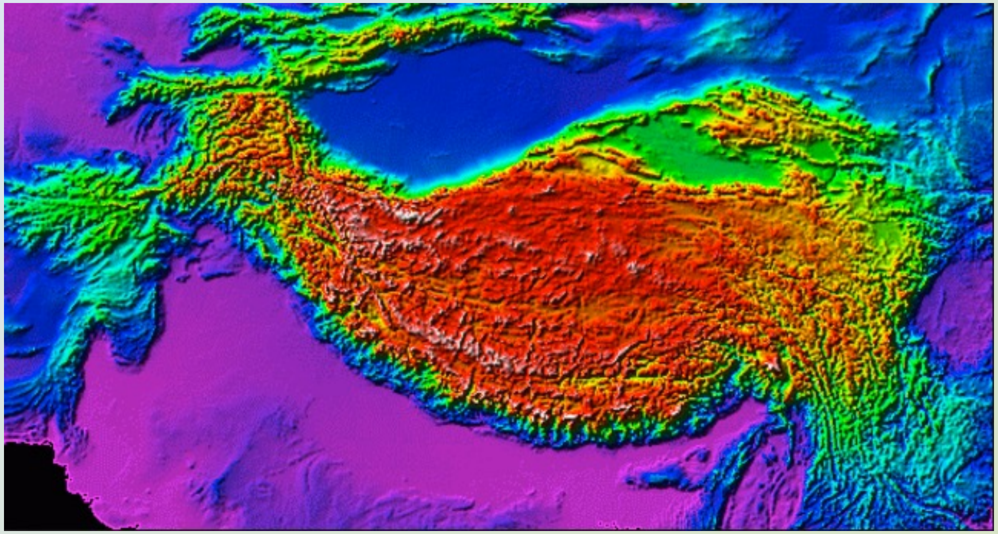
- Mountain belts have many characteristics in common with island arcs
- Himalayas trend down through SE Asia → becomes Indonesian Island Arc
- also Rocky Mountains of Cordillerean belt of North America continues on into Aleutian Arc → joins up with Japanese Arc

Tectonic plate boundaries



Folded mountain belts

- Folded mountain belts → also called orogenic belts
- active belts are areas of high relief, active rock deformation, igneous intrusive activity and metamorphism
- intense deformation in rocks in orogenic belts is due to horizontal plate convergence
- active orogenic belts occur at plate boundaries along continental margins
- old (inactive) orogenic belts show the same features but have been eroded down to surfaces of low relief



Topographic image of Himalayan mountain chain

Bergell granite, Southern Alps, Northern Italy

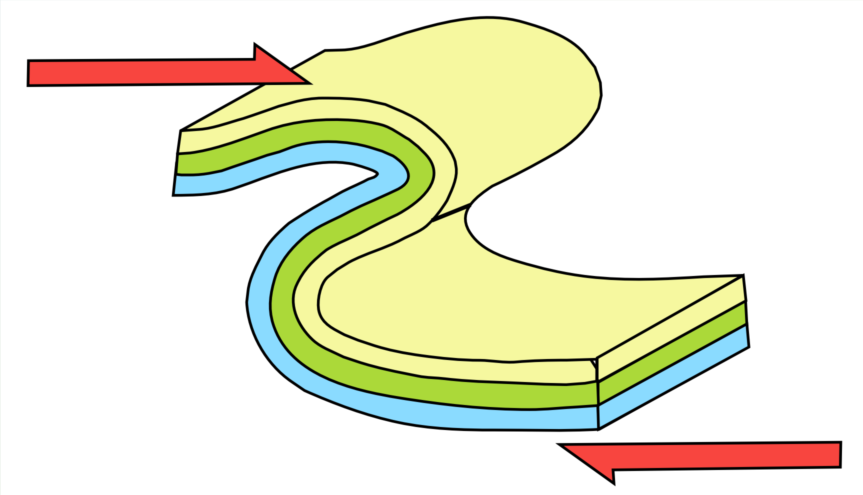
Recumbent folding

- Rocks forming European Alps → stacked up on top of each other → folded → piled up
- form in compressional zones where a mass of rock is thrust over another rock mass
- form recumbent folds → triple thickness of same rock sequence
- recumbent fold → overturned fold with horizontal axial plane and parallel limbs
- characteristic feature of nappes → sheets of rocks that have been moved up to 10s of km

Recumbent folding

Recumbent fold, Dent de Morcles

Bernese Alps, Switzerland



Australian highlands

- SE Australian highlands show orogenic features (igneous intrusions, metamorphism, deformed sedimentary rocks)
- region of subdued relief → old mountain belt no longer active (since Late Palaeozoic) → subsequently eroded
- present day relief → uplift related to breakup of Gondwana

Snowy River valley, Eastern Australia

Orogenesis

The process of mountain building is called orogenesis.

Orogenesis involves:

Accumulation of thick sedimentary sequences

- sedimentary pile → 10-15km thickness of sediment
- restricted environments where this can occur → continental margins

Pervasive structural deformation

- all of the rocks in orogenic belts are intensely deformed

Metamorphism and granite intrusion

- all rocks are metamorphosed to varying degrees

Erosion and isostatic adjustment

- mountains are rapidly eroded
- because horizontal compression continues → they still push up → continue to be eroded
- isostatic adjustment causes rebound

Sediment accumulation

- Orogenic belts show very thick accumulations of shallow marine sediments – as much as 15km thick (deeper than oceans)
- areas that are now mountain ranges were once beneath the sea
- much of this sediment shows structures, fossils or a composition indicating shallow marine conditions at sedimentation
- these areas must therefore have been regions of the crust that slowly subsided during deposition
- such sedimentation occurs on continental shelves and on the adjacent continental rise of passive margins

Origin of thick sedimentary sequence in shallow marine environment

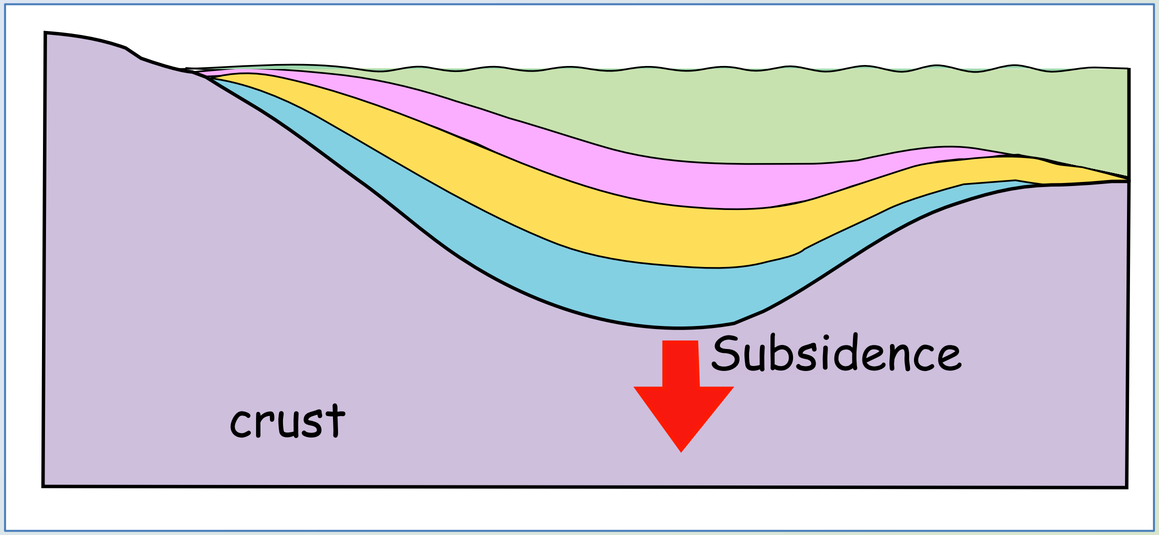
- Deposition of sediment and subsidence at site of sedimentation → have to be broadly in balance
- isostatic adjustment occurring → if material removed by erosion → continents rise
- if material is deposited → load on crust → subsidence of crust
- as more sediment is deposited → subsidence continues → thick deposit of relatively shallow water sediment

Subsidence resulting from sedimentation

- Billions of tonnes of sediment deposited in shallow marine environment weight of thick pile → subsidence of underlying rock

- thick layers deposited over millions of years

- thousands of metres of sediment can be deposited with water depth never exceeding a few hundred metres



Shallow marine evidence in orogenic belts

- Folded mountain belts are virtually all made up of mostly marine sedimentary rocks (limestone, shale, siltstone)
- upper formations of Mt Everest contain abundant marine fossils (trilobites, crinoids, ammonites, ostracods)
- summits of European Alps are either metamorphic rocks or granites → original rocks were Jurassic to Cretaceous sediments that were formed beneath the sea

Shallow marine evidence in orogenic belt - Himalayas

Ammonite fossils collected in Tibet at an altitude of 4500m

The summit of Mt Everest.
The topmost strata are grey, fossiliferous limestones that formed in a shallow marine environment

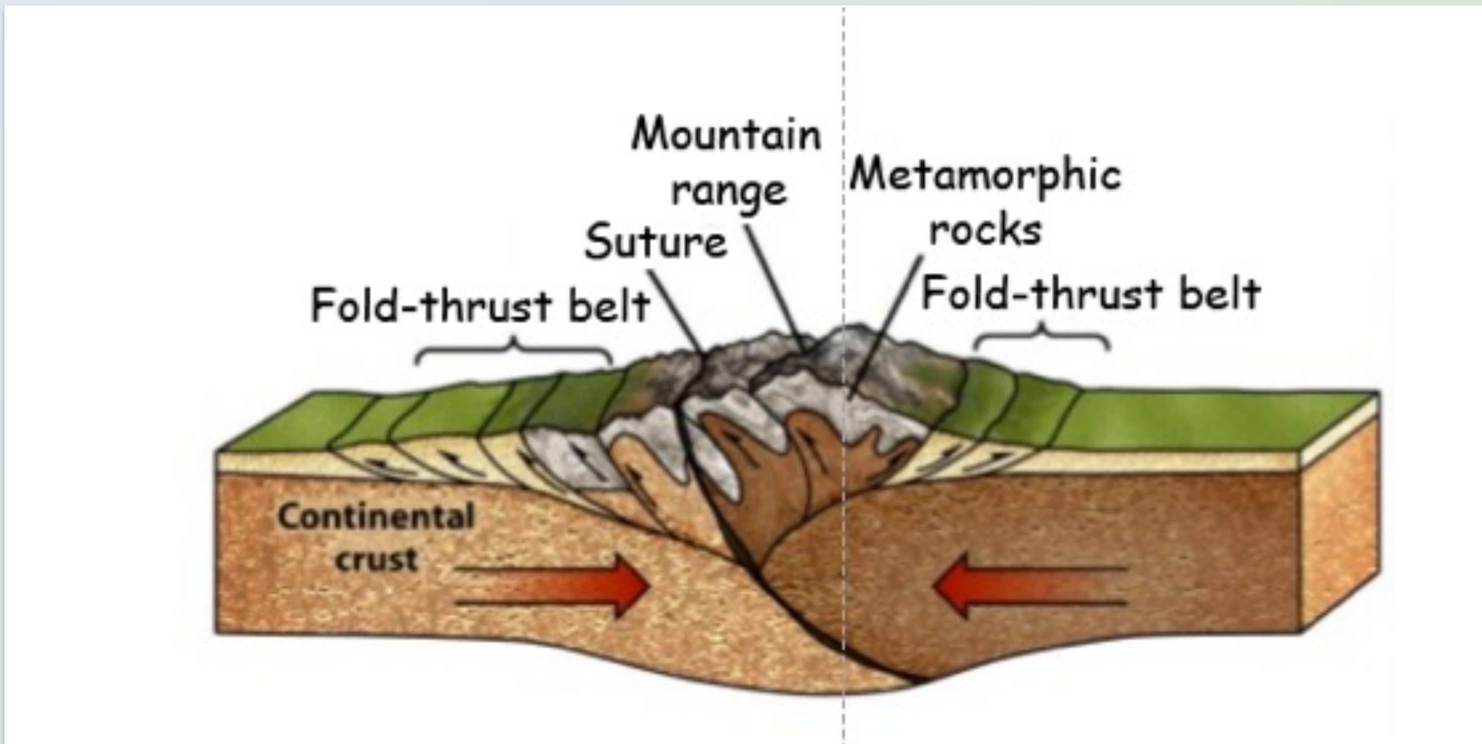
Orogenesis 2

- Orogenic belts metamorphosed to different degrees e.g. SE Australian and Scottish highlands
- both areas are topographically subddued → orogenesis inactive since Late Palaeozoic
- metamorphic belts and sedimentary belts characterised by large granite intrusions and batholiths
- wherever jagged mountains visible they are still pushing up (horizontal compression) and eroded → isostatic adjusment occurring

Kosciuszko National Park

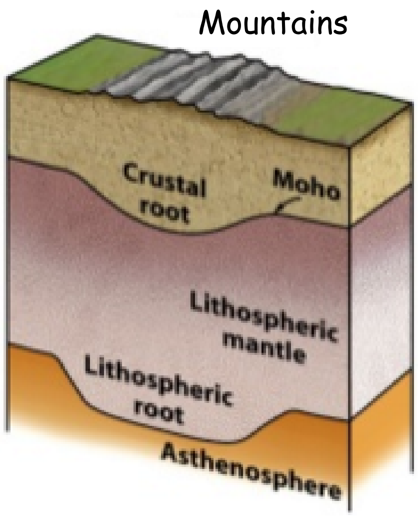
Crustal thickening

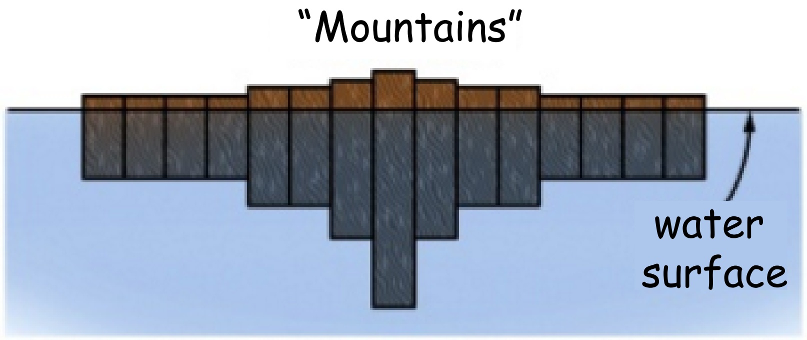
- A large amount of crustal thickening accompanies orogenesis
- continental crust in mountain belts typically 50-60km thick (up to 85km) c.f. normal continental crustal thickness → 30-40km



Crustal roots

- High mountains are supported by lithosphere thickened by orogenesis
- thickened crust helps buoy the mountains upwards

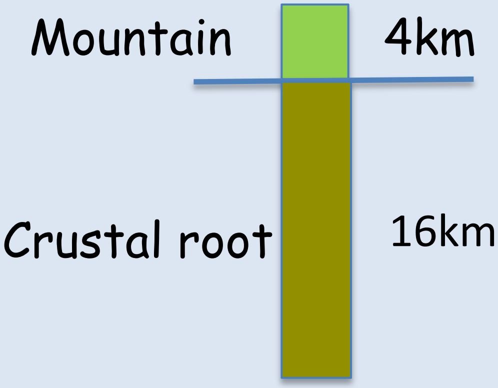




Post orogenic processes

- After continental collision finishes, uplifted mountain chain is relatively quickly reduced by erosion
- isostatic adjustment produces more uplift tending to maintain the surface elevation → extends life of orogenic mountains
- eventually the crust is worn down to a normal thickness with a very flat surface
- such deeply eroded mountain belts are typical of many parts of the continental crust
- many shield areas show indications of having once been orogenic belts

Effect of isostatic rebound



With erosion rate 2km/myr after 1myr

total thickness = 18km

mountain height = 18/5 = 3.6km

After further 2myrs total thickness = 16km

mountain height = 16/5 =3.2km

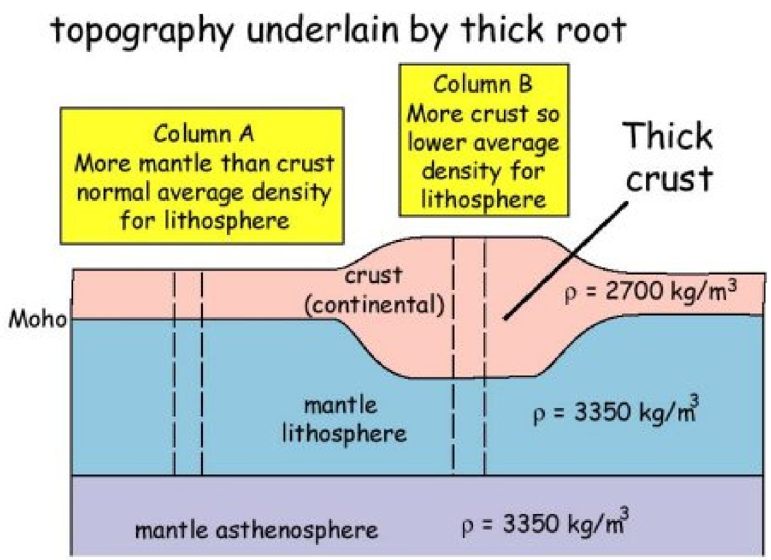
Mountain height reducing 0.4km/myr

Erosion, Southern Alps NZ

- Erosion of Southern Alps produces enormous amount of sediment
- erosion rate so great it would demolish mountain range in 2 or 3 million years if no other process going on
- it takes no more than about 10million years to completely demolish mountains 5km high down to sea level
- horizontal compression pushes mountains up → erosion rates and uplift rate of mountain belts → more or less in equilibrium
- only when horizontal compression forces cease, erosion wins and eventually erodes down to a plain SE Australian highlands

Isostasy

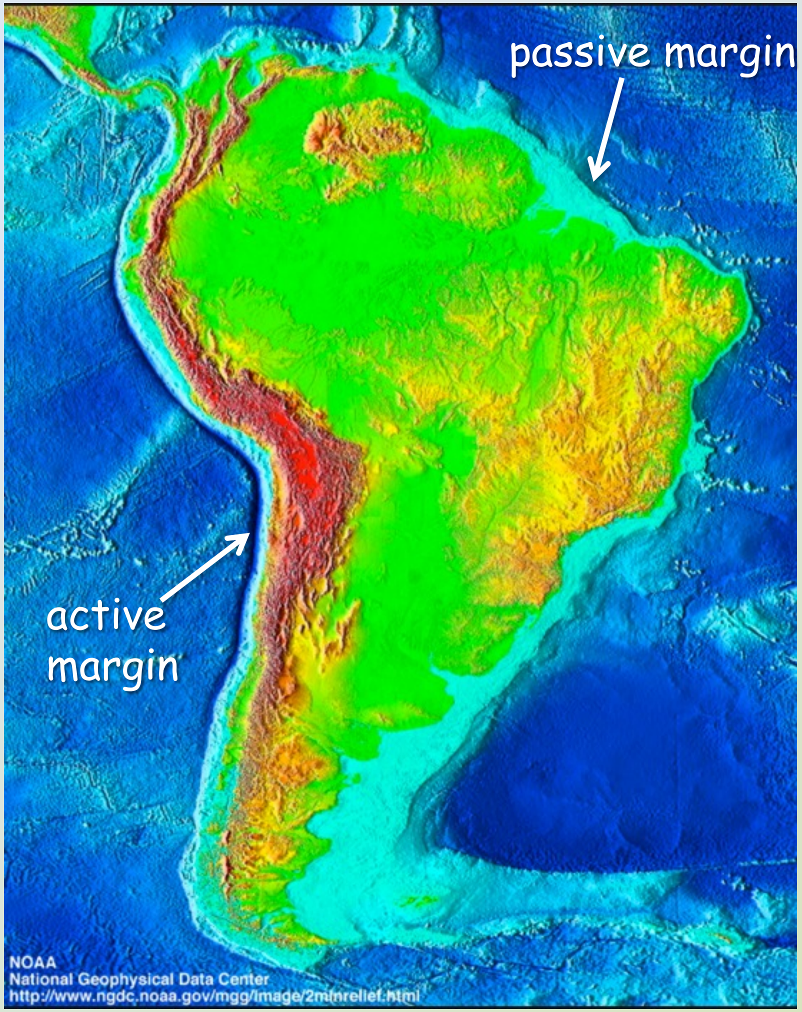
- Isostasy → state of buoyancy → object immersed in a fluid is buoyed with a force = weight of displaced fluid
- function of the density and thickness of the overlying crust
- adding weight pushes base of the lithosphere down → removing weight causes slow isostatic rebound



High topography (relative to surroundings) due to THICK CRUST
Example - Himalayas/Tibet

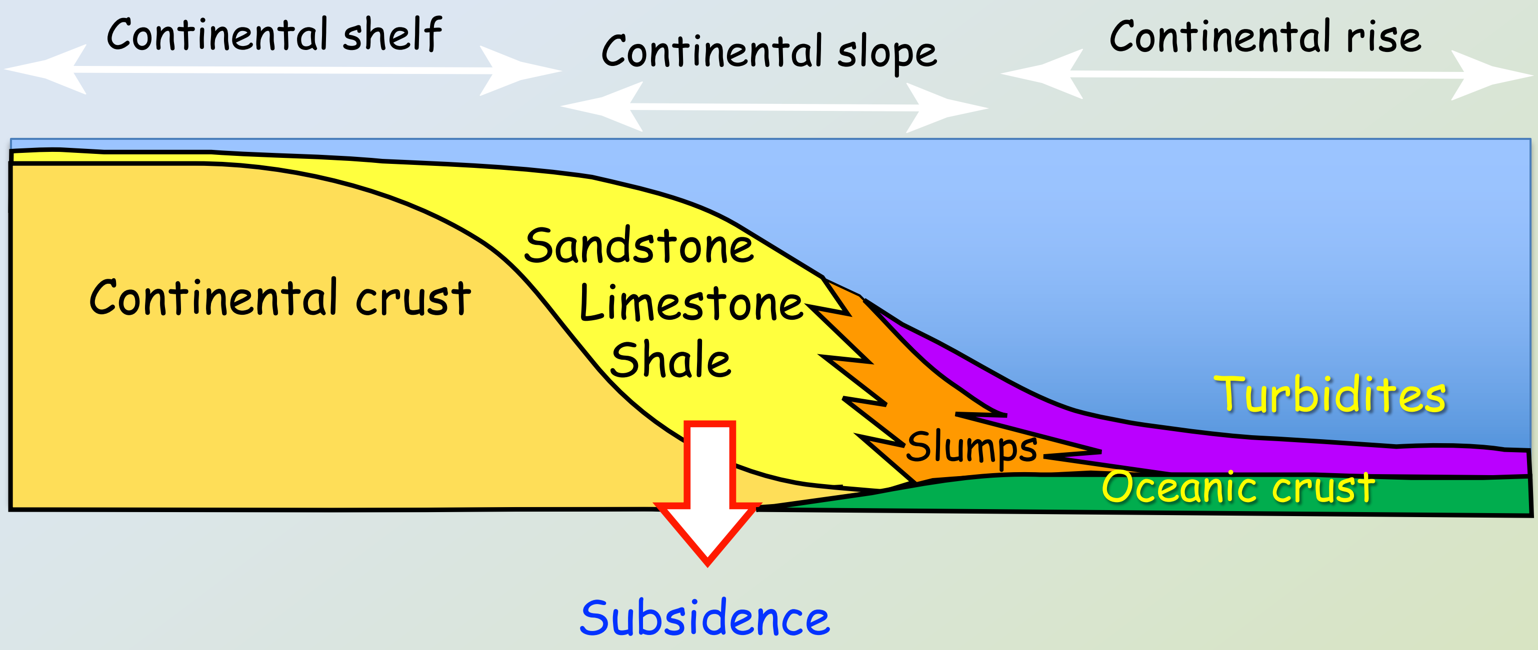
Types of continental margins

- 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
- ideal sites for sediment accumulation
- active margins are formed by subduction at convergent plate boundaries → seismically active



Structure of passive margin

- Passive margins cool as they move away from ocean ridge
- passive margins subside slowly as thick deposits of continental shelf sediments accumulate → depress underlying asthenosphere
- adjacent sequences of deep water turbidites accumulate on the continental rise



Types of plate convergence

- Folded mountain belts are produced at convergent plate boundaries
- three types of convergent boundaries are possible:

(1) Convergence of two oceanic plates

→ island arc e.g. Indonesian Archipelago

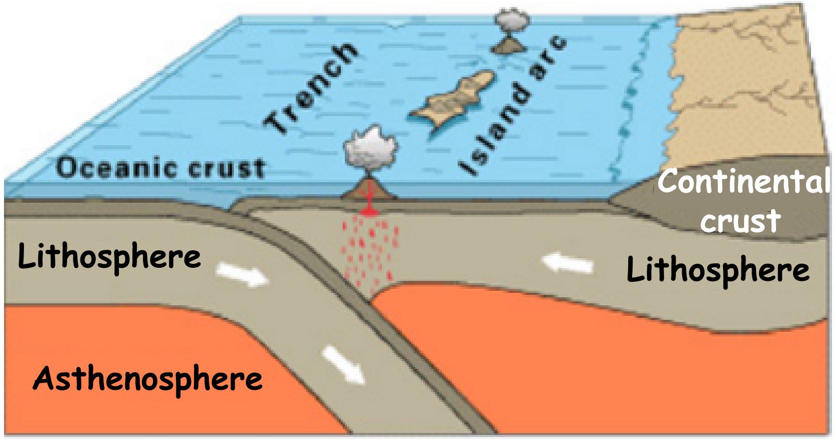
(2) convergence of oceanic and continental plates

→ continental volcanic arc e.g. Andes, South America; Cordillera, North America

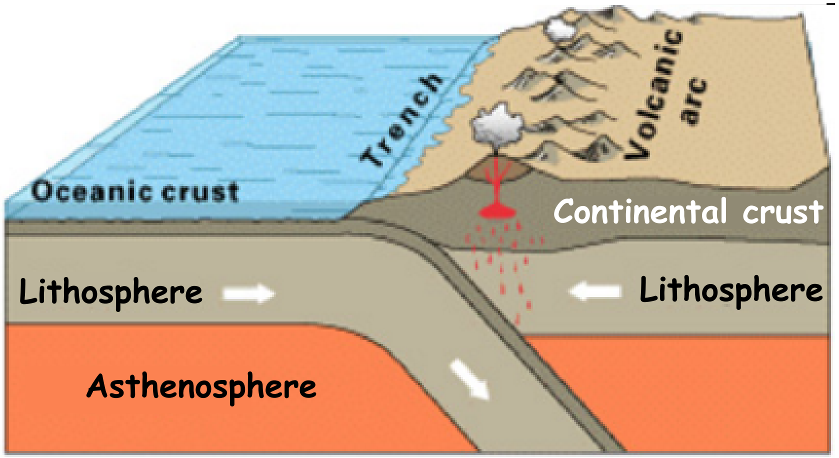
(3) convergence of continental plates

→ continental collision zones e.g. Himalayas, Alps

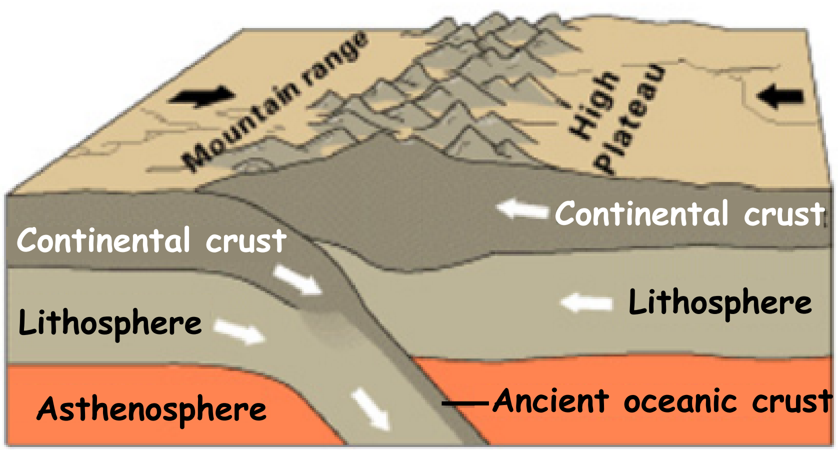
Convergent plate boundaries



Oceanic-oceanic convergence



Oceanic-continental convergence



Continental-continental convergence

Oceanic-continental orogenesis

- Similar features to those in island arcs are found in oceanic-continental convergence
- this style of orogenesis is distinctive in two ways:
  (1) Thick sequences of deformed marine sediments that formed on a former passive margin → not present in island arcs
  (2) High-silica magmas are emplaced in thick continental crust rather than oceanic crust
- this produces thick crust and therefore high surface elevations
- partial melting in the thick crust produces numerous granite batholiths

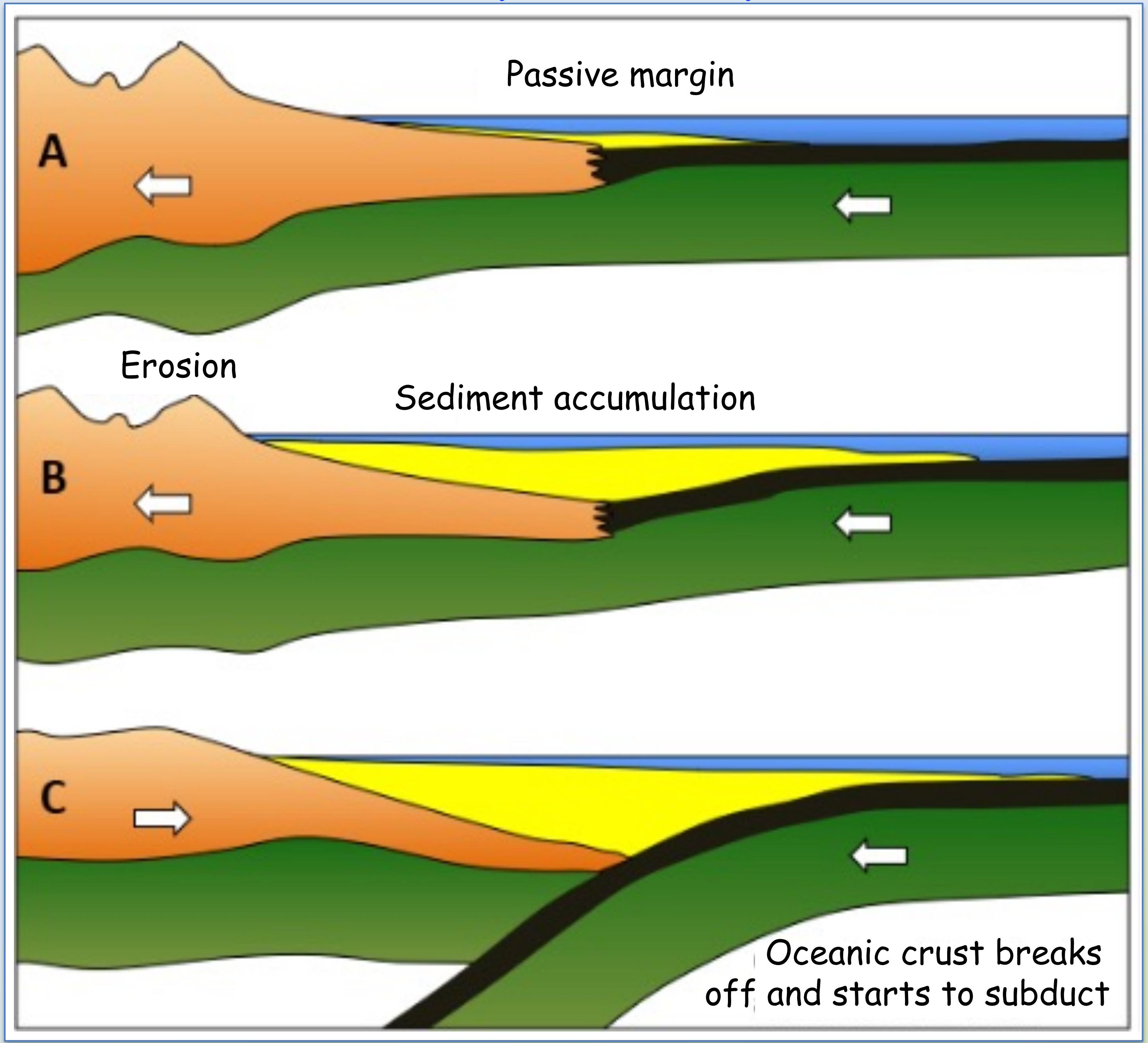
Oceanic-continental convergence
Parinacota, Chilean Andes

Oceanic-continental convergence
Rocky Mts, Colorado

Transformation of passive plate boundaries

- To produce orogenesis → passive margin → must transform into convergent margin of active deformation
- process not observed in modern times (relatively rapid?)
- due to cooling of lithosphere and the weight of accumulating sediment, plate detaches from continent and begins subducting → becomes convergent boundary → initiates orogenesis
- magma generation → heat input, deformation, metamorphism of deep pile of sediment

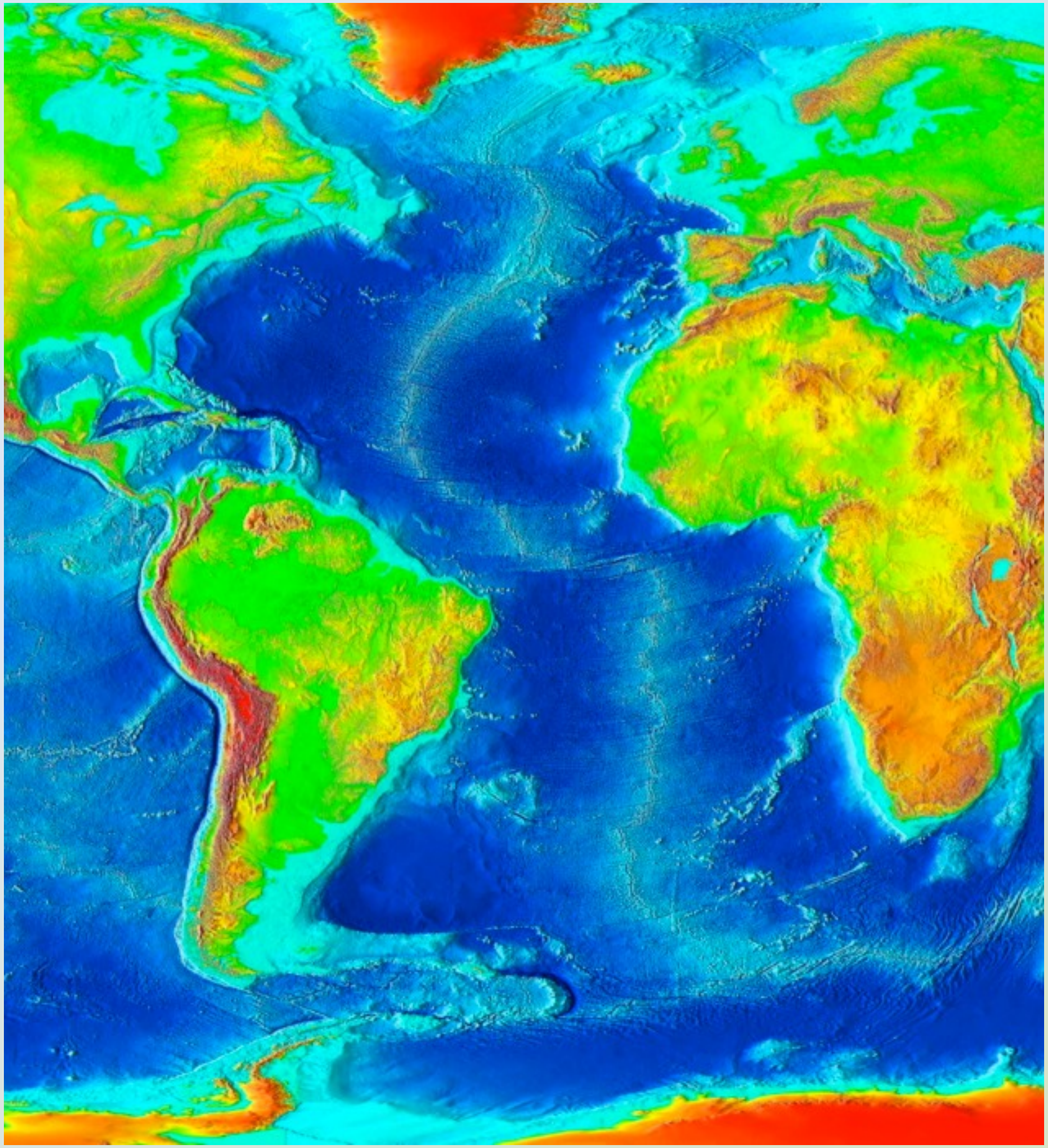
Transformation of passive plate boundaries



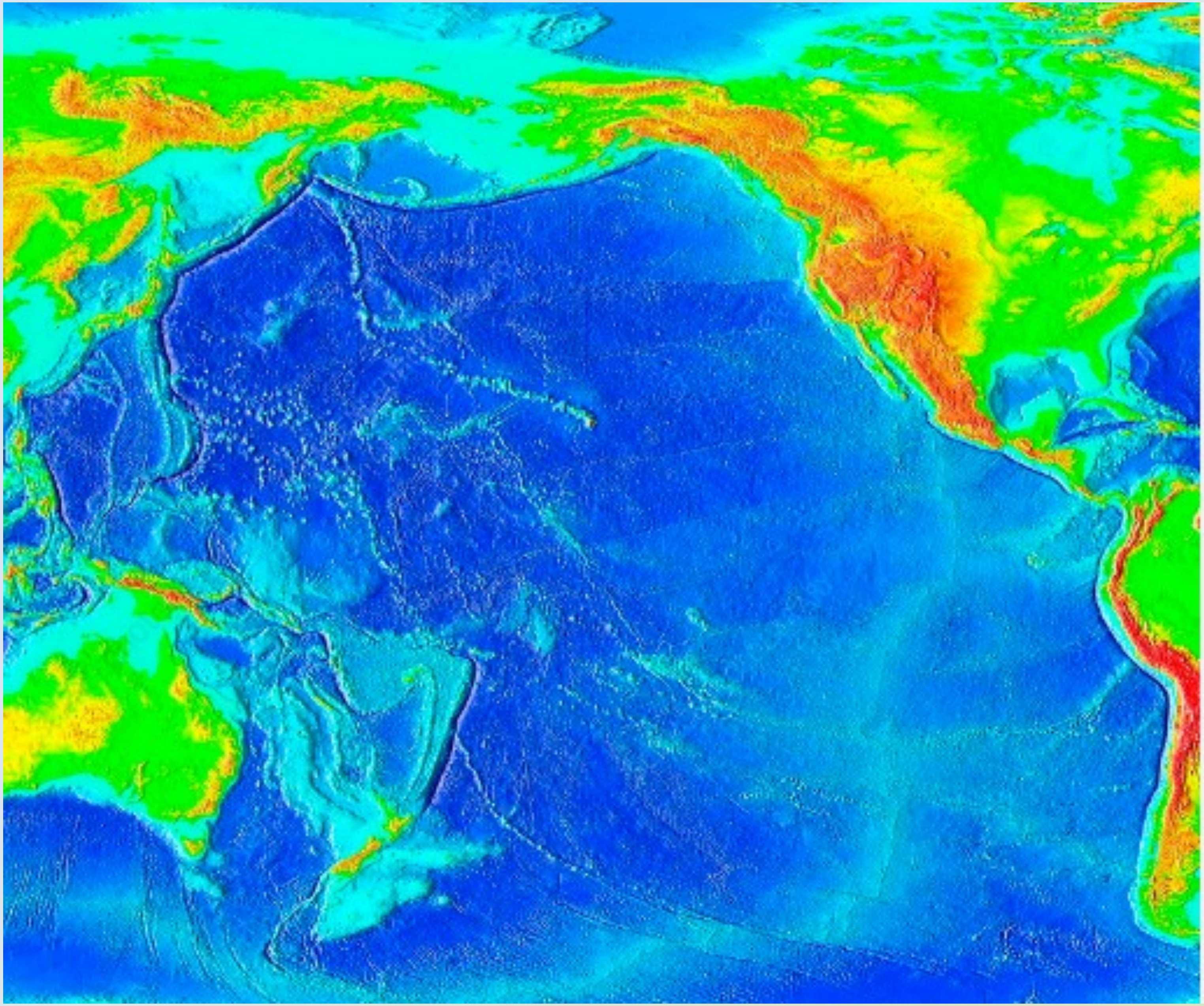
Continent-continent collision

- The rate of subduction may exceed the rate of generation of new crust at an oceanic ridge
- if rate of subduction > rate of generation of crust → ridge subducted
- in this case, the ocean will close rapidly due to continued subduction
- the two continental masses on each side will eventually collide with each other
- an island arc may also be involved in the collision
- because continental crust cannot be subducted the convergence is accommodated by intense deformation
- eventually collision causes subduction and then convergence to cease

Topographic image of Atlantic ocean



Topographic image of Pacific Ocean

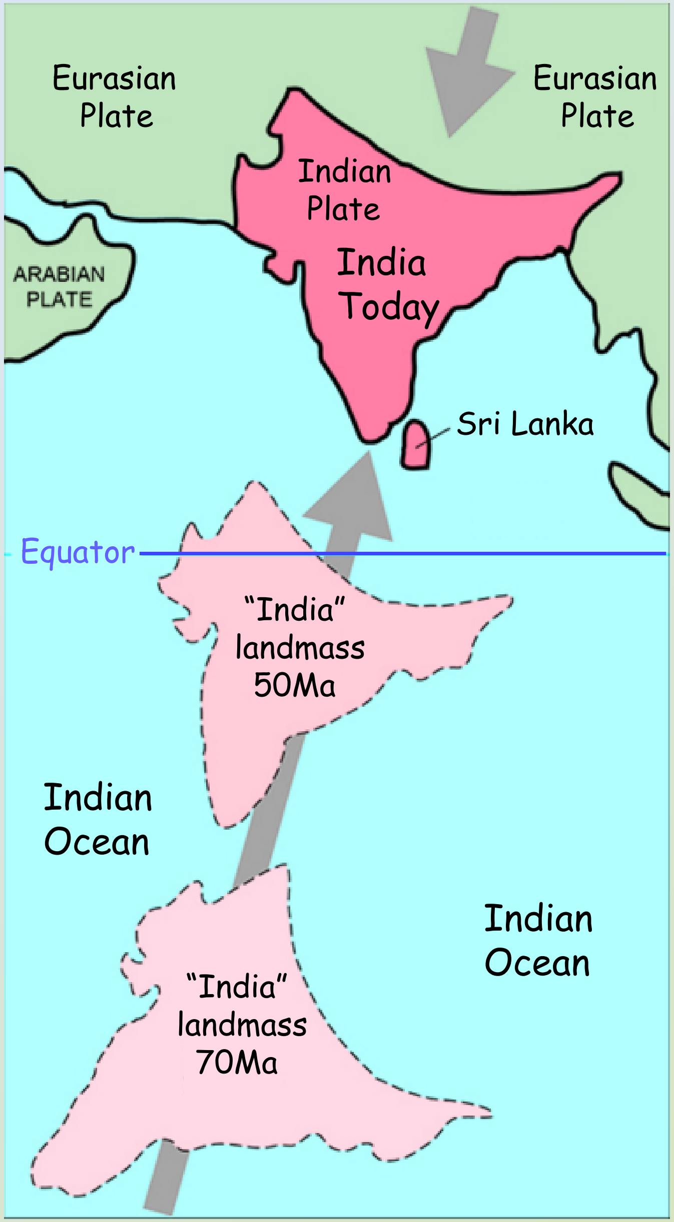


Collision orogenesis

- A closing ocean basin will bring active and passive continental margins together
- often slices of the destroyed ocean will be preserved as ophiolite belts
- these ophiolite belts mark the joining line (suture) between the two formerly separate continents
- welding together of two continents in this way produces a mountain range within a larger continent
- modern examples include the Himalayas, Alps and the Late Palaeozoic, Ural Mts
- a very thick crust and high elevations can be produced

Himalayan continental collision

- Supercontinent Gondwana began to breakup in the Jurassic Period ~200Ma
- India started to drift northward towards Asia
- Indian plate collided with Eurasian plate 40-50myr penetrating 3000km into Asia and still going
- as two continental plates collide → neither plate could be subducted
- continental crust folded and thickened through compression → formed Himalayas



Himalayan continental collision