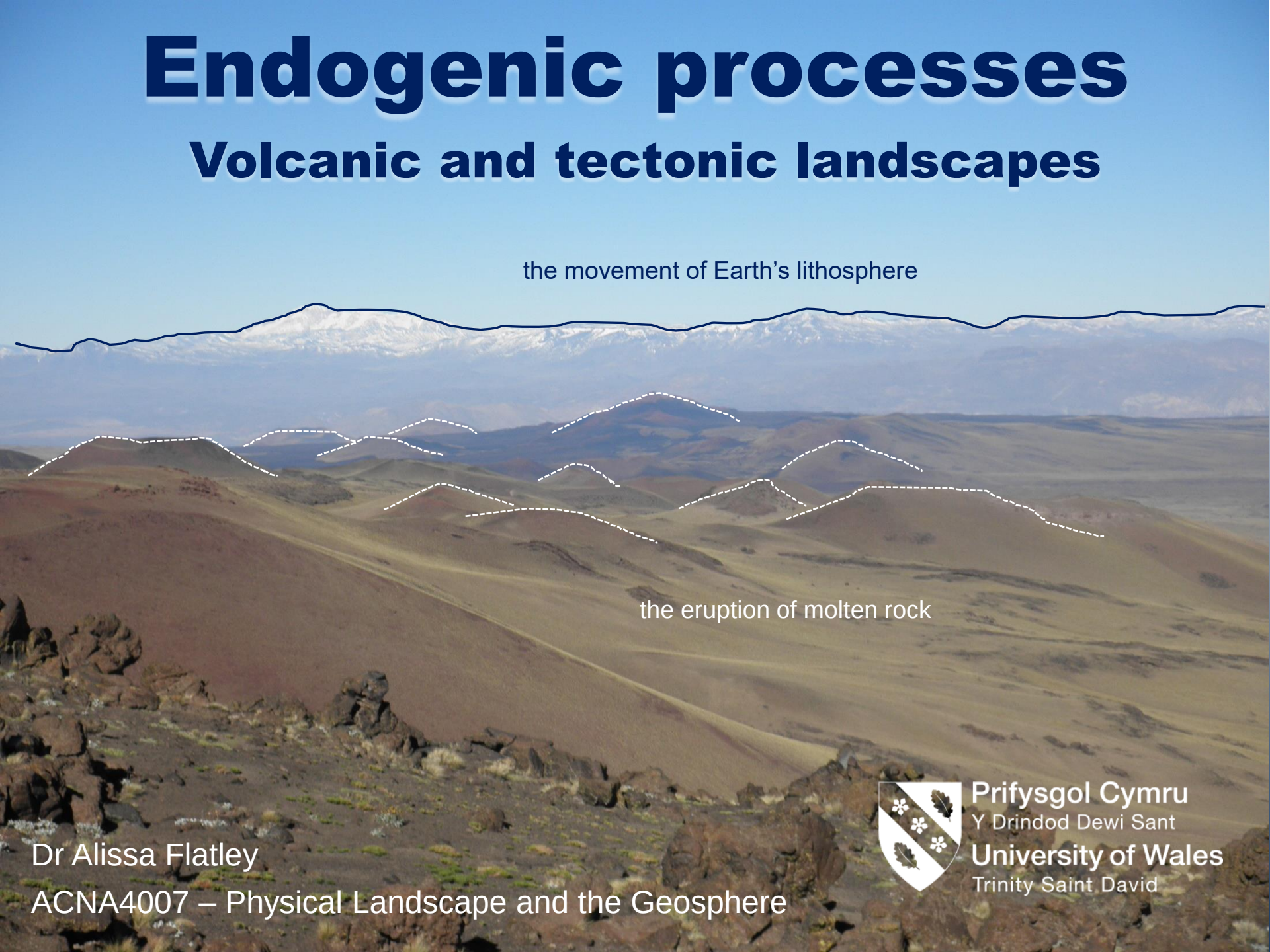
Endogenic processes

Volcanic and tectonic landscapes



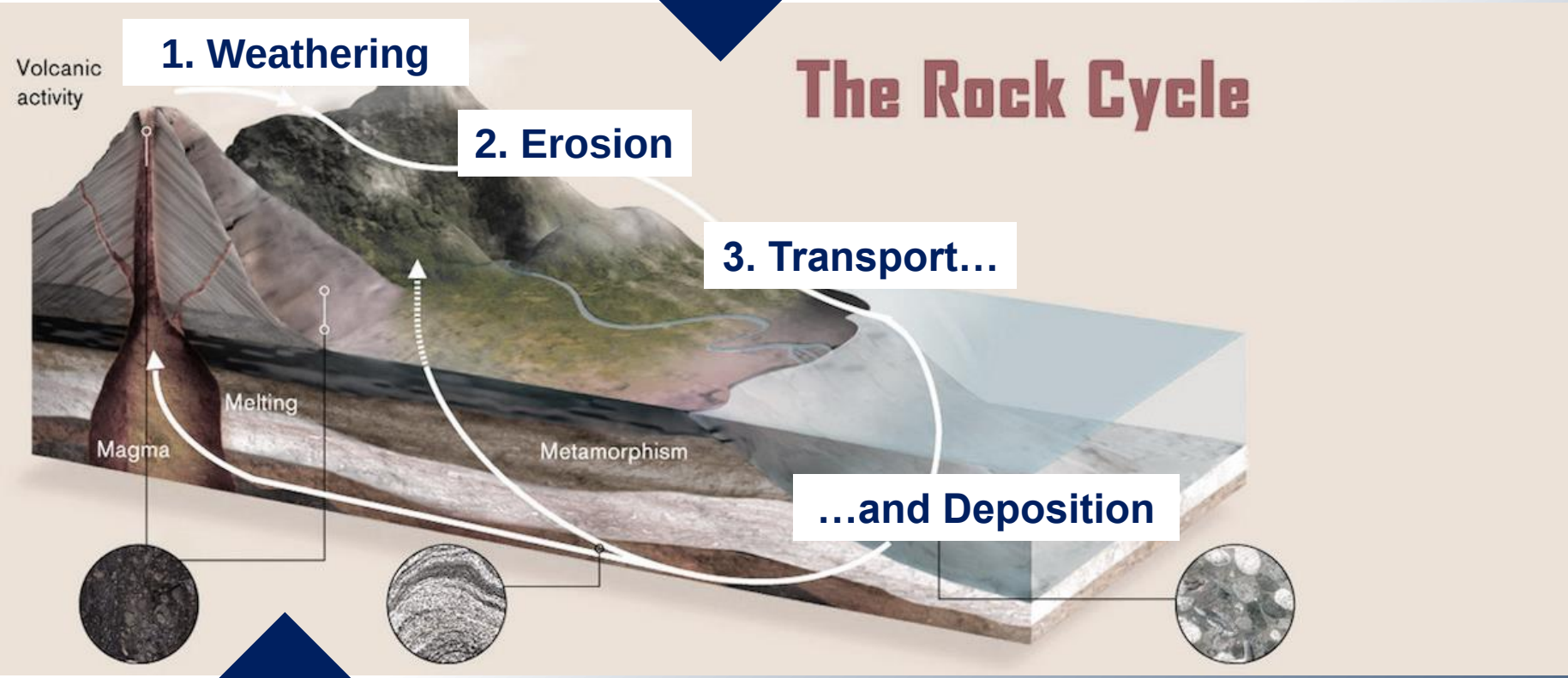
Dr Alissa Flatley

ACNA4007 – Physical Landscape and the Geosphere

Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

The Earth surface

Climate
(exogenic processes)



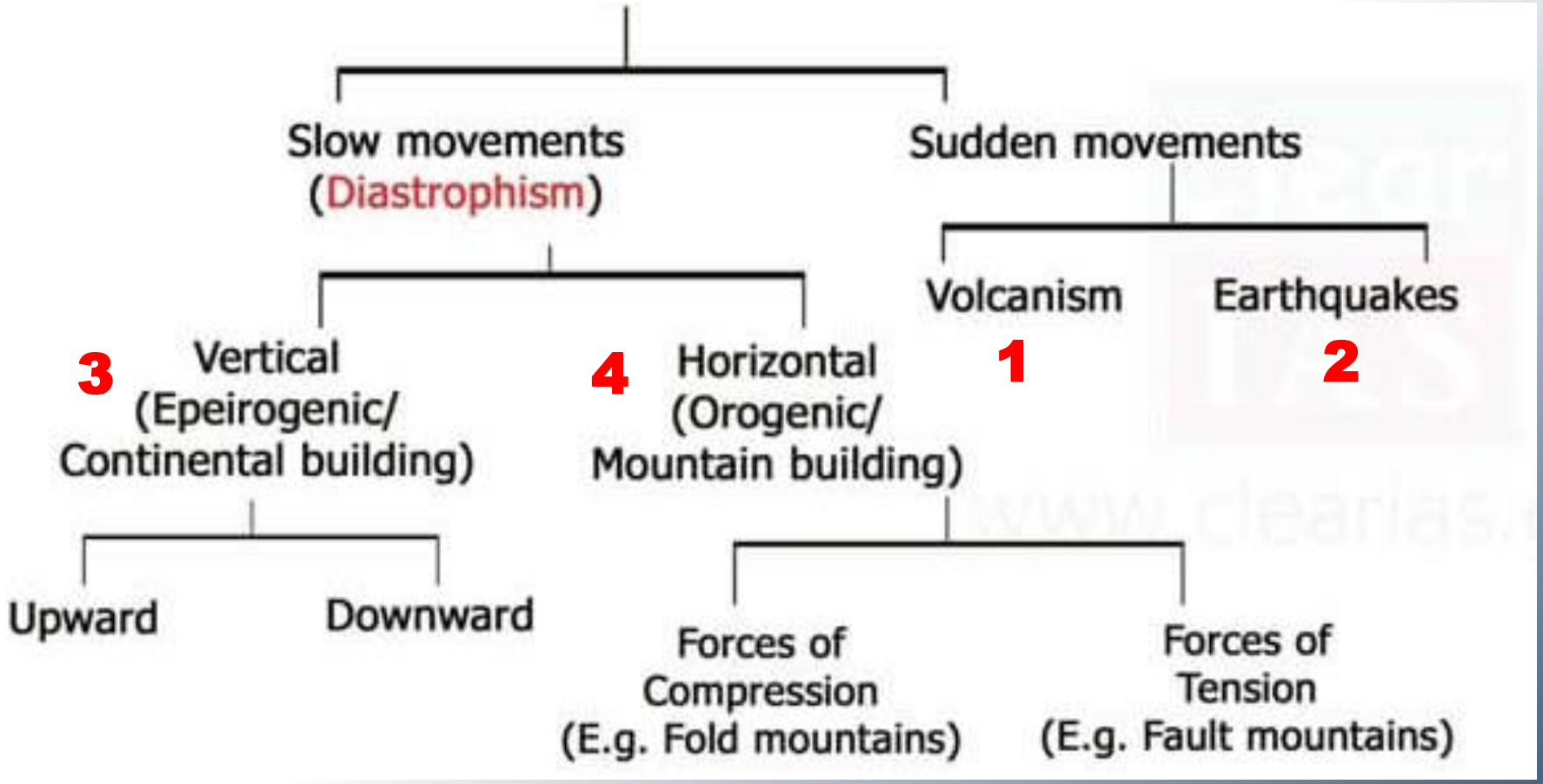
Endogenic Processes

- Endogenic and exogenic processes create landforms
- Endogenic processes – raise mountains and elevate topography above sea level

https://34kiwis.files.wordpress.com/2014/02/the-rock-cycle.jpg

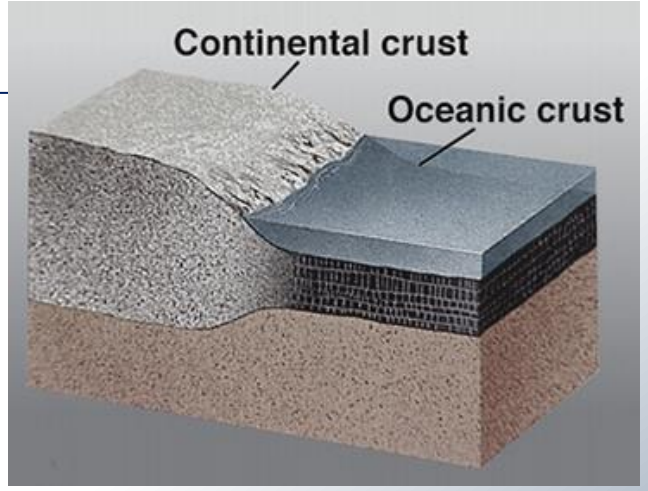
Endogenic Processes

Endogenic processes…

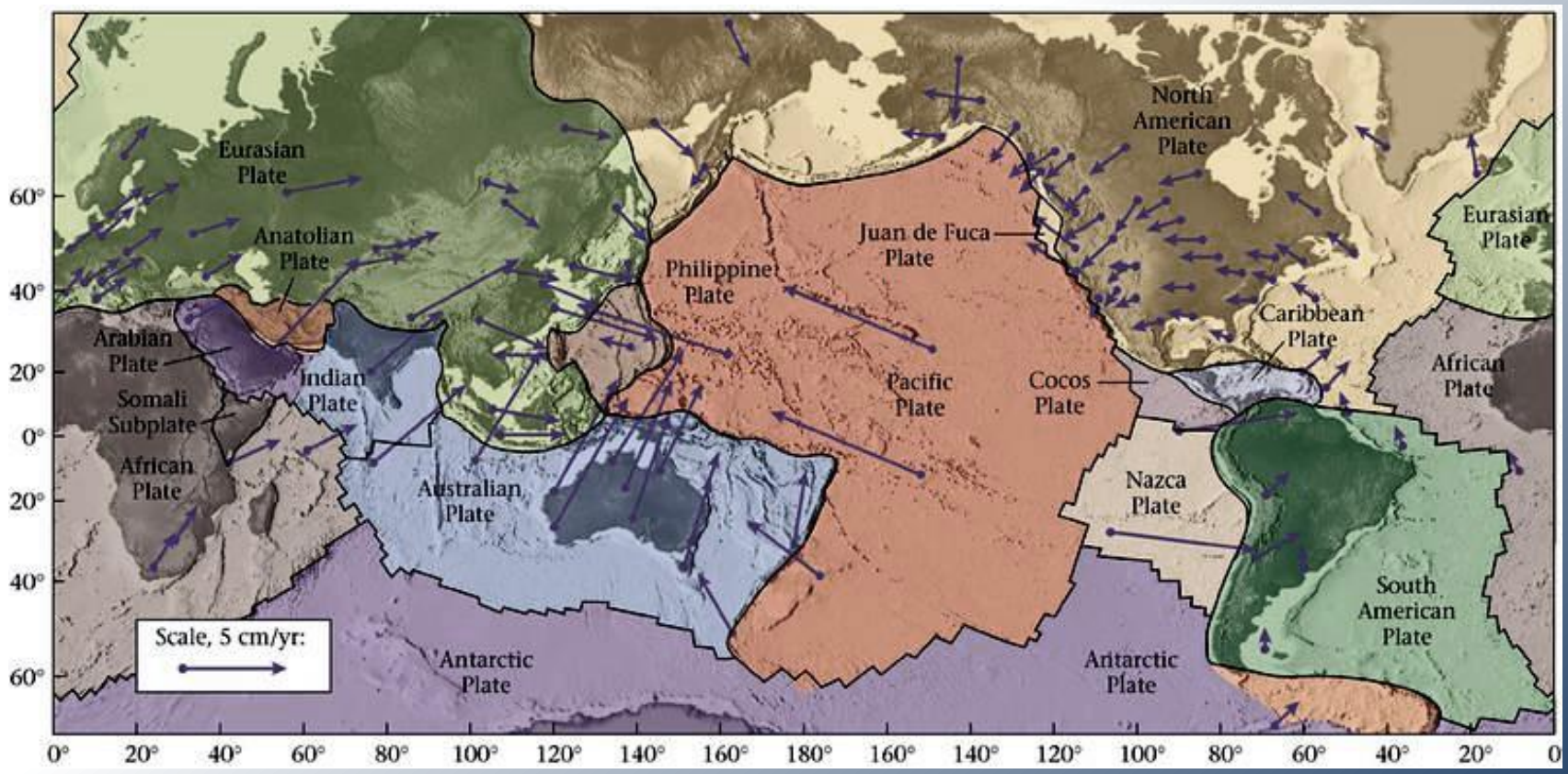


Fast vs slow – short vs long time scales

Plate Tectonics

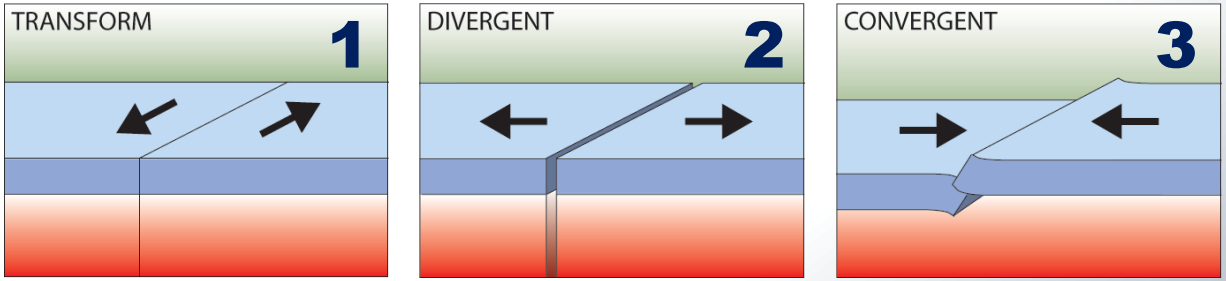


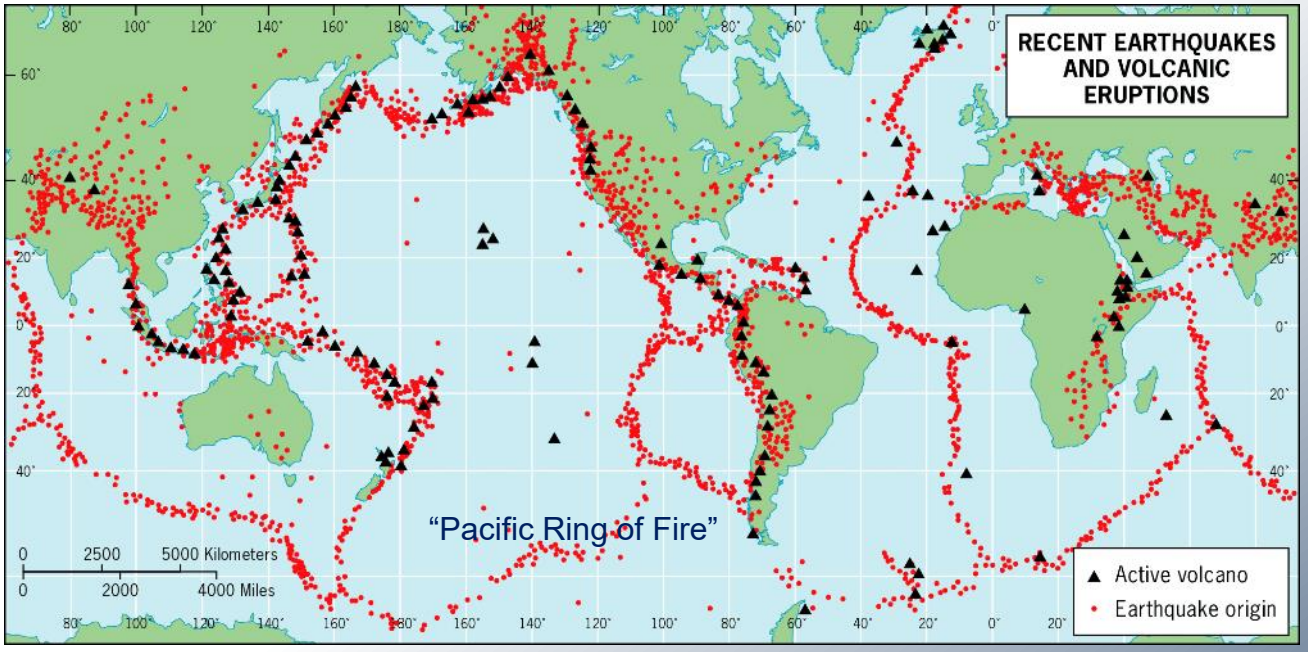
- **Continental Crust:** thick (10-70 km) - buoyant - mostly old
- **Oceanic Crust:** thin (~7 km) - dense - young
- 12 **major plates** (continental and/or oceanic crust) slide around on Earth (cms/yr)



Tectonics – Quakes and Fire

- Three types of plate boundary

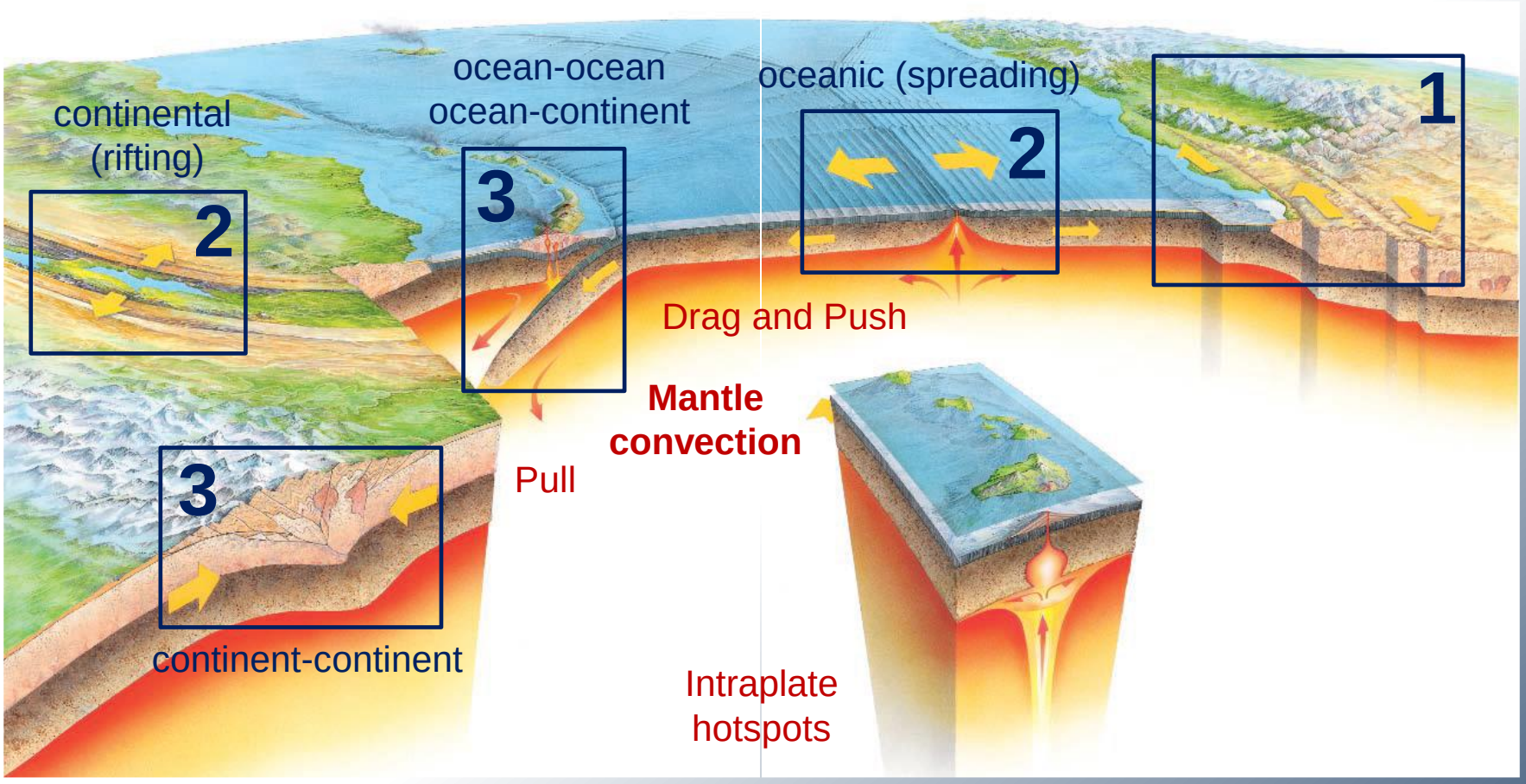




- Earthquakes and volcanism is mostly focused at plate margins
- General volcano types: Subduction - Rifting - Hotspots

http://planetolog.com/map-world-detail.php?type=TEC&id=1

Tectonics – Quakes and Fire



3. Convergent plate boundary

2. Divergent plate boundary

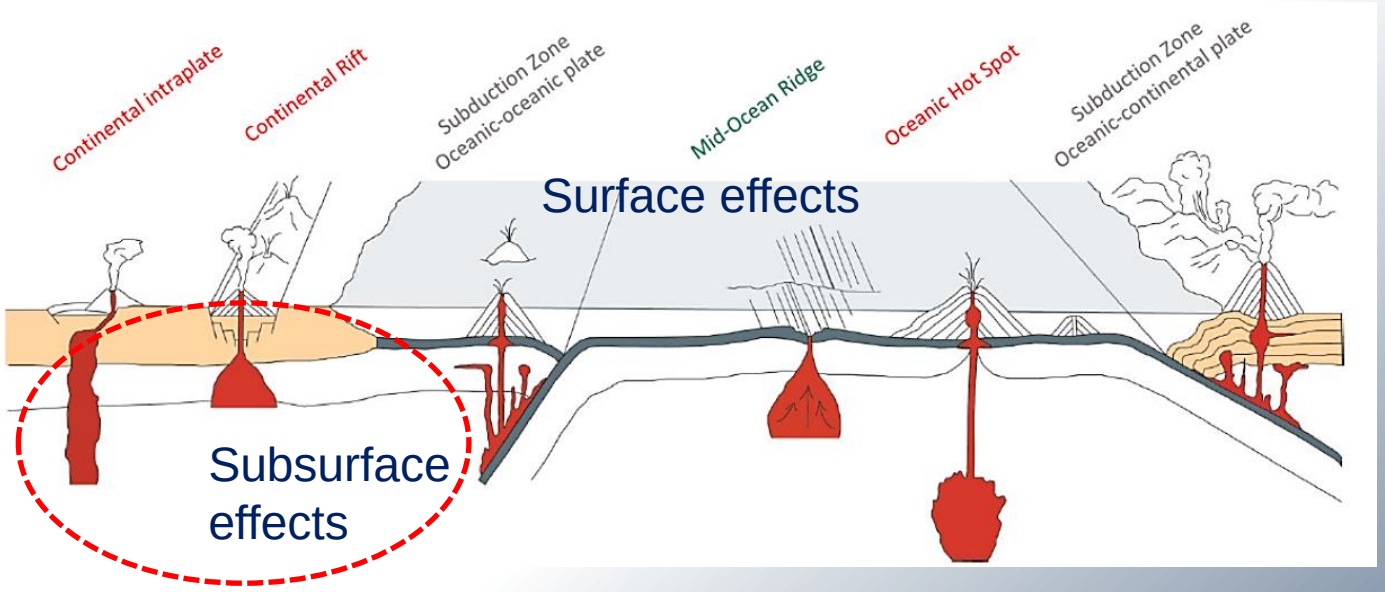
1. Transform plate boundary

Processes in space and time… !!

Marshak 2008

Tectonics, Volcanism and Lava

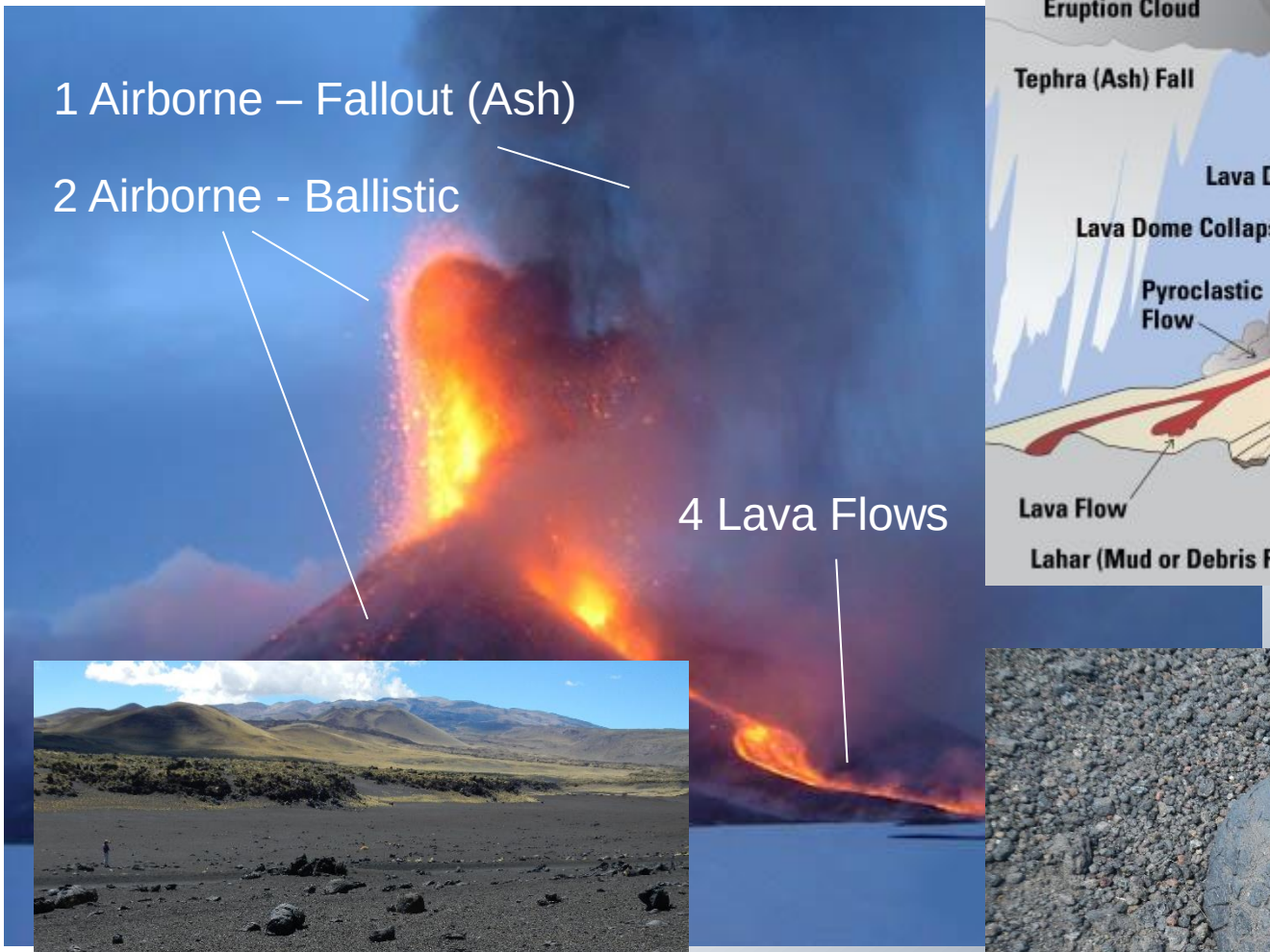
- **Relationship**: Tectonic setting – magma evolution and type – volcanism type

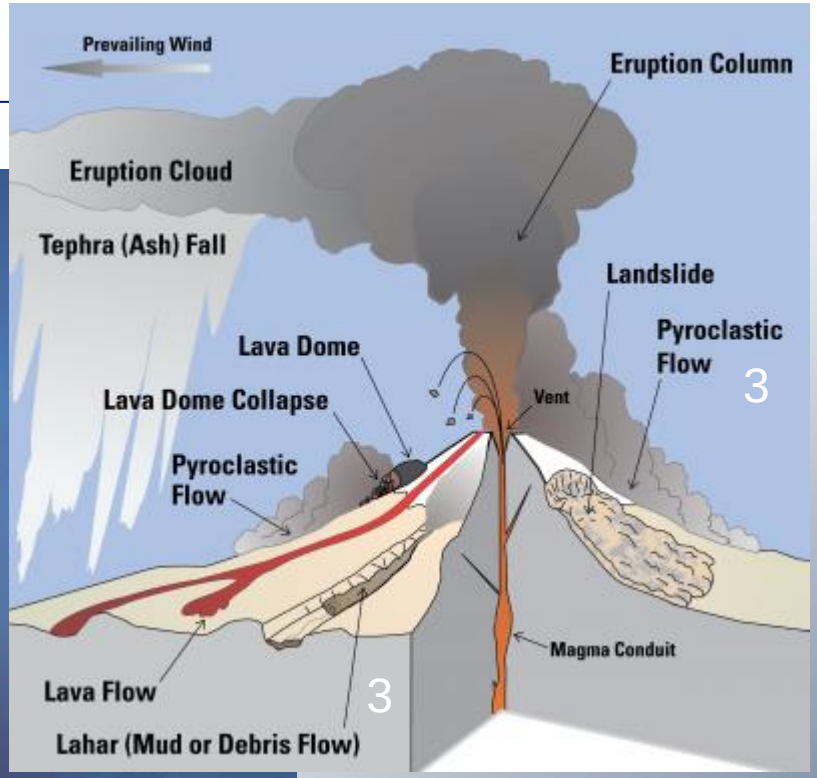


Composition	Rhyolitic	Dacitic	Andesitic	Basaltic
Silica content	70%		60%	50%
Eruption temperature	750°–900°C		900°–1000°C	1100°–1200°C
Viscosity (water = 0.01 poise)	1×10^7 poise		3×10^4 poise	500 poise
Gas content	5.0%		2.0%	0.5%
"Explosiveness"	More explosive			Less explosive

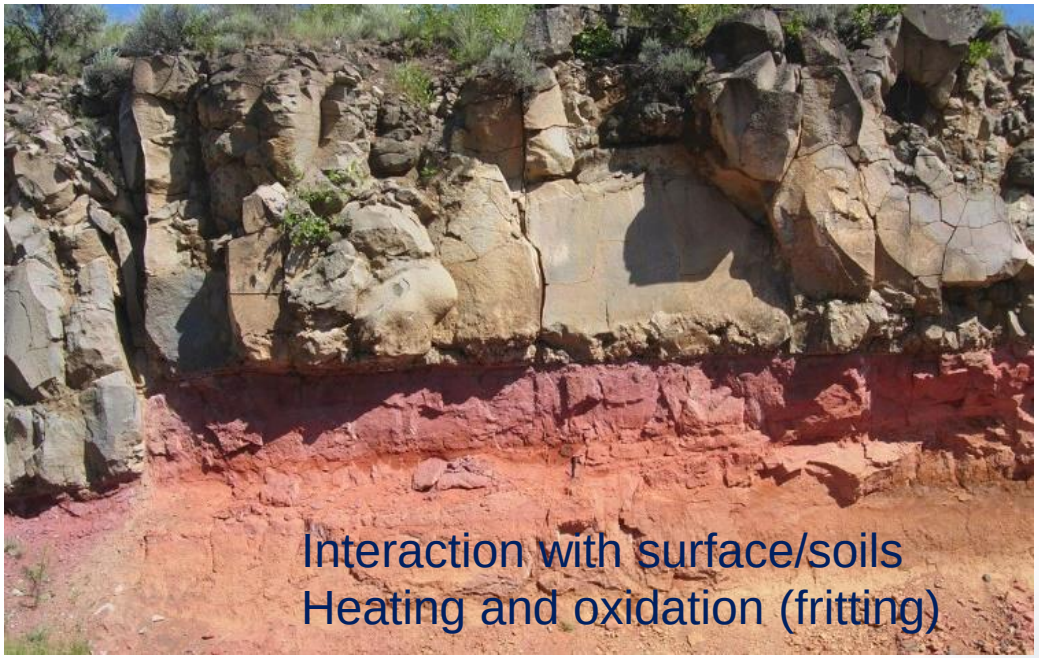
Hydrothermal Alteration and Landscapes

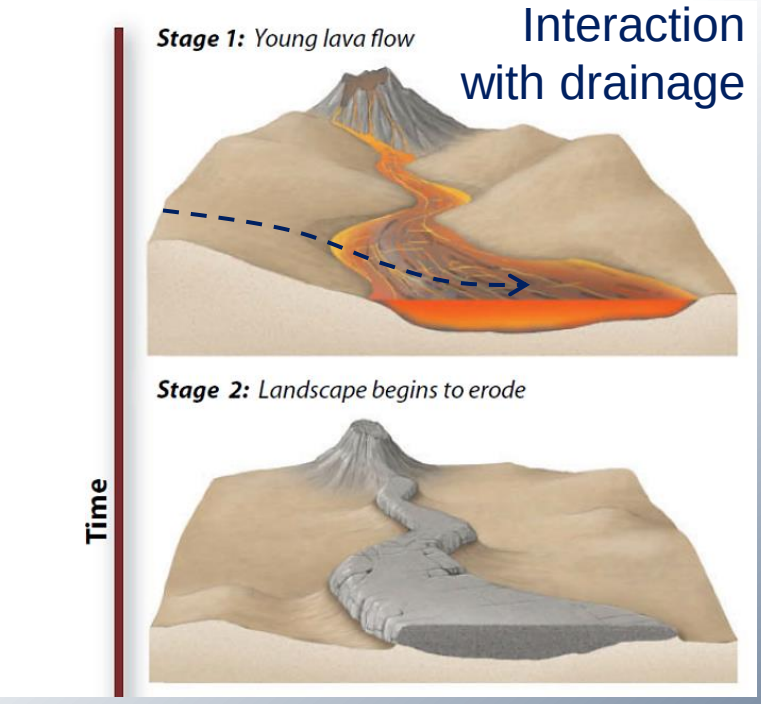
Volcano Deposits





Volcanic Deposits & Landscape (1)





Volcanic Deposits & Landscape (2)

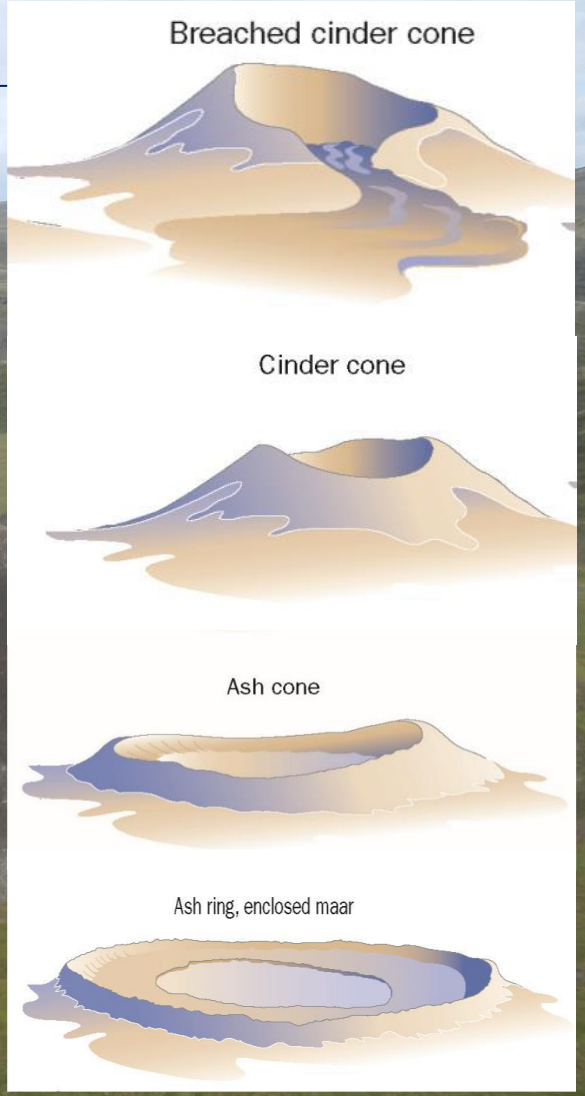
- Difference in **flow behaviour** leads to different surface morphologies and flow types

viscosity
vs
discharge rate and slope

2 minutes...

Volcano Types (1)

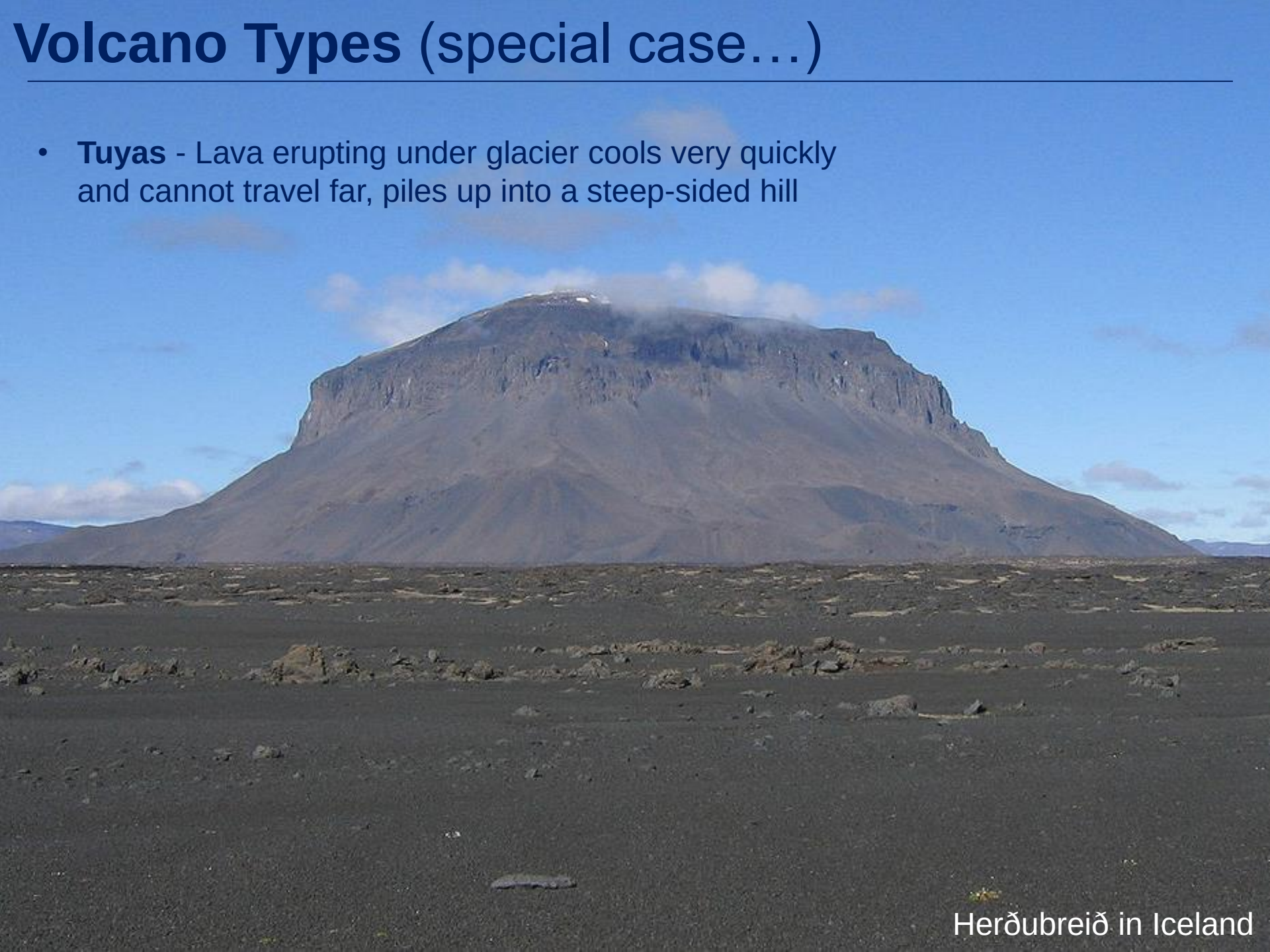
- **Cinder (Scoria) Cones**
- monogenetic fields
- shape is defined by the eruptive material (mostly ejecta/scoria) piled up at its angle of repose



- Phreatic or phreato-magmatic eruptions (explosive contact with water)

Volcano Types (special case…)

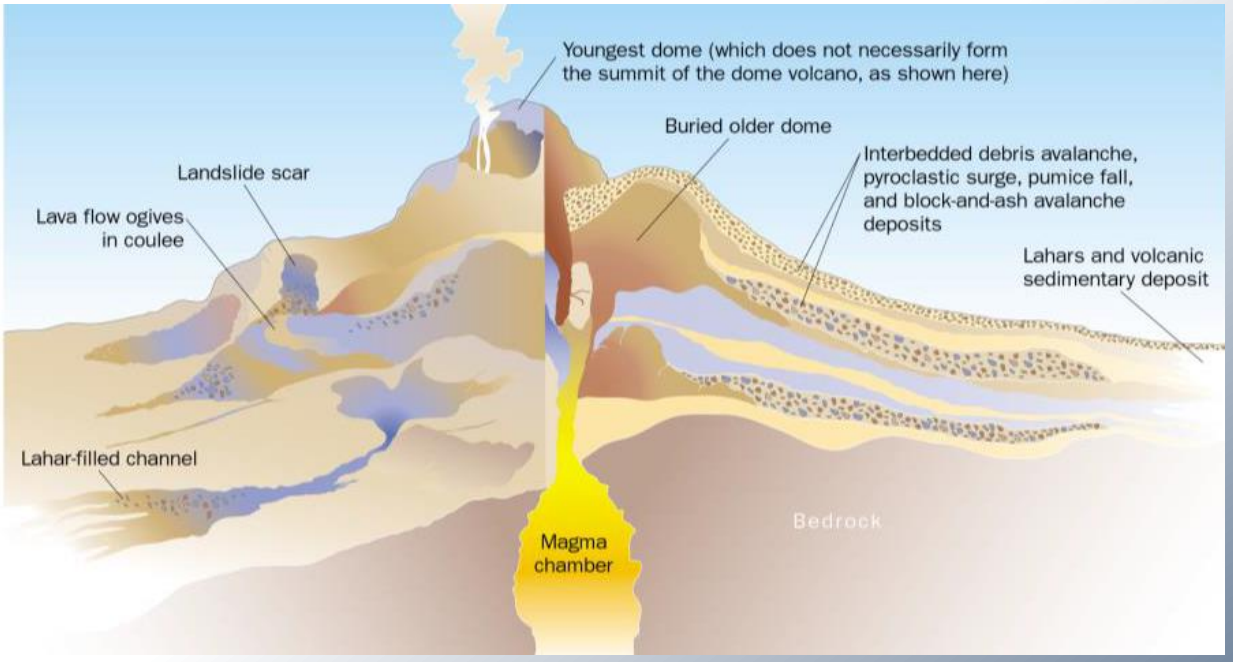
- **Tuyas** - Lava erupting under glacier cools very quickly and cannot travel far, piles up into a steep-sided hill



Herðubreið in Iceland

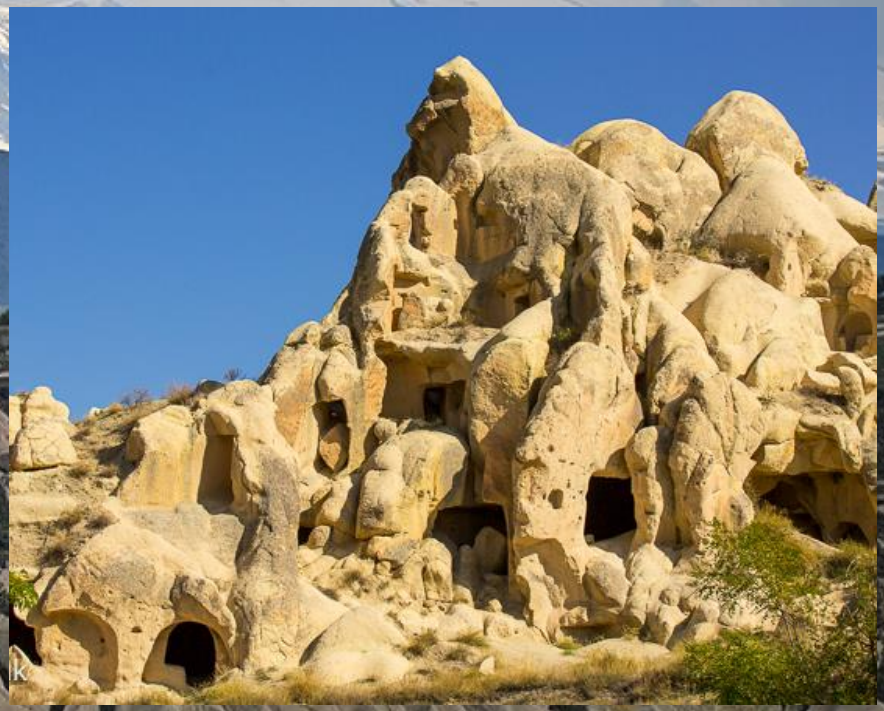
Volcano Types (2)

- **Stratovolcanoes**
- Height: 100s to 1000s of m, ~ km's
- Material: 70-80 % ejecta; but an equally large percentage of lava flows might be present (lava flows are most commonly blocky a'a) – composite and polygenetic



Volcano Types (2)

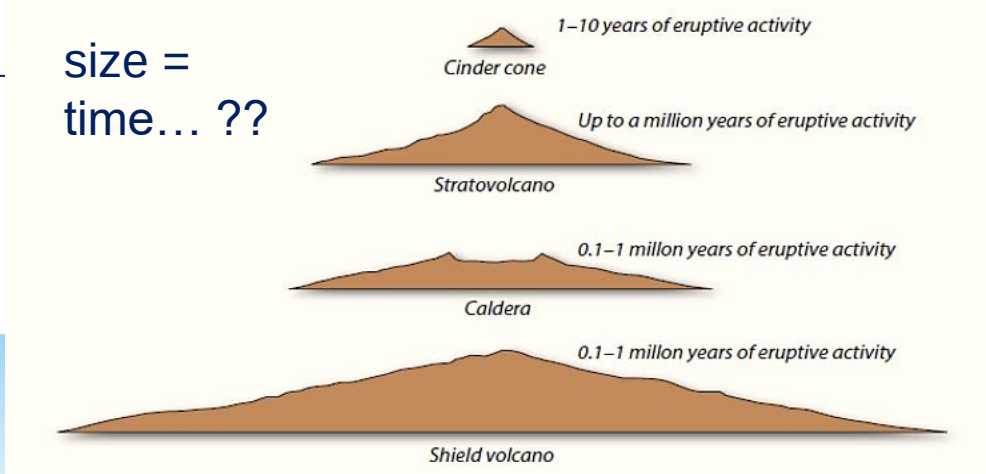
- Cappadocia (Turkey)
- Miocene to Quaternary volcaniclastic deposits
- Relatively soft (tuff and ignimbrite, i.e. from ashfall and pyroclastic flows)

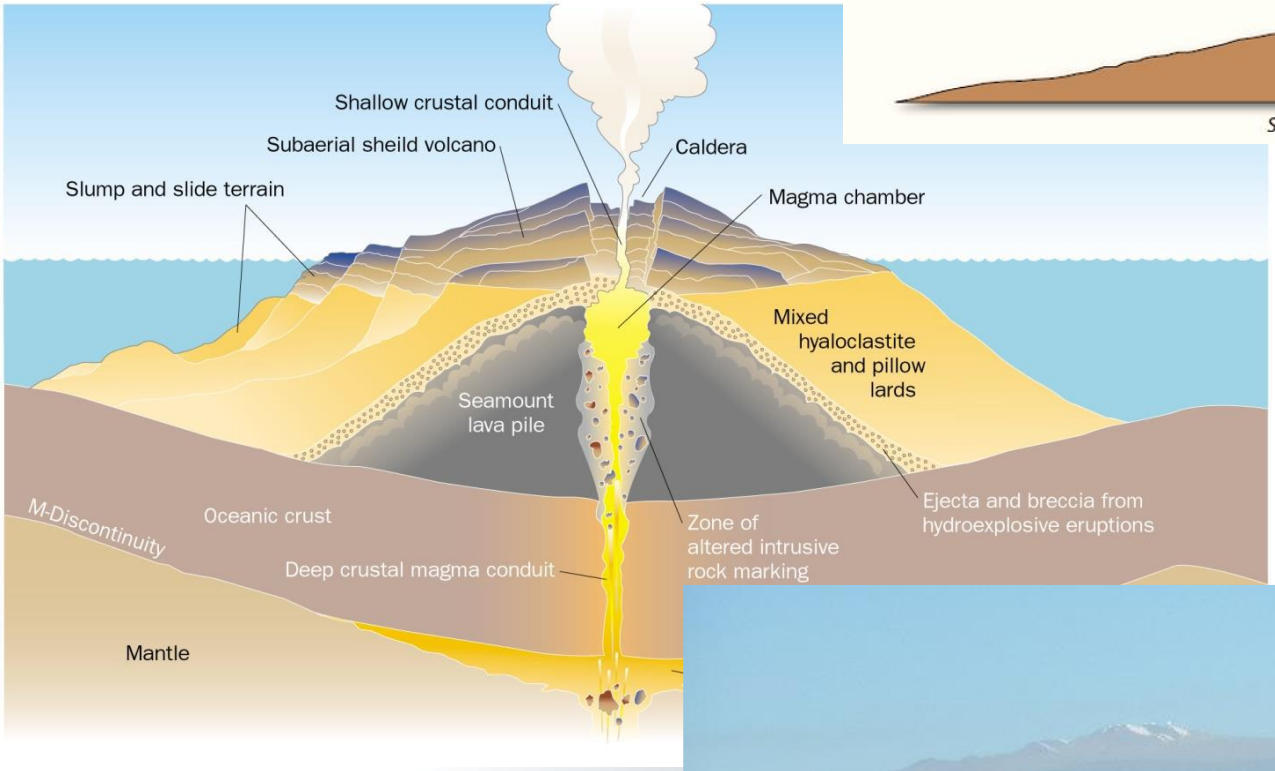


Volcano Types (3)

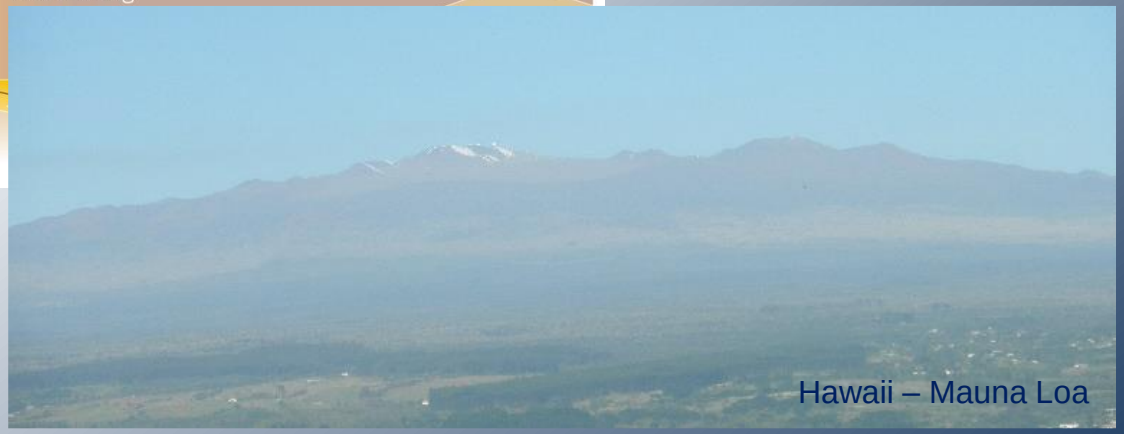
- **Shield volcanoes**
- polygenetic
- Gentle slopes of 2-12°

size =
time… ??





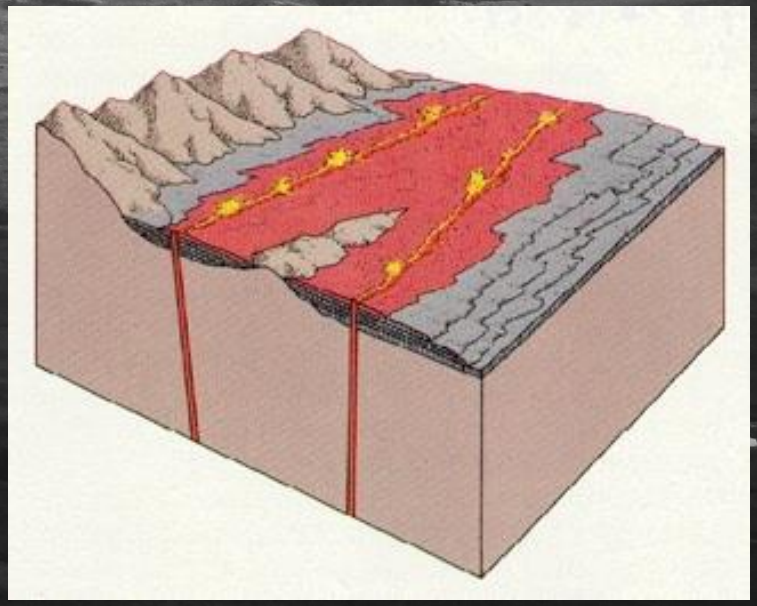
- Development of a Hawaiian shield volcano from the ocean floor to above sea level



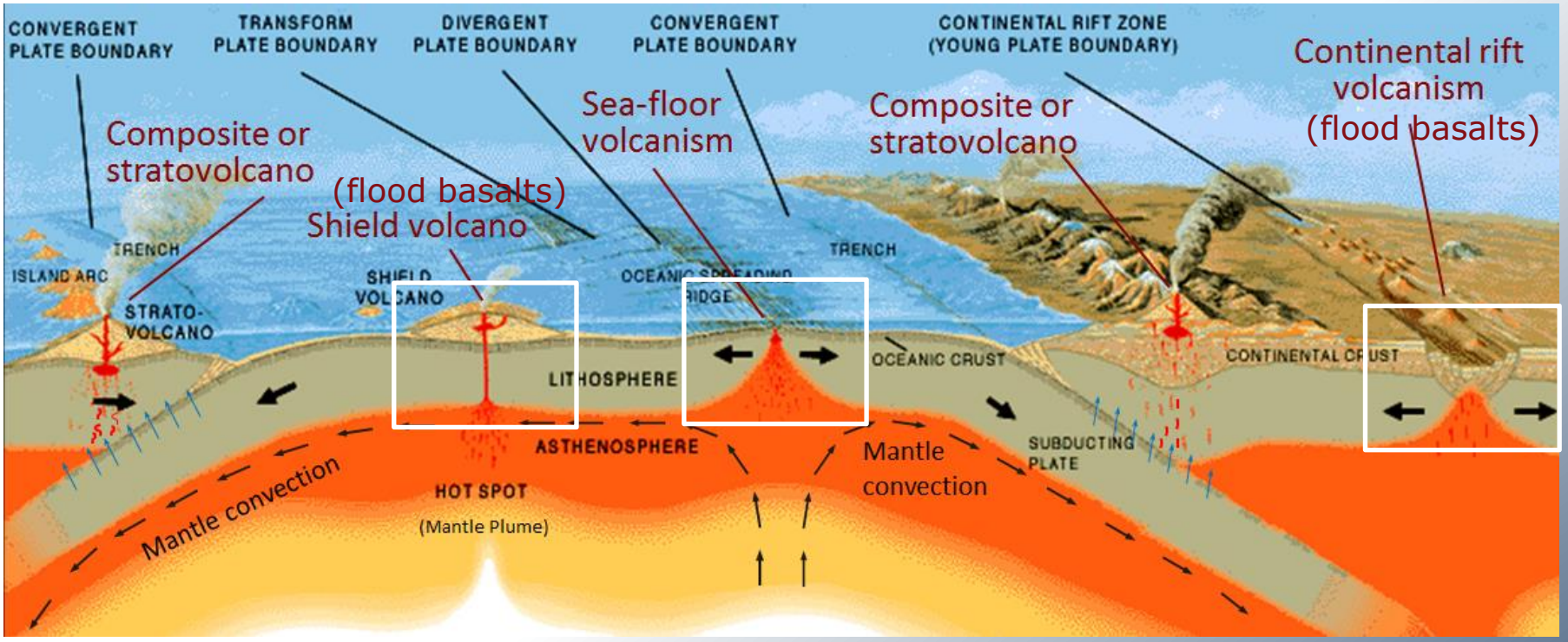
Volcanism – Large Igneous Provinces

- **Flood Basalts** - high volume eruptions that flood vast areas of the Earth (LIP, $>1\times10^5$ km^2) covering broad regions with flat lying lava surfaces

- Result of mantle convection through **hot spots**



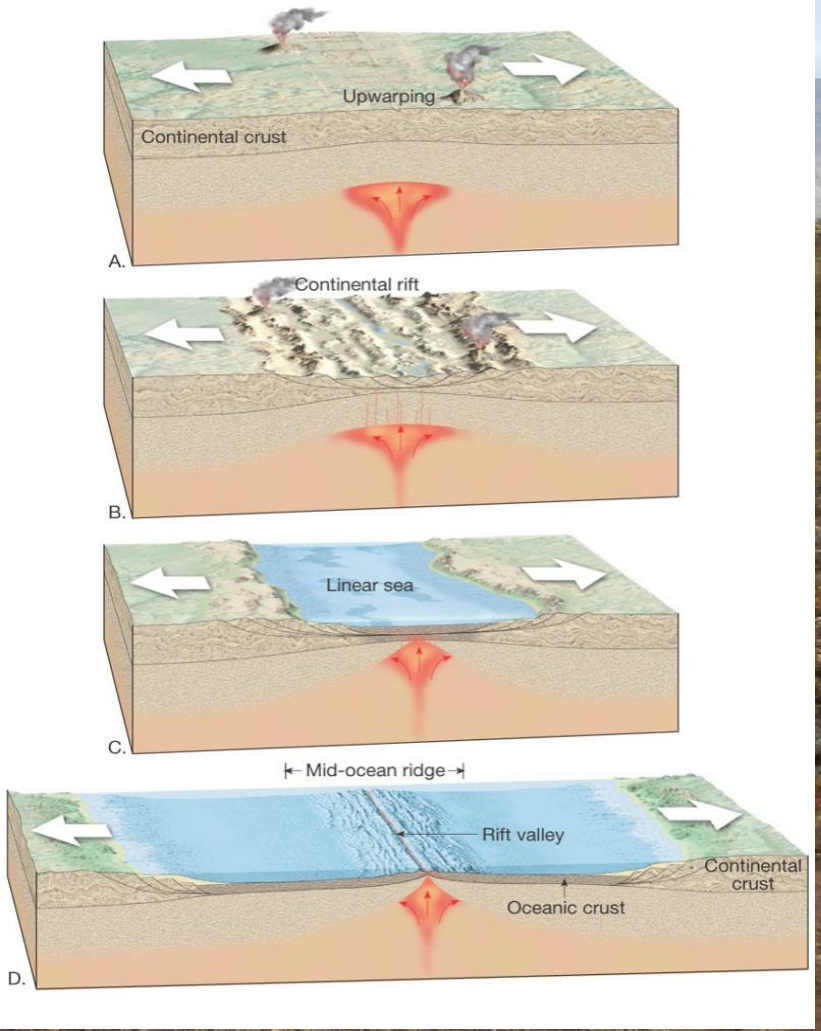
Volcanism & Tectonic Setting



- Setting determines … (i) silica and water content of magma …. (ii) controls its behavior … (iii) and the geomorphology of the resulting volcanic landform

Rift Valleys

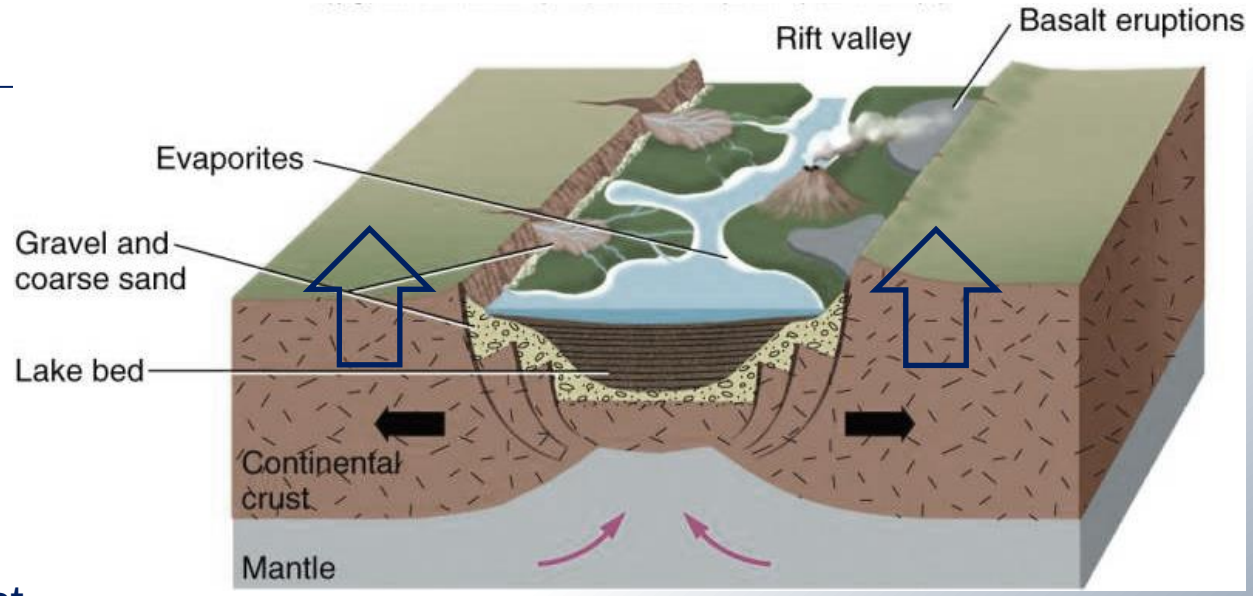
- Extension of continental crust leads to formation of a continental rift zone
- Rifting of a continent can lead to formation of a new ocean

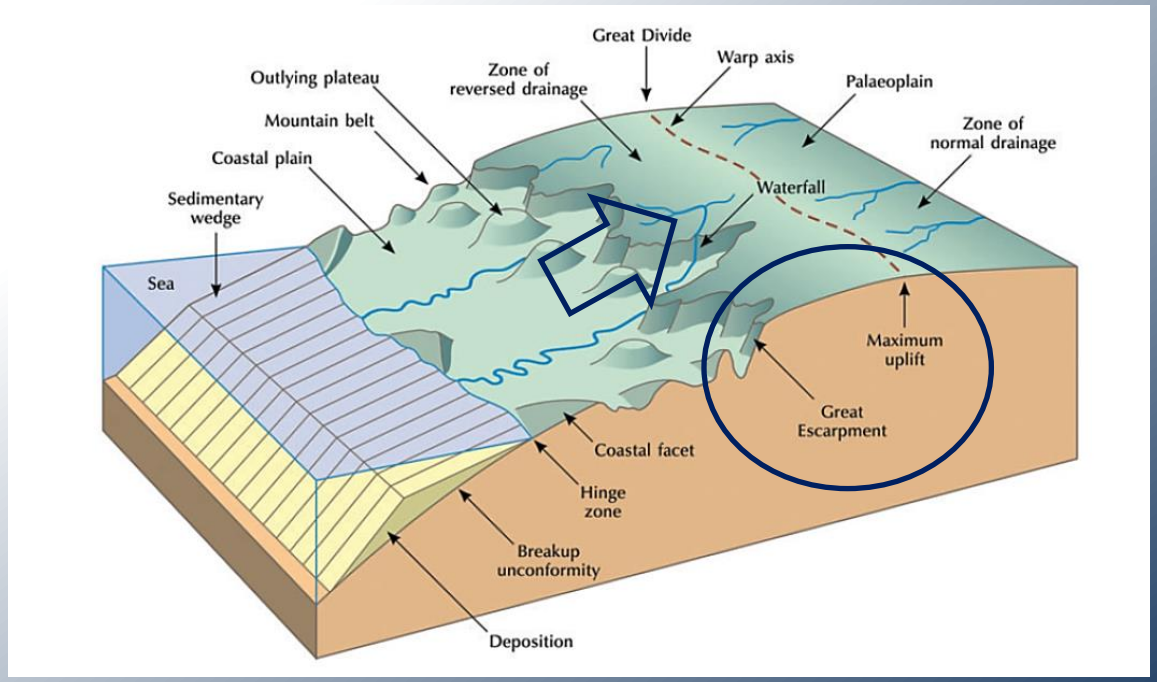


Pingvellir Iceland

Rift Valleys

- Rift valley forms and fills with thick wedges of gravel and coarse sand along faulted margins - lake deposits & associated evaporates in the bottom of the rift
- **Extensional uplift** - crust stretches and thins and the ascent of hot buoyant mantle at the base of continental lithosphere induces broad uplift and stretching of crust (grabens form due to extension in rift zones, volcanism begins as magma rises through thin crust)
- Rift shoulder and great **escarpments**….

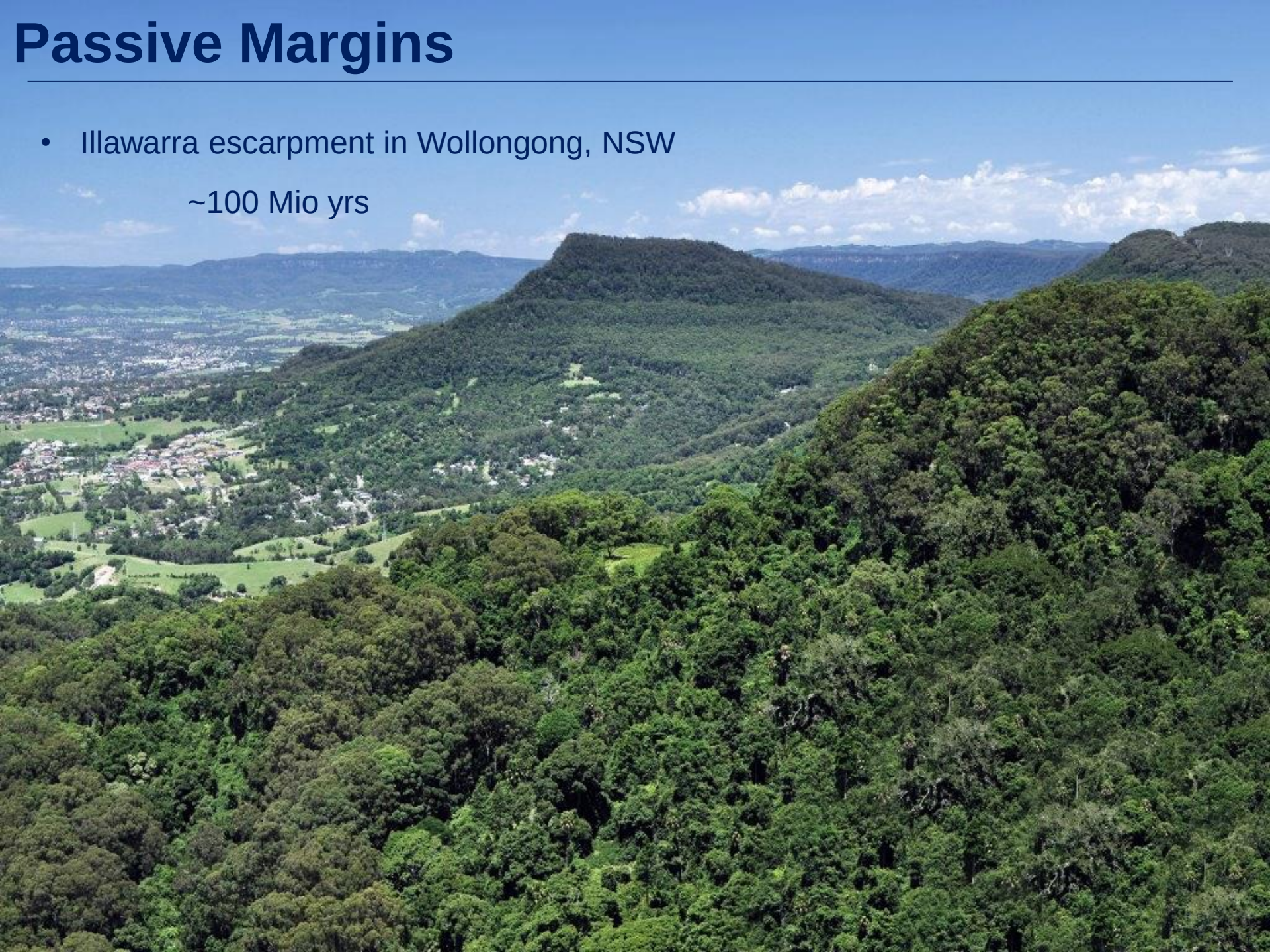




Passive Margins

- Illawarra escarpment in Wollongong, NSW

  ~100 Mio yrs



5 minutes...

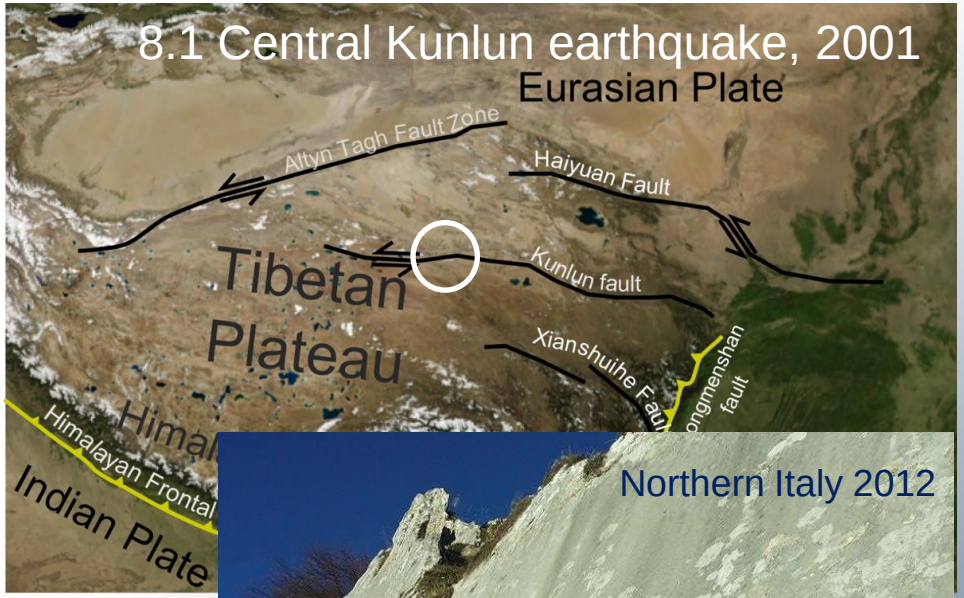
Earthquakes and Tectonics

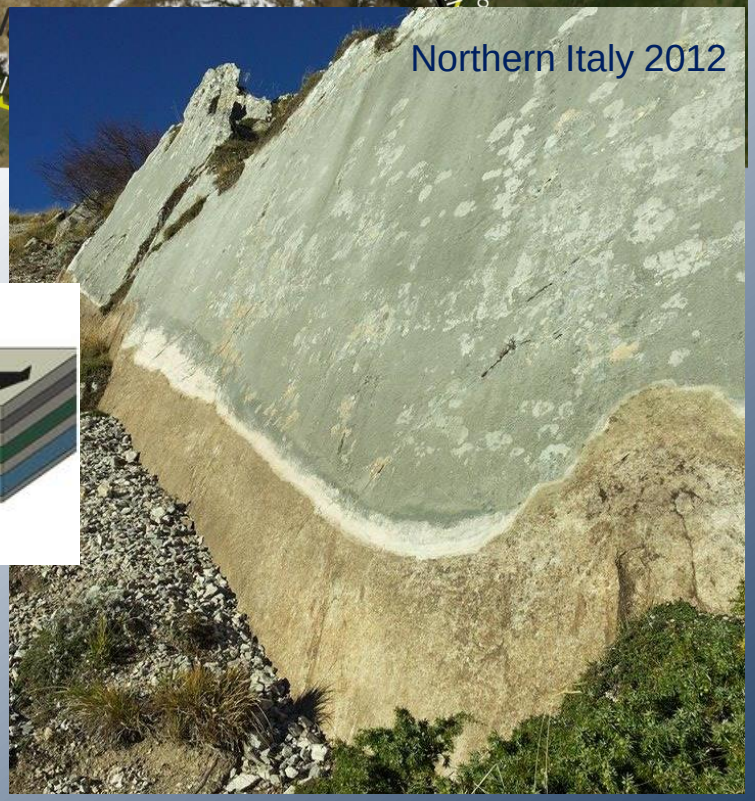
- Tectonic effects on geomorphology can range from scales of millions of years to minutes or less

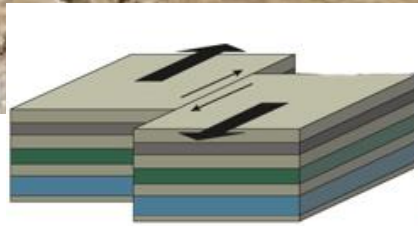
- **Neotectonics** - study of young tectonic events which have occurred or are still occurring …
- The tectonic events are recent enough to permit a detailed analysis by differentiated and specific methods, while their results are directly compatible with seismological observations

Landscapes and Tectonics

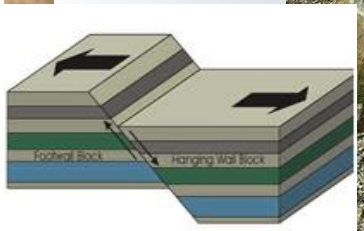
- 400-km-long surface rupture zone, up to 16.3 m of strike-slip



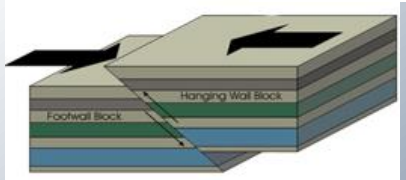




Strike-slip fault



Normal fault

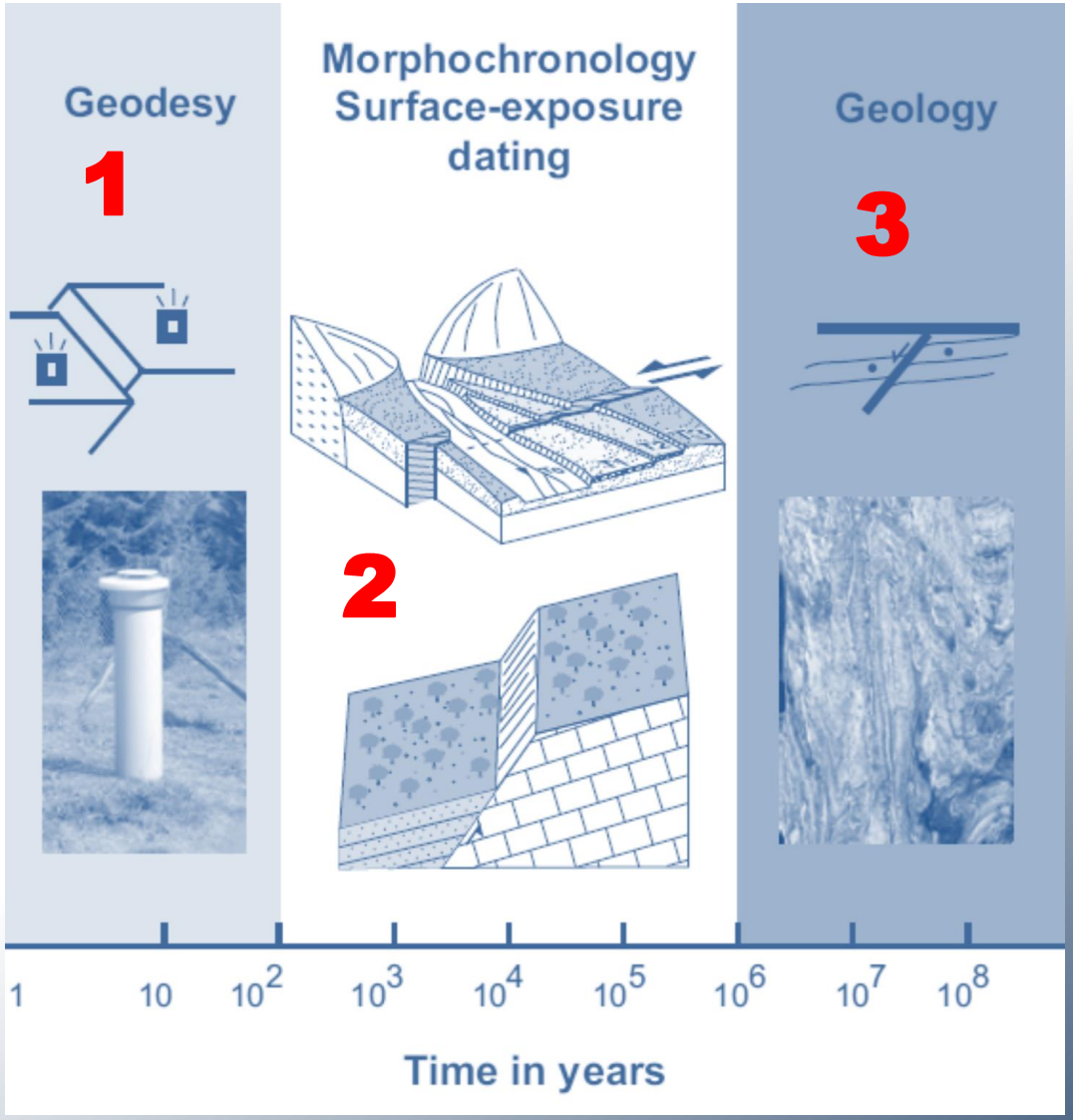


Reverse fault

- Ruptures and fault geometry

Landscapes and Tectonics

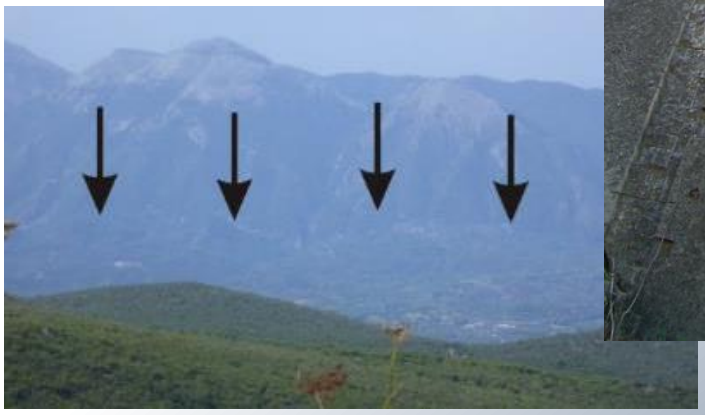
- How can we learn about earthquake **frequency and magnitude ?**

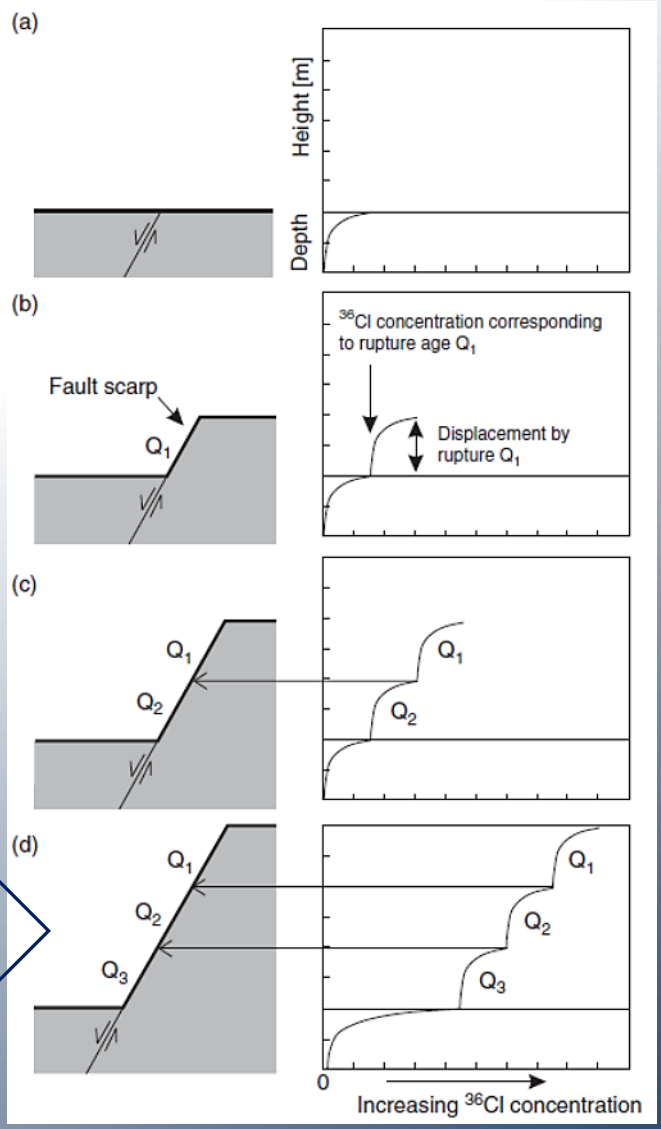


Benedetti & Van der Woerd 2014

Landscapes and Tectonics

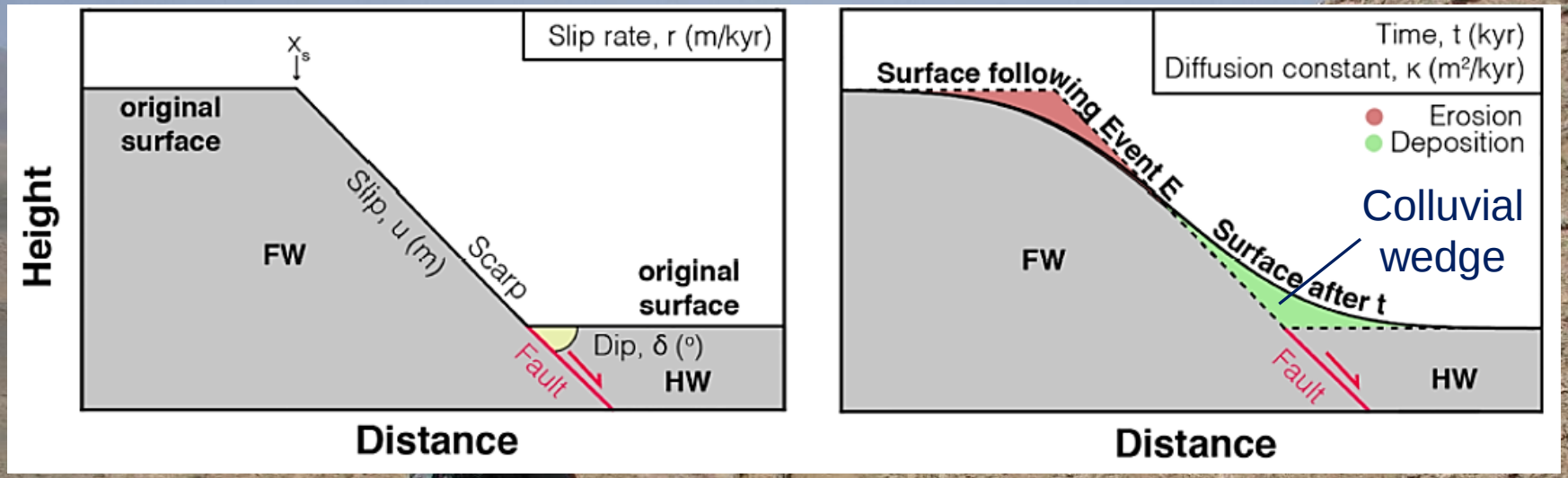
- **Sparta Fault** in southern Greece historical 464 BC earthquake that destroyed ancient Sparta
- cosmogenic exposure dating…
- five historical earthquakes on the fault scarp
- recurrence period 2800 ± 300 yrs
- strong event must be expected

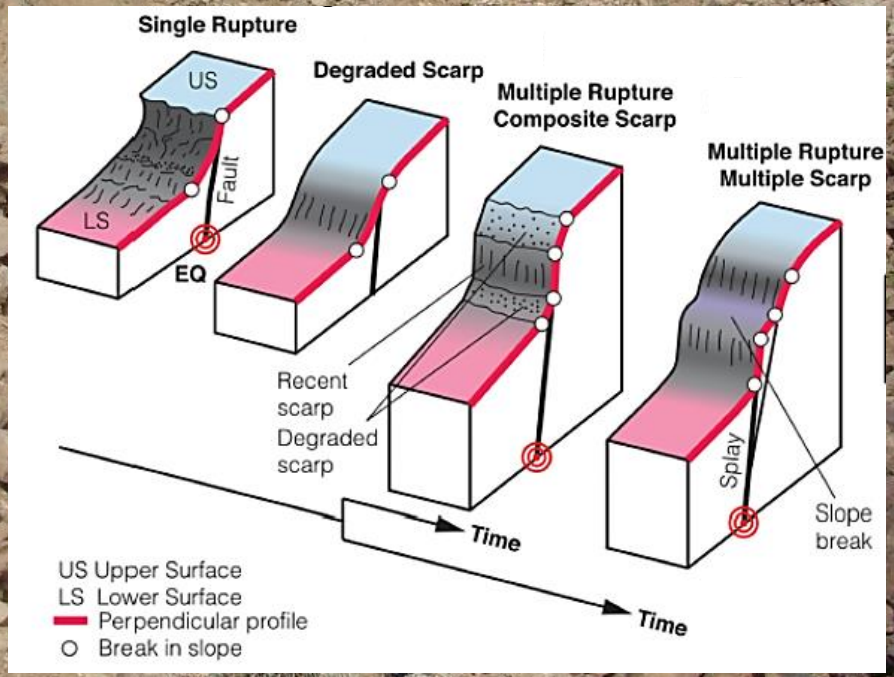




Dunai 2010 after Palumbo et al. 2004; paleoseismicity.org

Landscapes and Tectonics



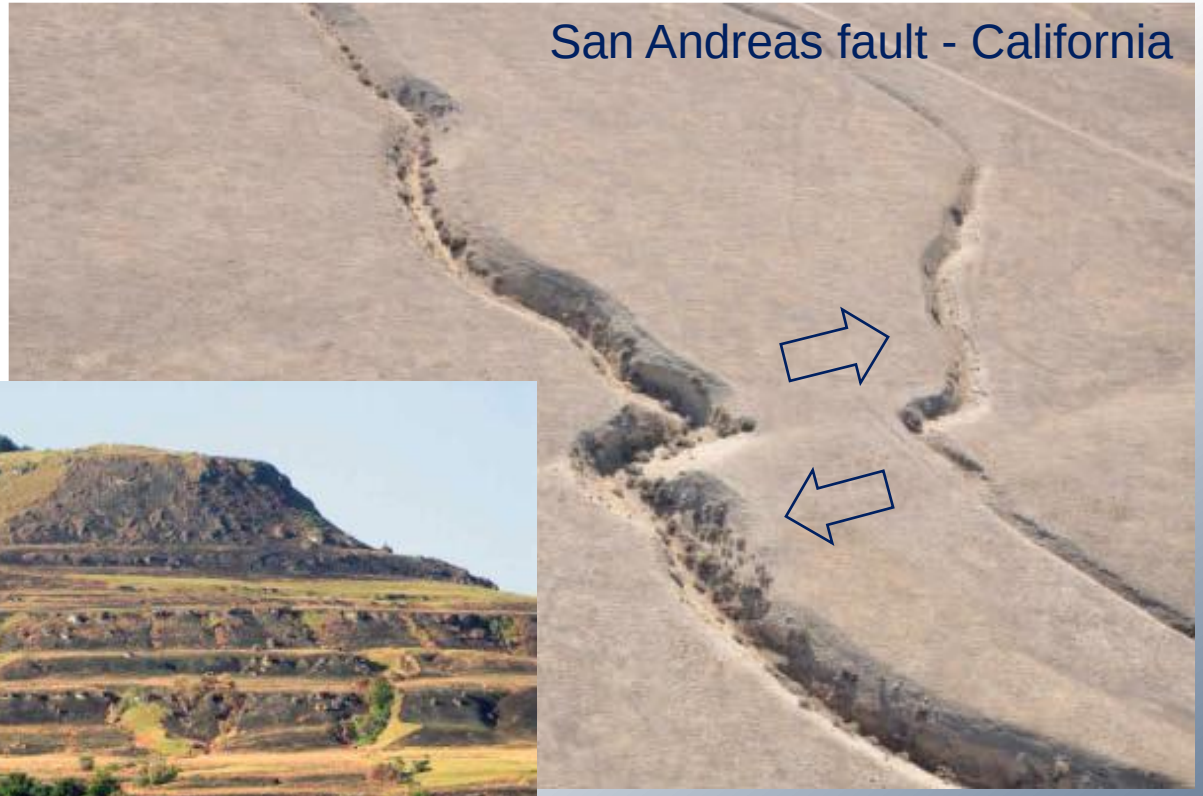


1957 earthquake,
Ih Bogd, Gobi Altai

Hodge et al. 2020

Landscapes and Tectonics

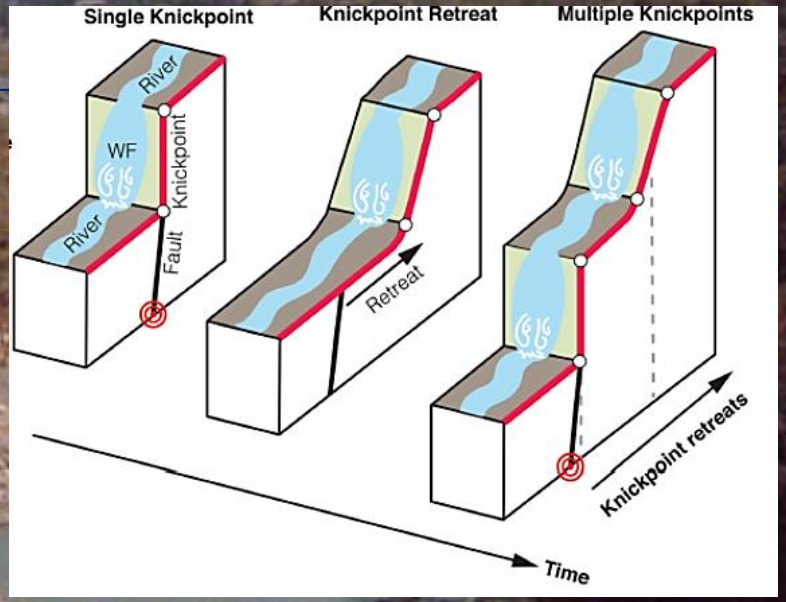
- Type of tectonic process – **geomorphic marker !**



- Local vs regional scale…

Landscapes and Tectonics

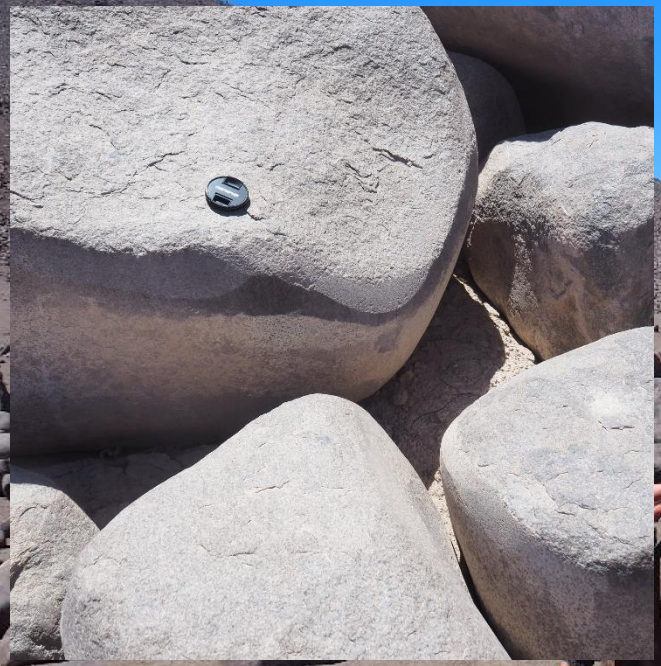
- Direct and indirect indicators



Chelungpu thrust fault, Chi–Chi, Taiwan 1999 earthquake

Hodge et al. 2020

Landscapes and Tectonics



- **Arid Atacama block clusters ?**
- 5.2 M quake in 2010 (2-3 /yr) – dancing boulders…

Quade et al. 2012; http://www.geosociety.org

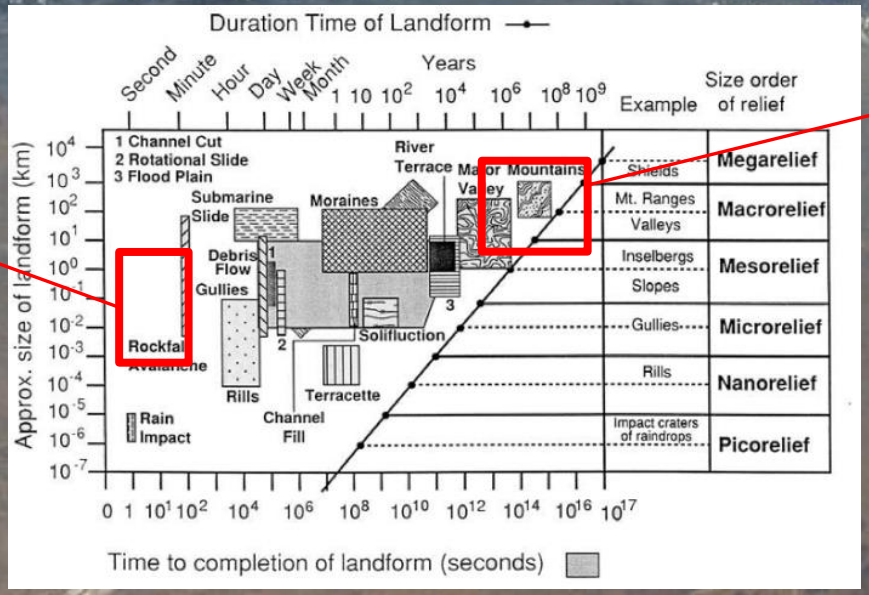
Tectonics and Mountain Building…

"Megageomorphology" ??

A new global-scale geomorphology ?

http://geoinfo.amu.edu.pl/wpk/geos/GEO_COMPLETE_TOC.html

Effect of individual earthquake



Effect millions of years of earthquakes

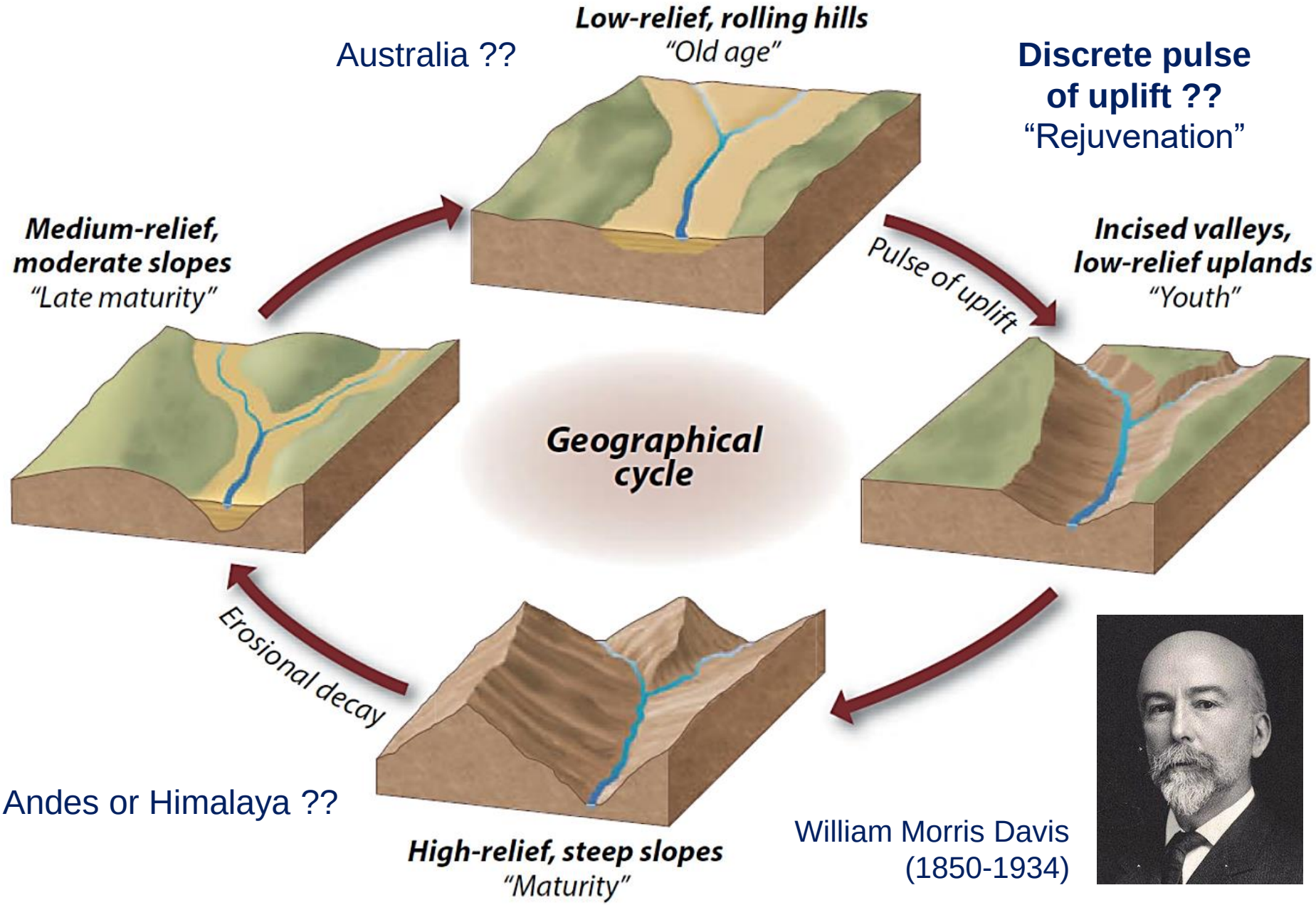
But… processes, timescales and driving forces of mountain building… ??

2 minutes...

Early concepts – Geographical cycle

Australia ??

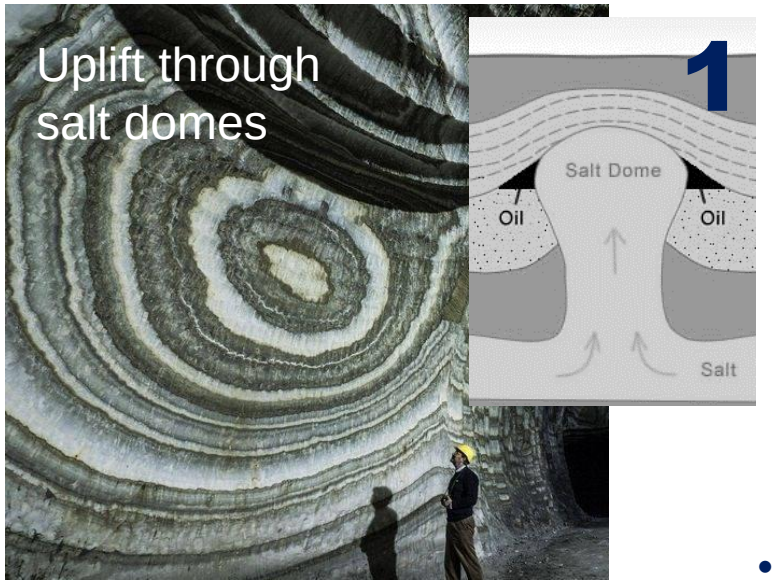
Discrete pulse of uplift ??
"Rejuvenation"



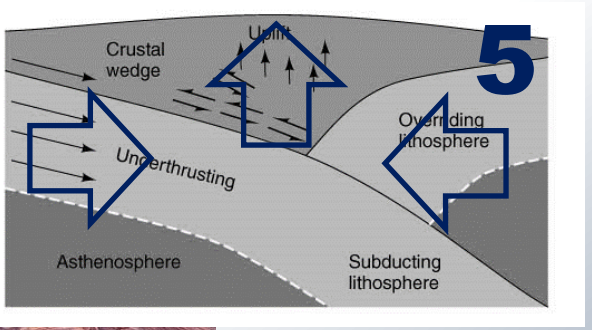
Andes or Himalaya ??

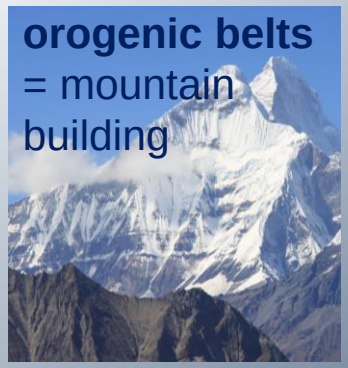
William Morris Davis
(1850-1934)

Uplift - Vertical motions of the Earth's crust



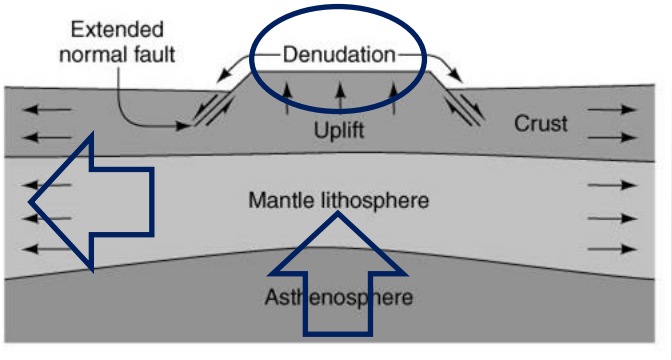
Collisional Uplift…

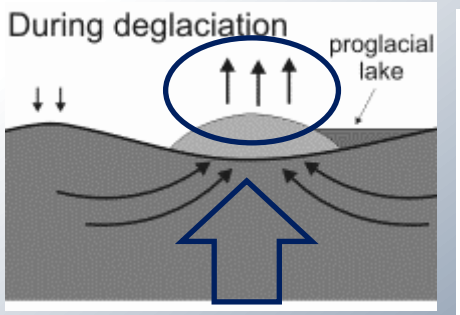


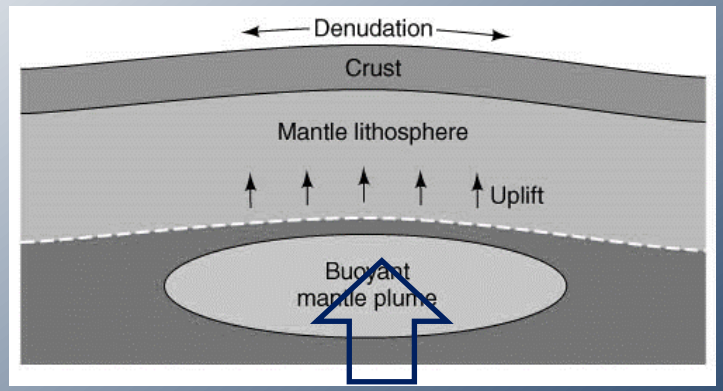


- Uplift with complex deformation (folding and faulting, intrusion of magma) and crustal thickening

2 **Extensional** uplift (thinning - mantle upwelling)





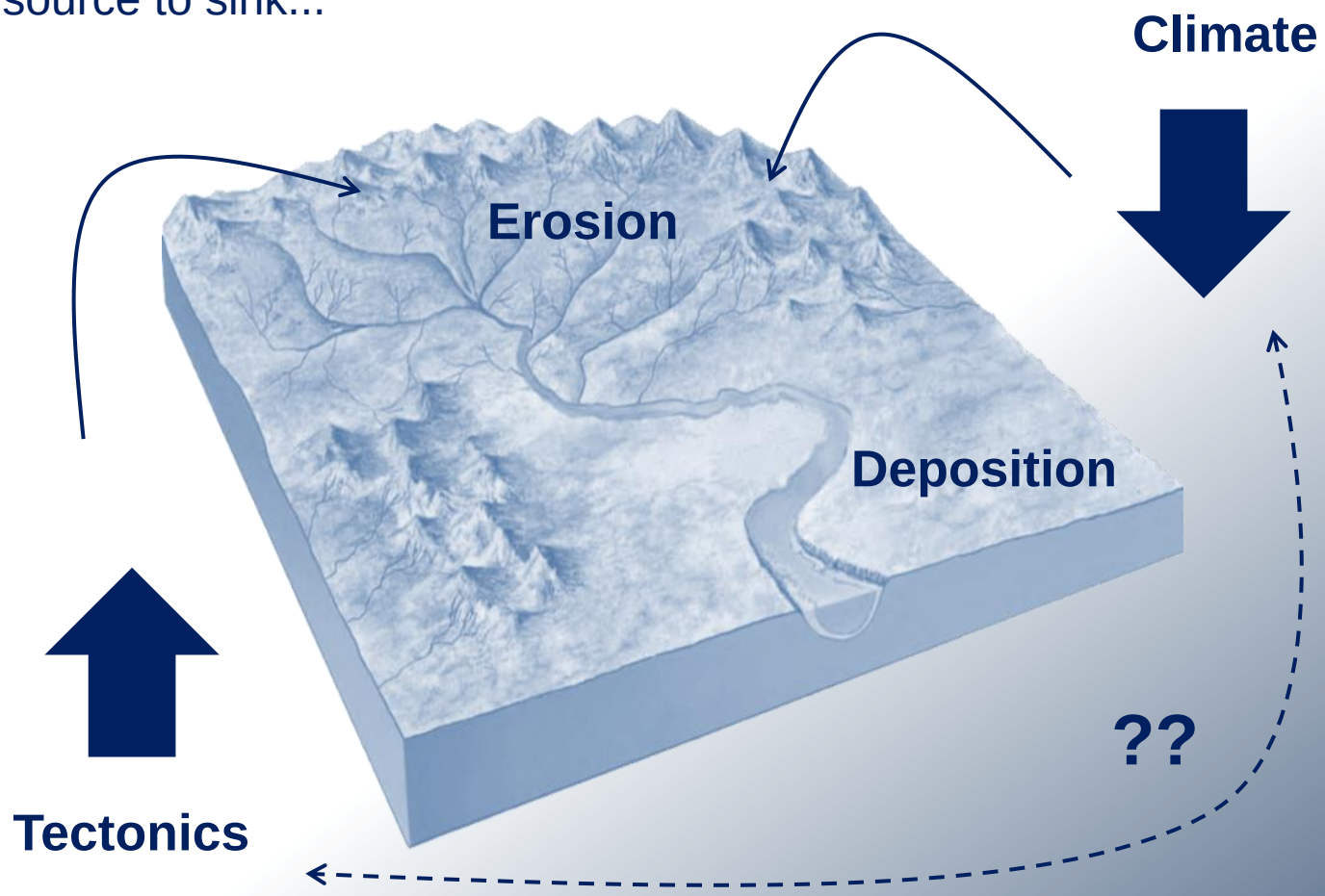


3 **Isostatic** uplift (thinning / (un)loading and buoyancy)

4 **Epeirogeny**
broad regional upwarp in cratons (stable interior) mild deformation), causes not well known

Mountain Building and Landscape Evolution

From source to sink...

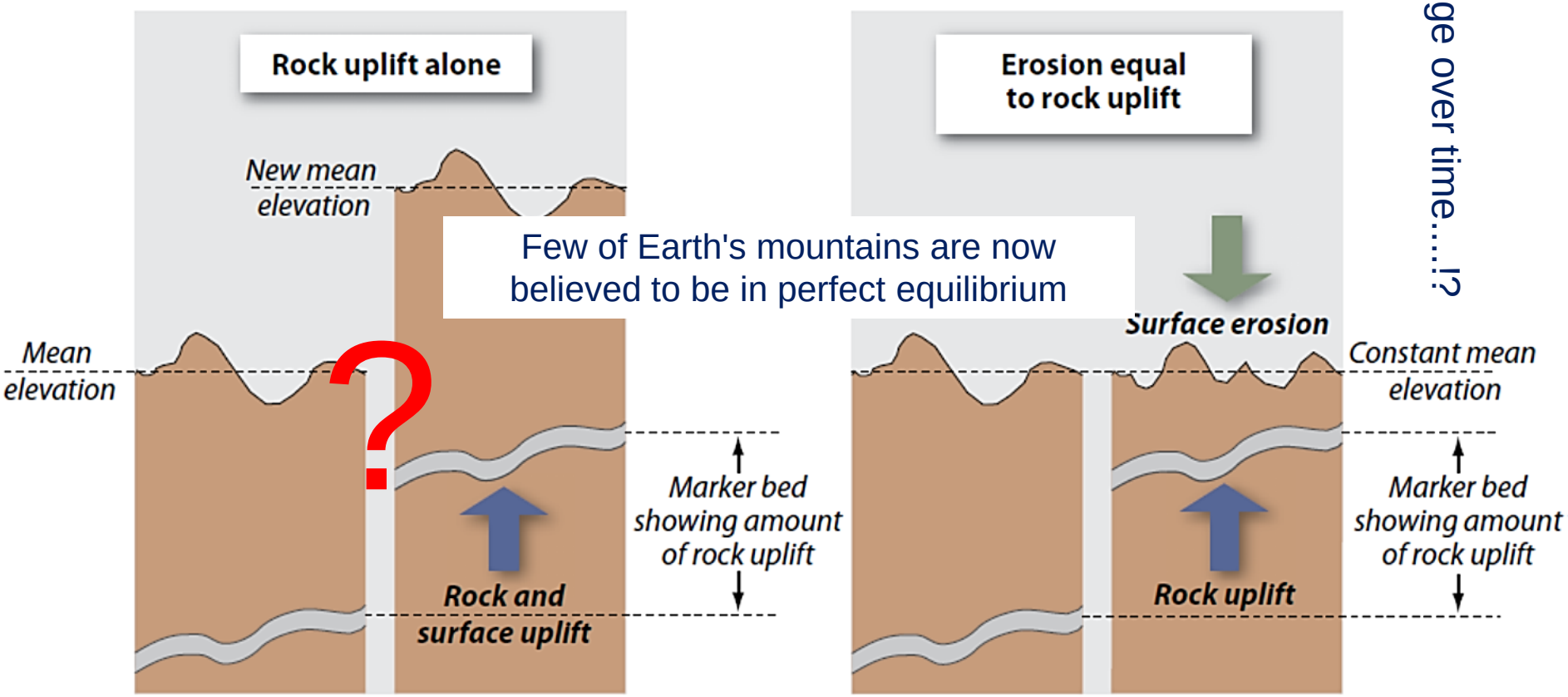


- How do these variables contribute to the **mountain building**...?

Grotzinger et al. 2008

Steady-state Topography

Change over time....!?



Few of Earth's mountains are now believed to be in perfect equilibrium

- **Rock uplift** without surface erosion = net **surface uplift**, raising the mean elevation of the landscape and raising marker beds relative to sea level but not changing their depth below ground.
- When surface erosion matches rock uplift, the mean elevation of the landscape remains constant. This causes **exhumation** (unroofing) of rocks, bringing once deep-seated rocks closer to the ground surface.

Uplift, Topography and Erosion

- **Uplift** leads to decreasing temperatures – less vegetation – increased physical **weathering** (e.g. periglacial processes)

- Increase in relief and slope lead to **increased erosion** (gravity and mass wasting, and stream power)

- Stronger uplift = stronger erosion = stronger reduction in elevation… i.e. higher mountains erode more quickly ??

- **Negative feedback** (basis for W. M. Davis cycle but is uplift pulse realistic?

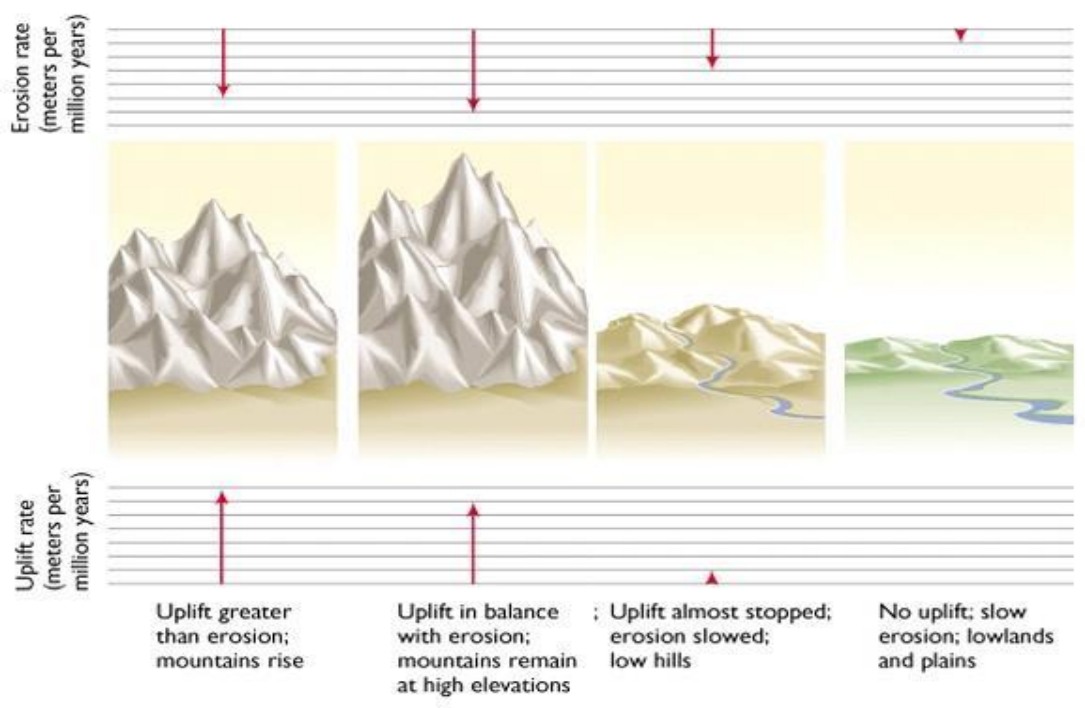


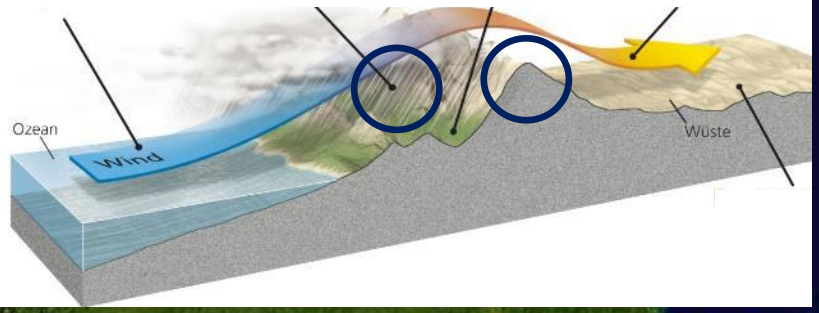
Plate convergence

Erosion linked to elevation…

Uplift, Topography, Climate, Erosion

- Warm and wet = chemical weathering increases (windward)
- Wet = physical weathering and fluvial erosion increase
- Wet and cold = Glaciers grow and erode… (in mountains)
- **This is another negative feedback**

Rain shadow

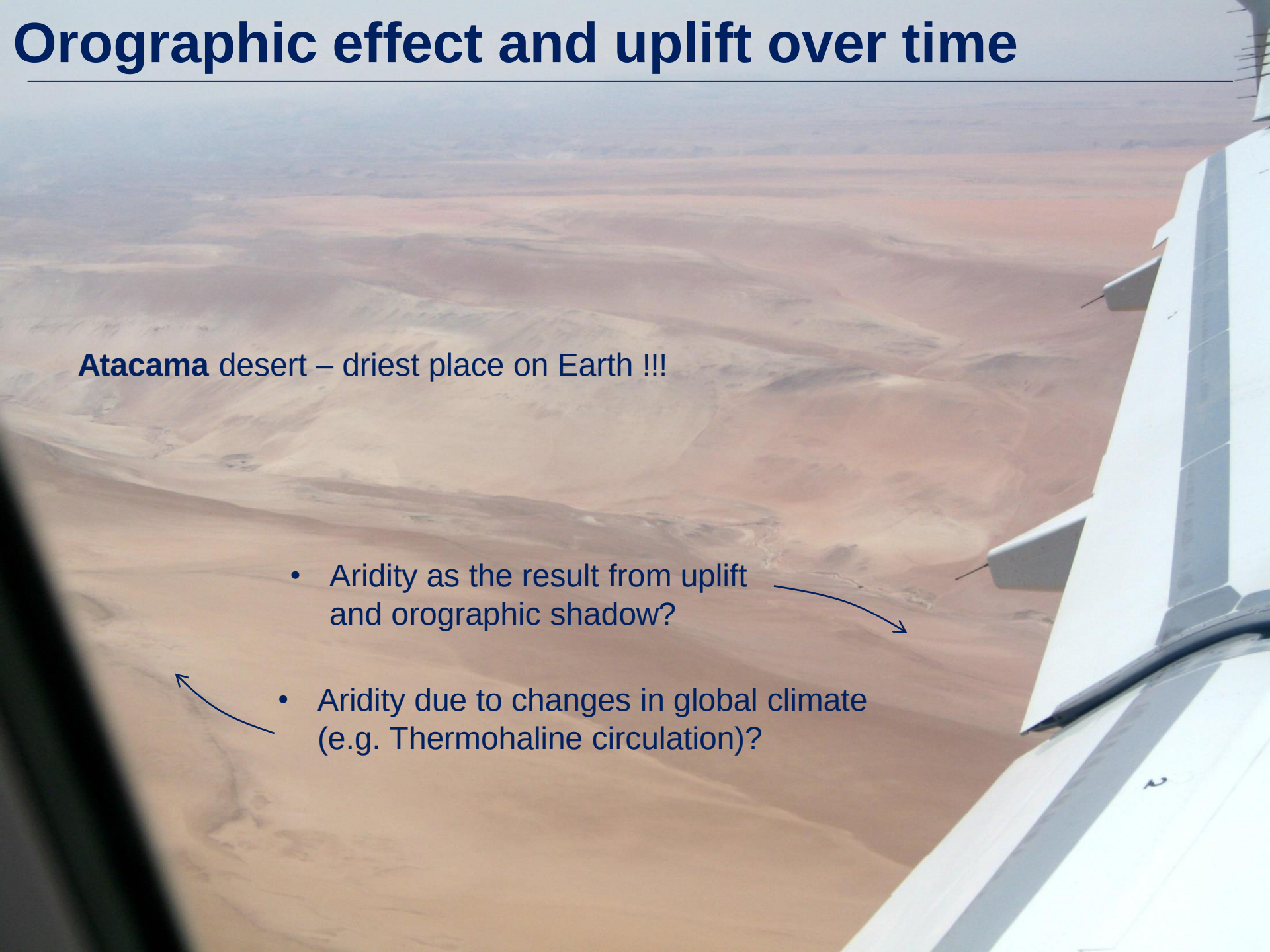


+

Monsoon !!!

Topography affects local to regional-scale climate and Global atmospheric circulation !!!
(or also vice-versa?)

Orographic effect and uplift over time



Atacama desert – driest place on Earth !!!

- Aridity as the result from uplift and orographic shadow?
- Aridity due to changes in global climate (e.g. Thermohaline circulation)?

Orographic effect and uplift over time

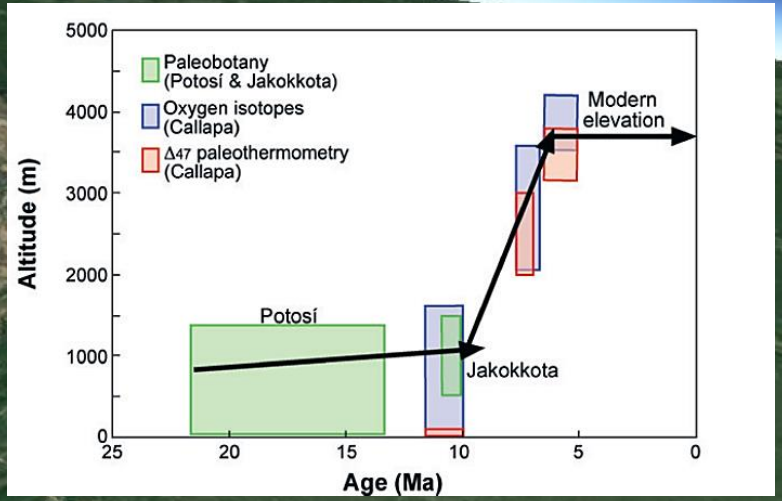
Atacama desert

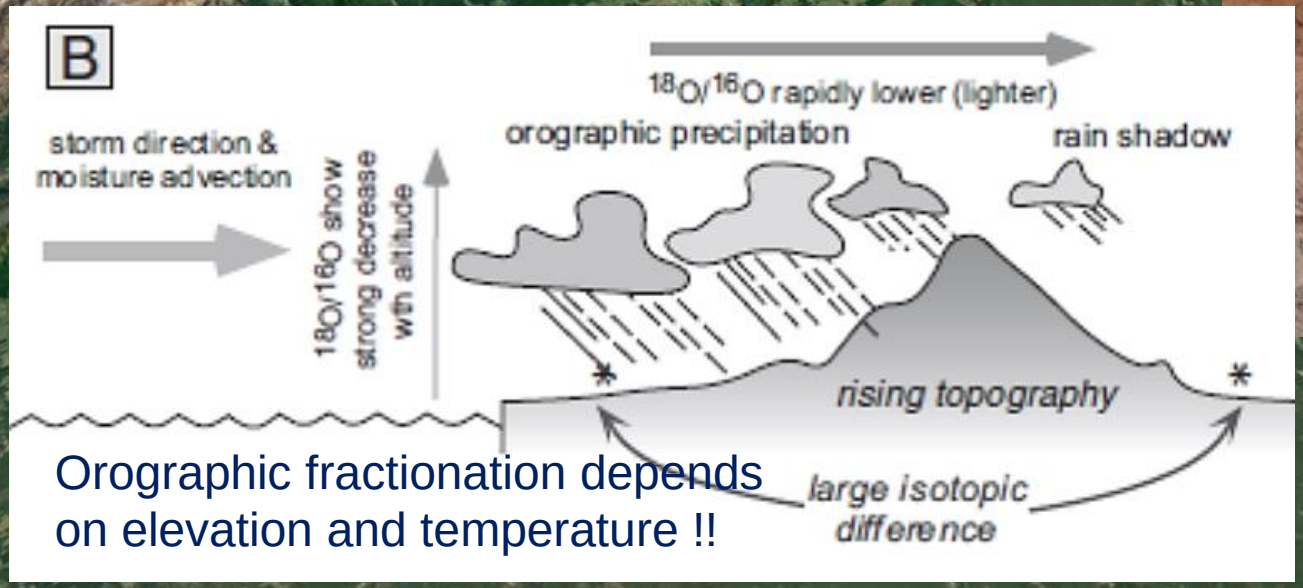
Altiplano in the Andes

1 Uplift

2 Eastward propagation of uplift

2000-7000 mm/yr





Orographic fractionation depends on elevation and temperature !!

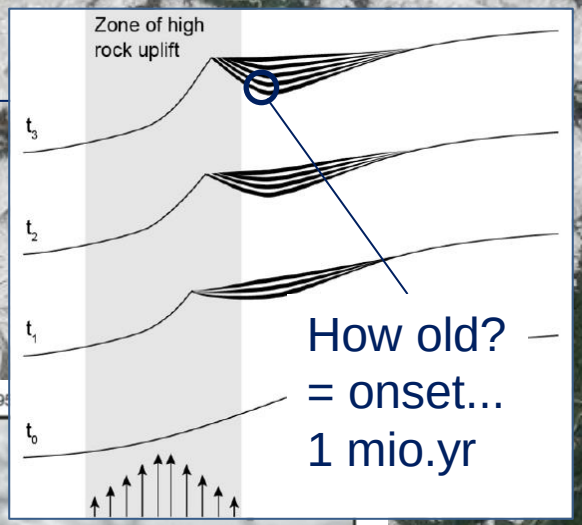
Effects ???

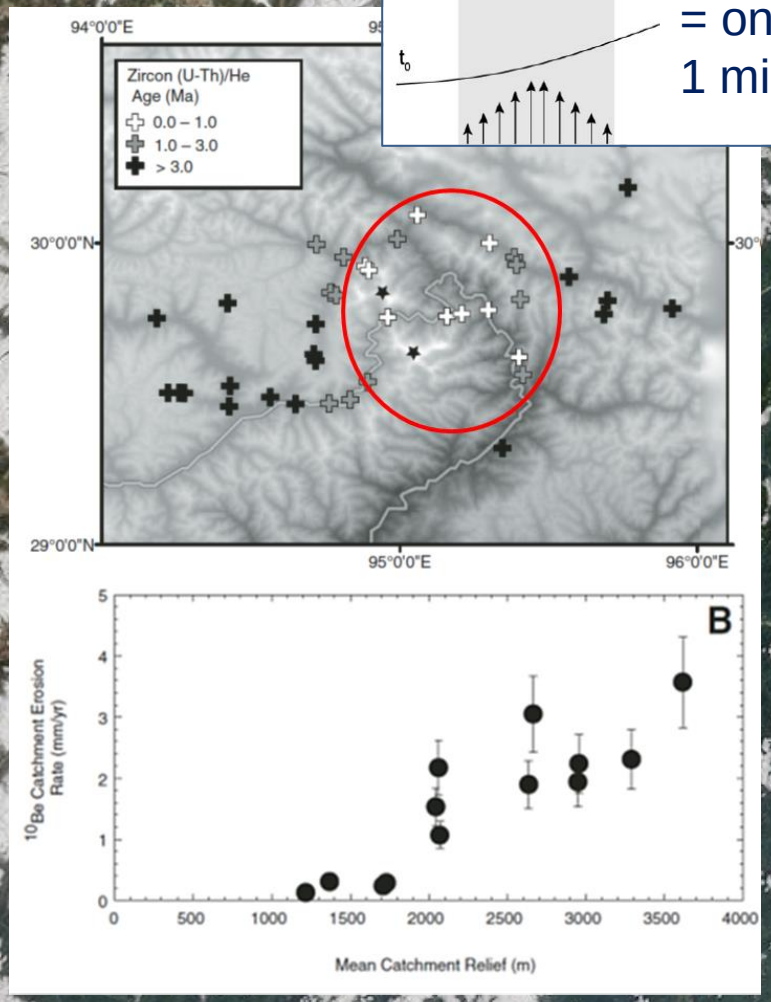
N

100 km

Deepest = highest?

- Tight spatial correspondence of **fluvial incision potential**, high relief, and young cooling ages (i.e. uplift and exhumation rates)





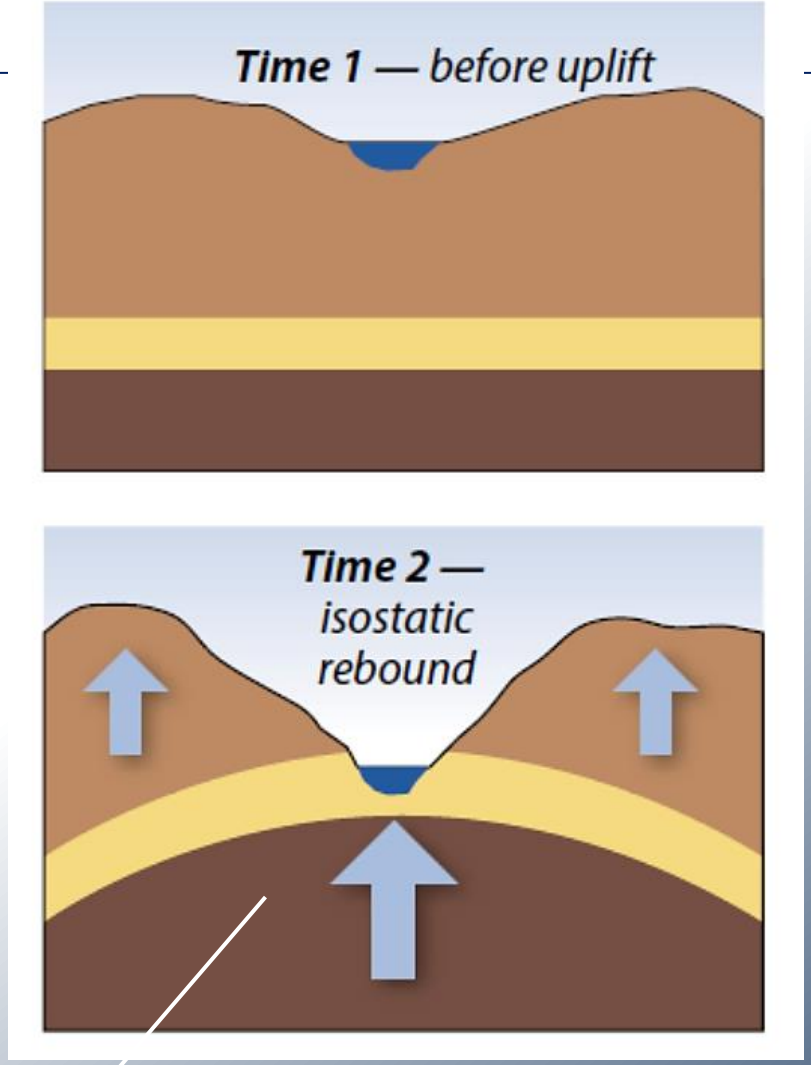
- **Positive feedback between uplift and erosion… !**

Erosion and uplift…?

- Erosion of deep valleys can **focus exhumation** (i.e. the process by which rock that was formerly buried approaches Earth's surface), resulting in **preferential rock uplift** (through isostatic rebound) along major rivers

- Removal of mass is localized (in the valleys), but **isostatic response** lifts the entire mountain block, including both valleys and peaks.

- Focused erosion along the course of major, range-crossing rivers unroofs rocks at speeds greater than in areas away from the river courses (creating anticlines)

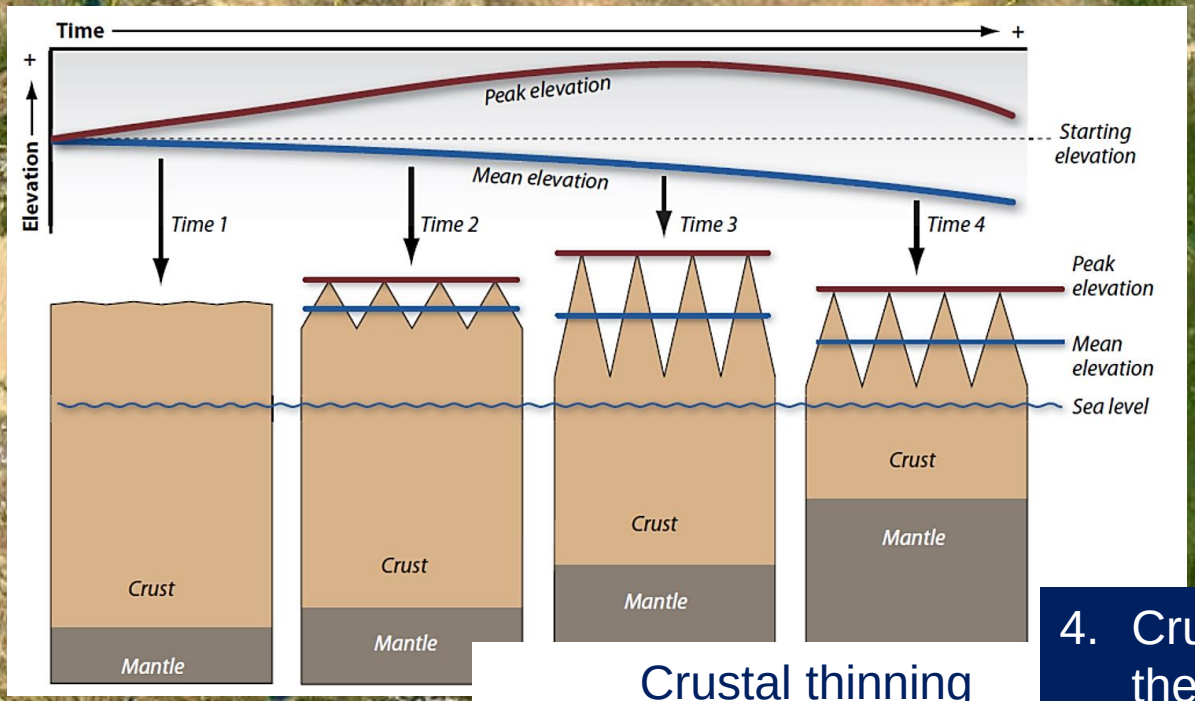


- **Tectonic aneurysms** (i.e. abnormal swelling or bulges) supplying more mass for erosion and leading to extremely high rock uplift rate

New model for mountain building

Compression & uplift → intensive erosion → isostatic uplift → erosion → crustal thinning

Tectonic compression = uplift through crustal thickening



Crustal thinning

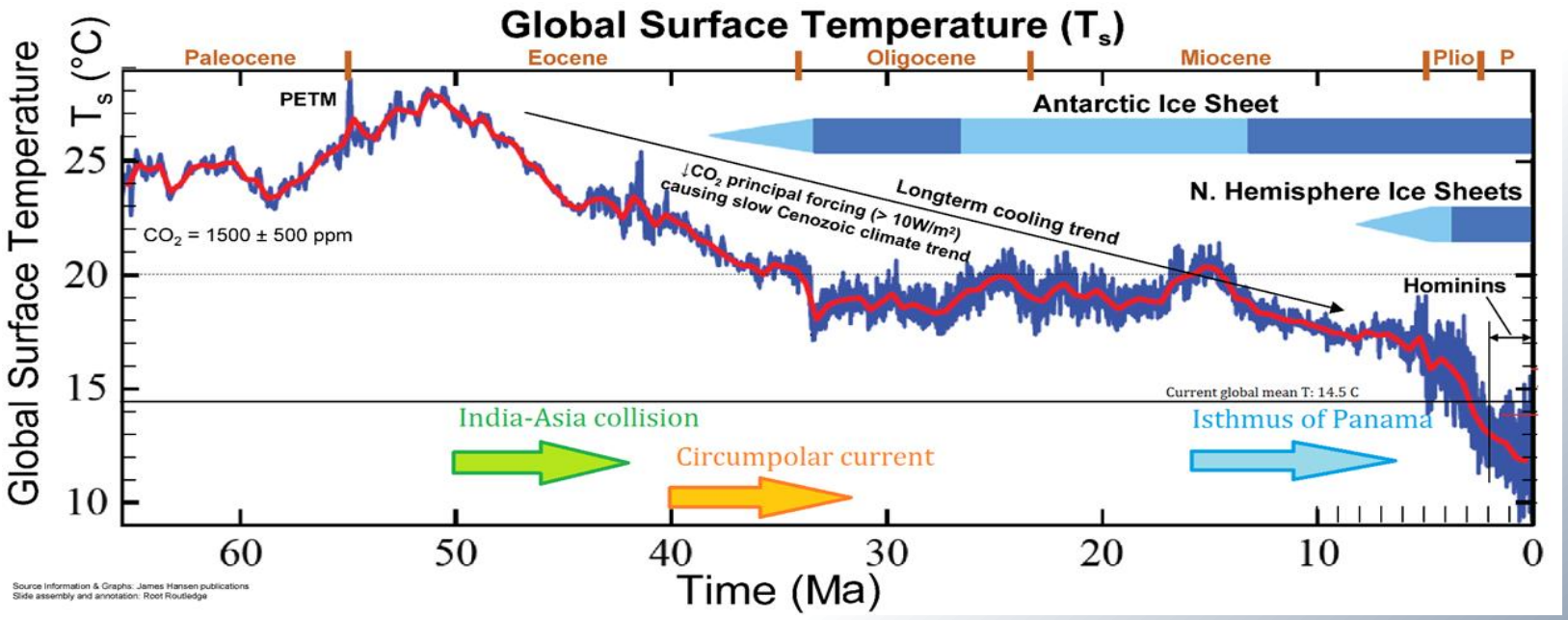
1. uplift by tectonic forces above sea level

2. Base-level fall and incision

3. Isostatic compensation uplifts peaks (but mean elevation lower)

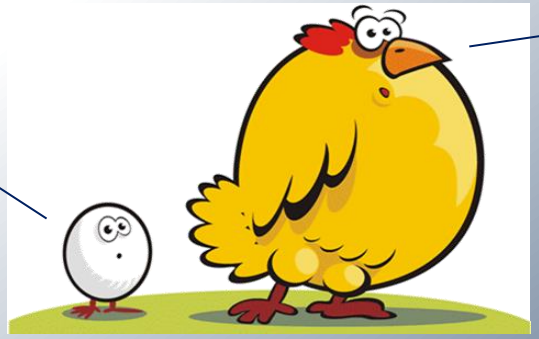
4. Crust erodes and the crustal root thins, mean and peak elevation decrease.

Mountains make climate makes mountains…?



- Major episode of mountain building over last ~40 Mio yrs (e.g. Himalaya, Andes and Rockies, Alps, NZ etc.)

Tectonics drive global climate (via erosion & CO_2 draw-down)?

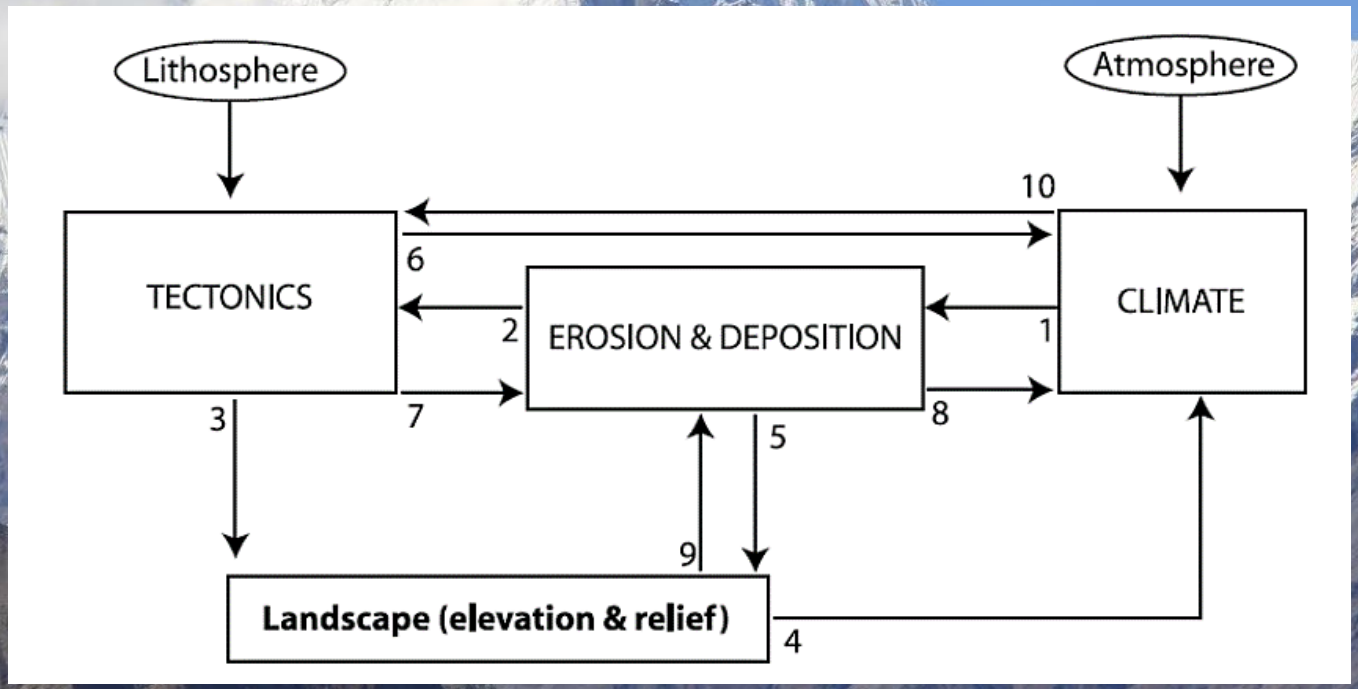


Global climate drives erosion with feedback on mountain building and uplift?

- Molnar, P. and England, P., 1990. Late Cenozoic uplift of mountain ranges and global climate change: chicken or egg?. Nature, 346(6279), pp.29-34.

Summary

- endogenic processes produce positive relief, such as mountain-building, volcanoes etc…
- …with wide range of secondary effects
- New understanding of mountain building shows how tectonic forces, Earth's climate and topography **interact…**
- ... to create some of Earth's most spectacular landscapes



Appendix

- Effect of climate on erosion (link 1) and landscape (link 5), and effect of erosion on tectonics by modifying pattern of deformation (link 2)
- Erosion also affects the thermal structure of the crust and the mean crustal thickness, which in isostatic equilibrium dictates the maximum elevation of mountain ranges (link 3)
- The topography, in turn, affects the climate (link 4) by modifying the atmospheric circulation, and global climate.
- The idea that glacial and periglacial condition are able to modify the distribution of the surface elevation and limit the topography of a mountain range (link 5) is named the “glacial buzzsaw”
- Other links are the direct tectonic effect on the climate (e.g., volcanism, link 6) and on the erosion itself (link 7) by fracturing of rock, and earthquake-triggered landslides.
- The direct effects of erosion/sedimentation on climate through chemical weathering and carbon burial are depicted by link 8
- The most direct effect of the landscape on erosion is the slope/ erosion relationship (link 9).
- Finally, climate affects tectonics by loading or unloading the lithosphere (link 10)