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Weathering and Soils – Ground beneath our feet

Dr Alissa Flatley
ACNA4007 – Physical Landscape and the Geosphere

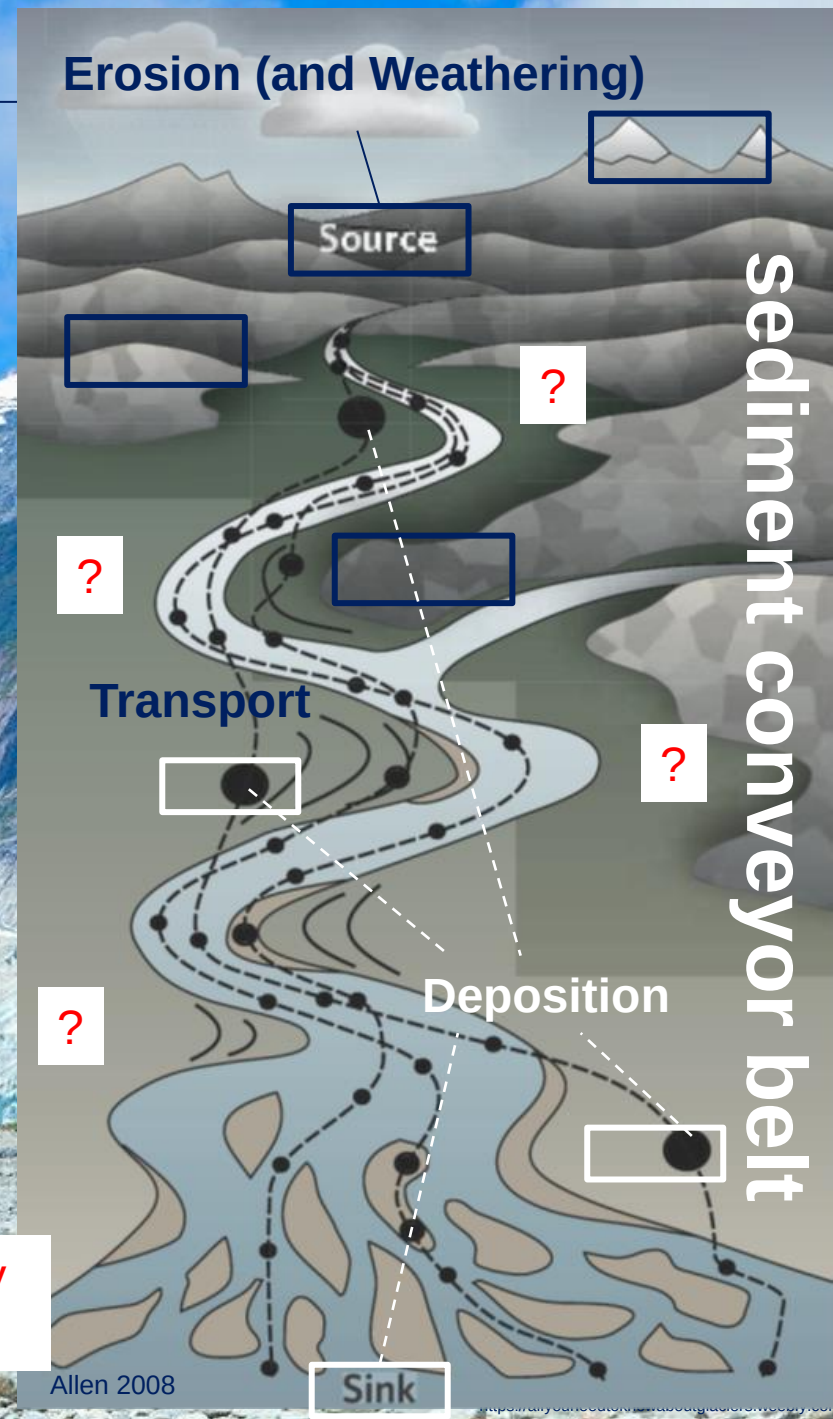


Introduction...

Endogenic Processes: uplift of mountains, formation of new rock and relief

Exogenic Process: weathering, erosion, transport and deposition by ice, water, wind etc.

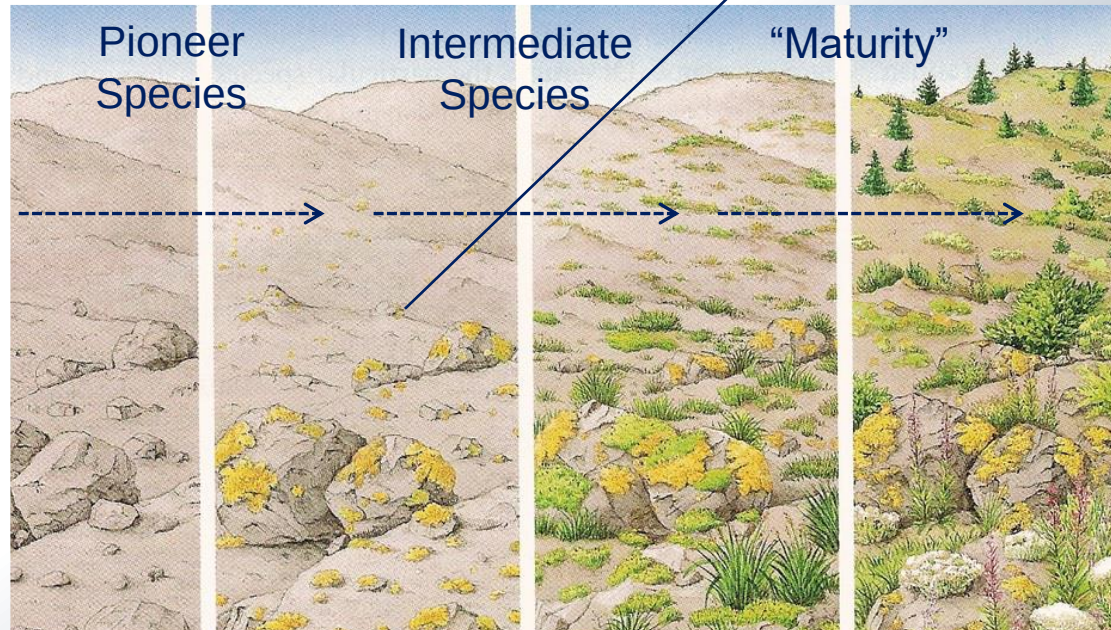
What happens everywhere else (away from the „sediment conveyor“)..?



Weathering (review)



Succession
- process by which life
'develops' (or
'comes back') after disturbance



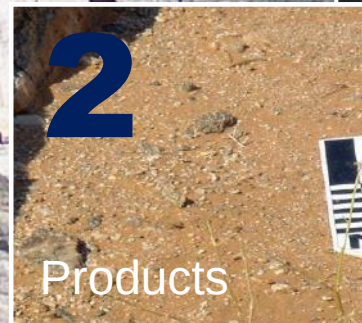
Rock break-down...
= ??

Why can intermediate species establish?

Weathering (review)

- **Weathering** - the processes that break up rock at Earth's surface
- Rocks / sediment **react** with hydrosphere, atmosphere, biosphere

A **Physical** - Mechanical **breakage** and disintegration



Weathering (review)

B

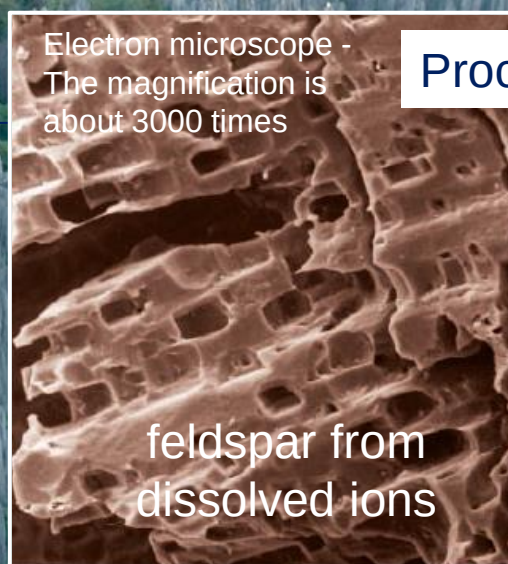
Chemical - Decomposition
by reaction with water (CO_2
helps greatly), e.g.:

- a) Dissolution
- b) Oxidation
- c) Hydrolysis
- d) Hydration

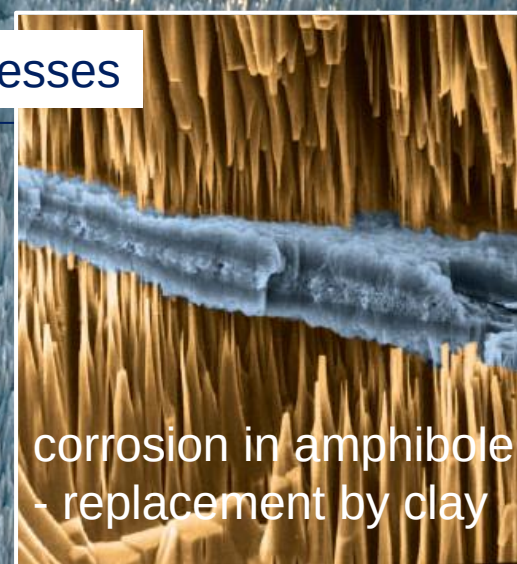


Electron microscope -
The magnification is
about 3000 times

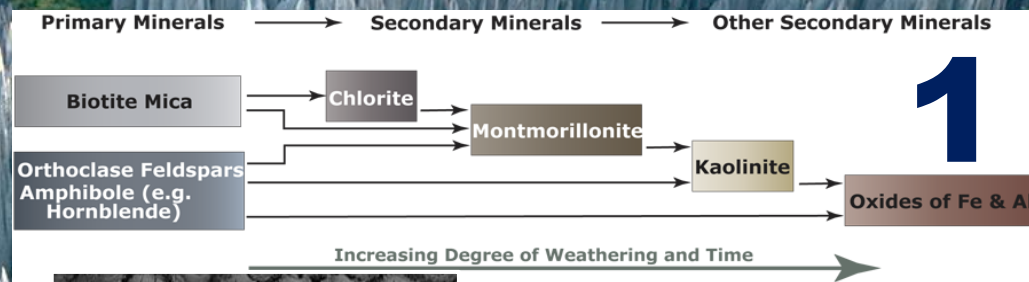
Processes



feldspar from
dissolved ions



corrosion in amphibole
- replacement by clay



Hardening



Weakening

Forms



Products



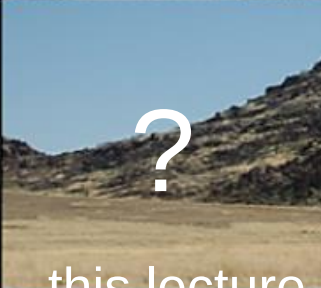
2



3

Clastic
Sediment

Weathering...

Scale	Key questions	Example
Micro Spatial scale = <mm to m Timescale = $10^0 - 10^2$ years	Which co-associations of processes / conditions produce these features ?	
Macro Spatial scale = ms to kms Timescale = $10^3 - 10^5$ years	How are weathering, soils and erosion linked across hillslopes?	
Mega Spatial scale = 10s to 100s km Timescale = $> 10^6$ years	How does weathering contribute to landscape evolution ?	

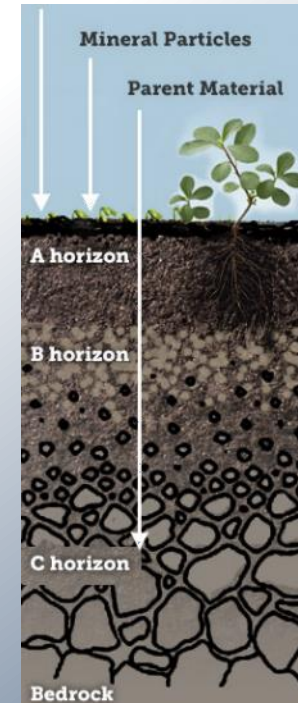
this lecture

?

- Look further back in time
- Look further into the ground
- Look wider into the landscape

!

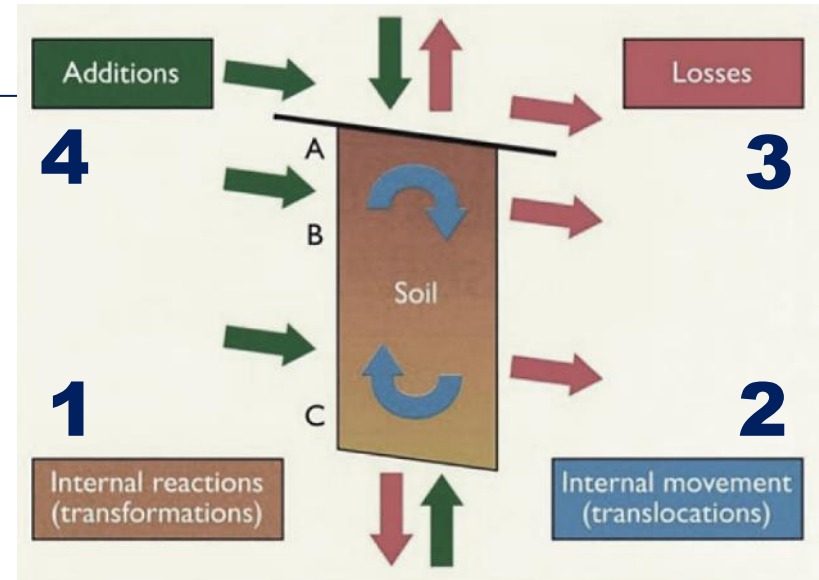
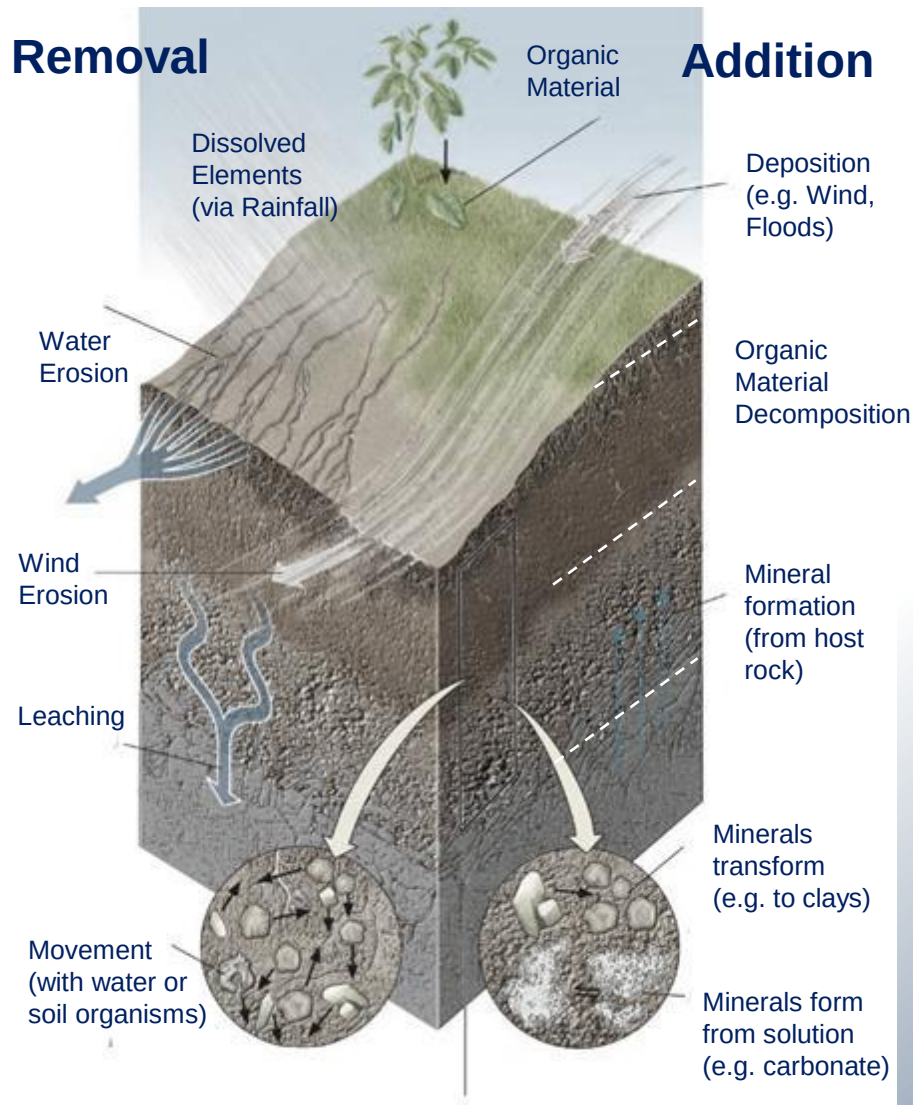
Weathering helps / leads to...



Soil...

... a mixture of **organic matter**, minerals, gases, liquids, and organisms that together **support life**

Soil Formation (review)



... open system

- Wide range of biological, chemical and physical processes... (Pedogenesis)
1. Neoformation- and **transformation processes** (e.g. weathering)
 2. **Translocation processes**
 - Soil horizons and soil types (taxonomy varies by country or system)...

Soils... and life

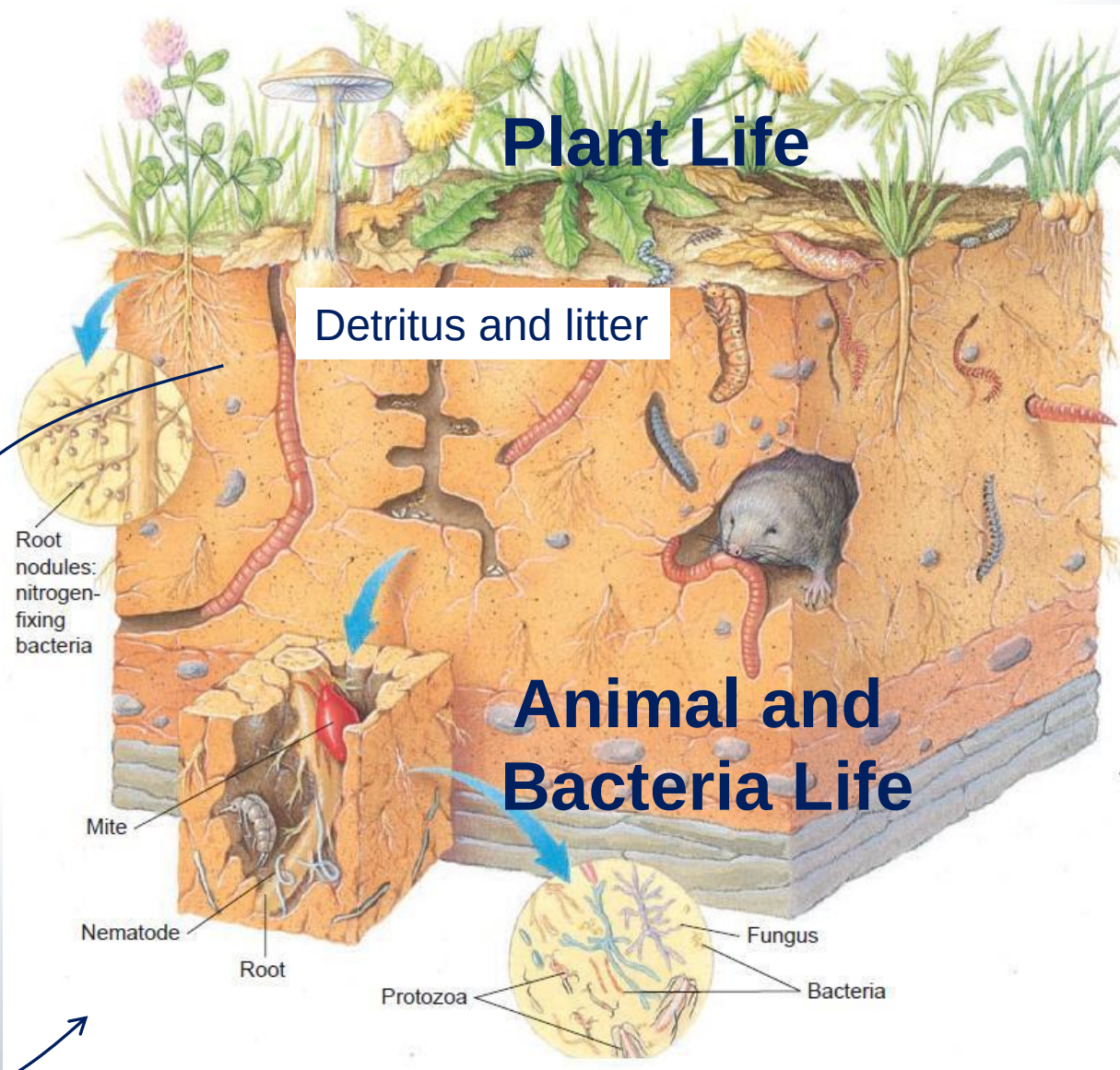
- Vary in physical and chemical properties... (soil types!)
- Habitat on various scales for flora *and* fauna
- Provide nutrients for primary production (life)

Decomposition =

Mineralization (oxidation of organic matter to release nutrients)

+

Humification (transformation of organic matter into stable forms to improve soil properties)



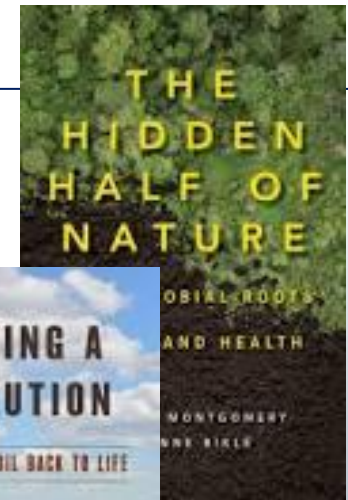
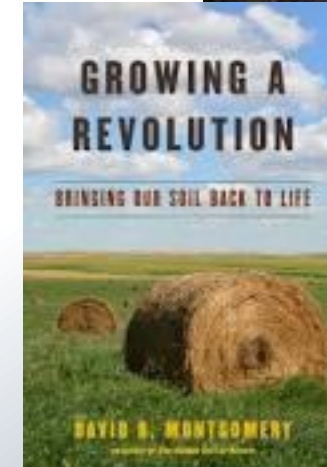
The worlds biggest recycling machine!

Tip... (optional, as usual)...

Soil – Growing a Revolution

(1:11 h length):

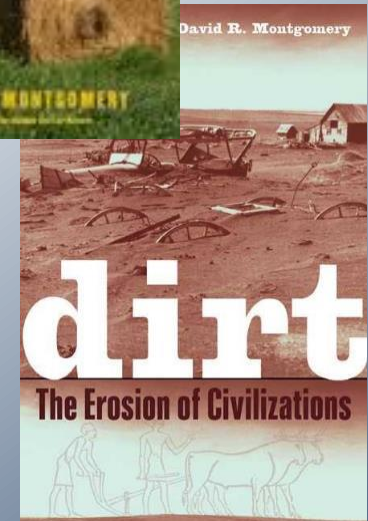
<https://www.youtube.com/watch?v=c4p-kQ6D8aA>



Soil Erosion – Historical Perspective

(1:02 h length):

<https://www.youtube.com/watch?v=KcY4Kwa9fsk>

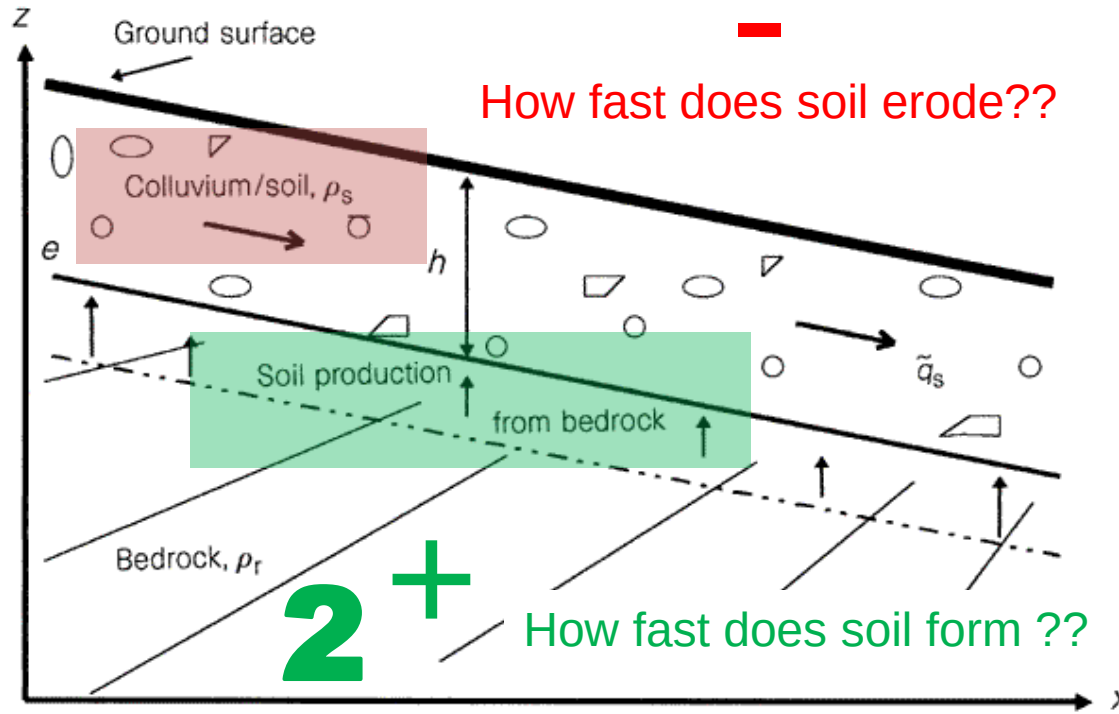


Talks by David R. Montgomery Ph.D., Professor,
Quaternary Research Center and Department of Earth and
Space Sciences, University of Washington, Seattle, WA

3 minutes...

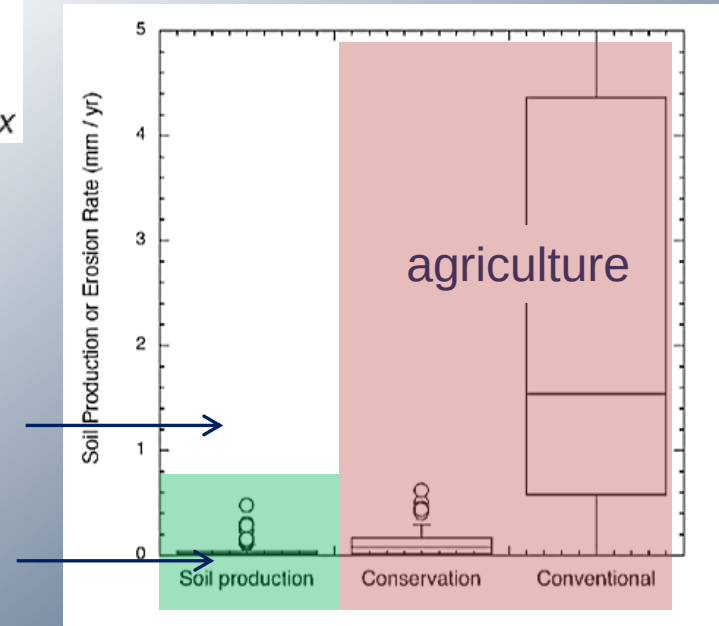


Soils and Landscape



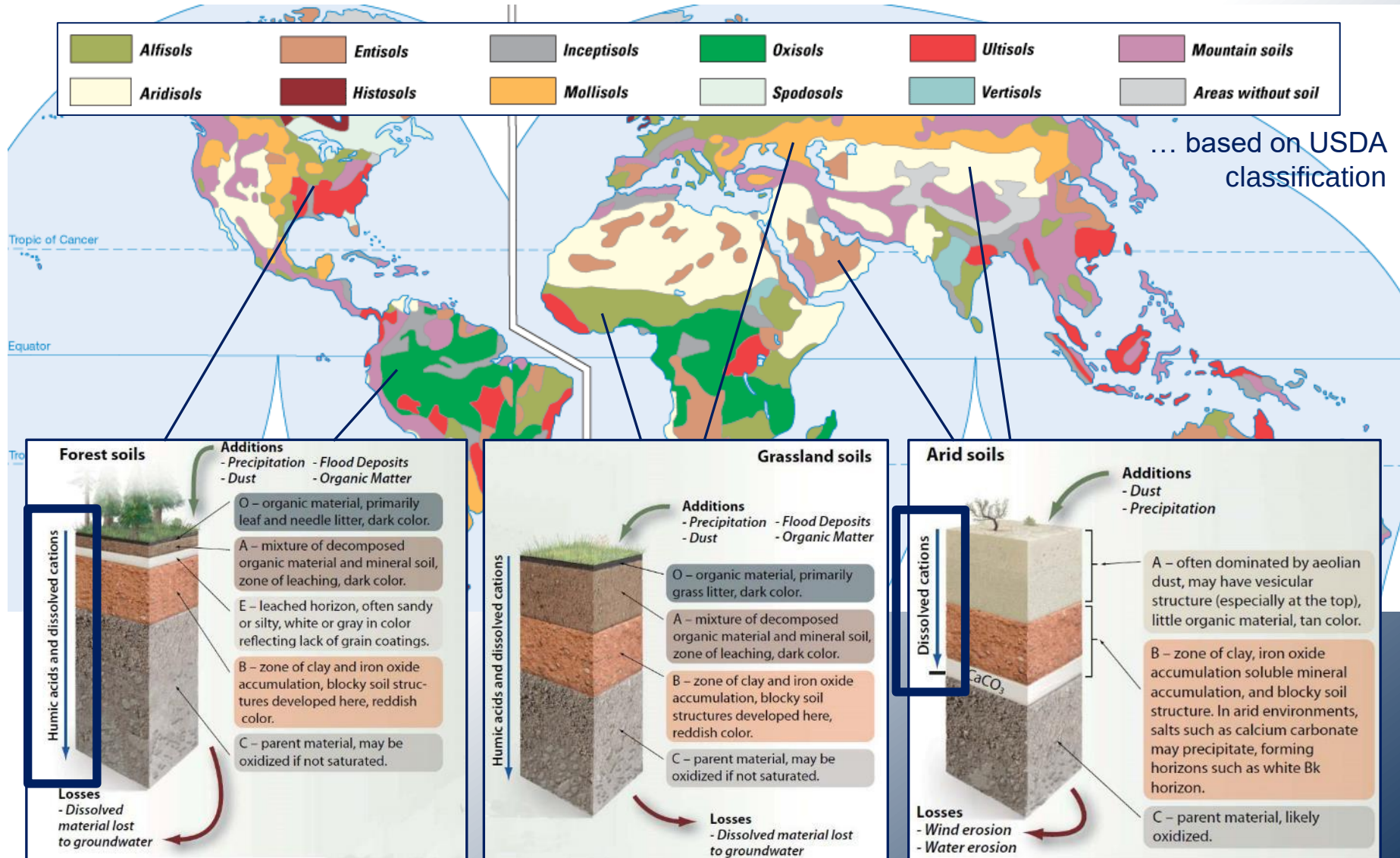
- Soil formation possible only if formation rate is faster than erosion

- Soil production rate vs removal (erosion) rate under agricultural use... is an issue!
- Global average: 114 mm per 1000 years (Stockmann et al. 2014)
- So, what drives soil formation ??



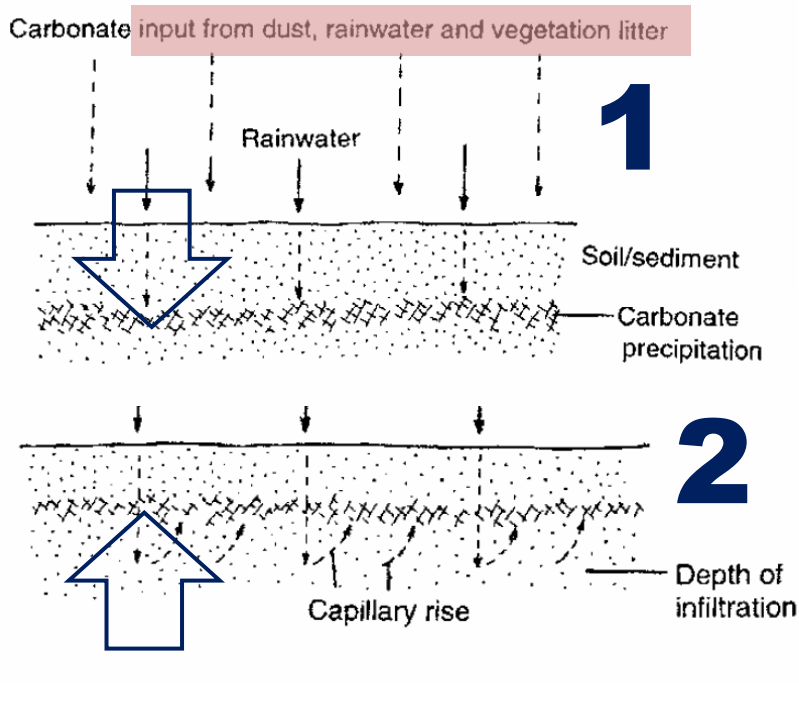
What drives soil formation? Part 1

- Soil = f (humans, lithology, **climate, vegetation...**)



What drives soil formation? Part 1

- Semi-arid hydrology and subsurface enrichment



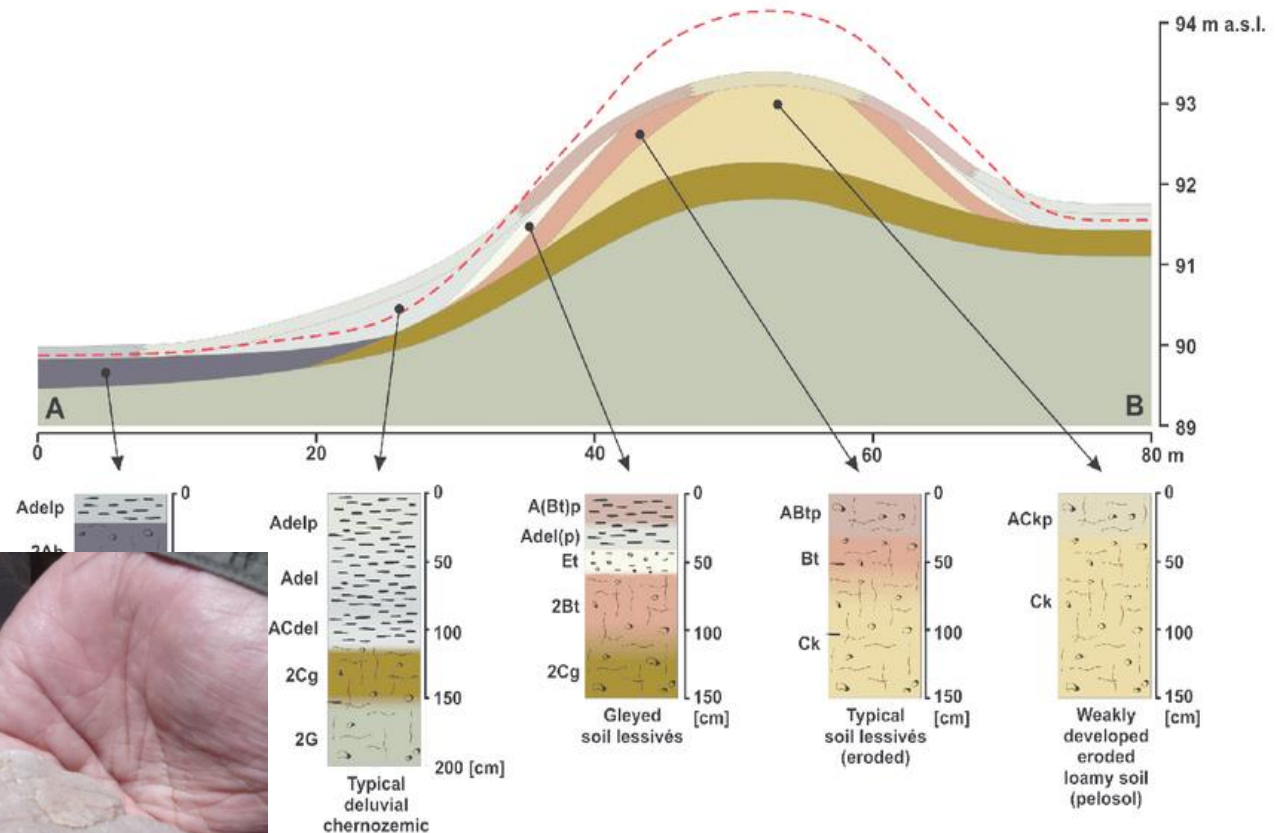
per ascensum and per descensum

- Successive mineral precipitation and hardening (stages of development)...
- Duricrusts**, e.g. Calcrete (carbonate), Gypcrete (gypsum), Silcrete (silica), Ferricrete (iron),... Soil horizon with rock properties!



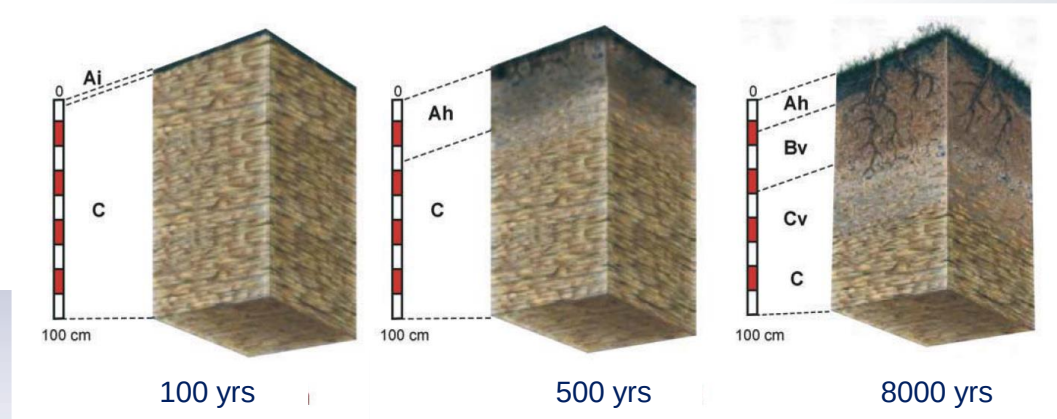
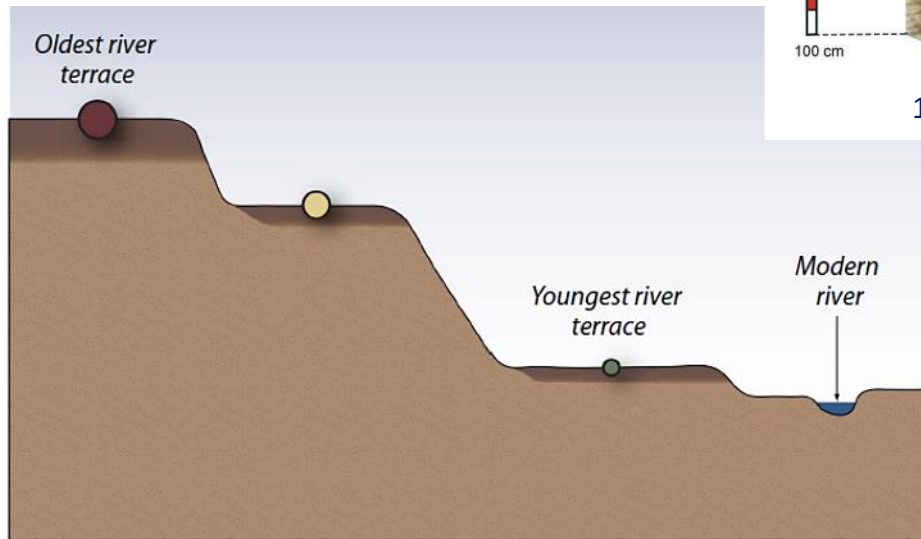
What drives soil formation? Part 2

- Soil = f (humans, lithology, climate, vegetation, relief/topography)
- Topo-sequence (catena):
sequence of varying profiles along changing relief/ topography (comparable parent material !?)



What drives soil formation? Part 3

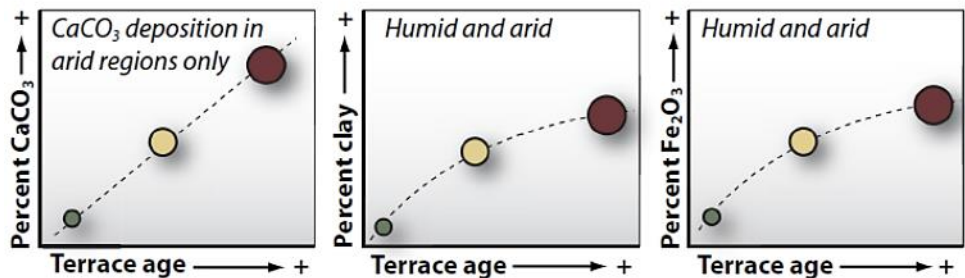
- Soil = f (humans, lithology, climate, vegetation, relief/topography, time)
- Chrono-sequence: sequence in substrates of varying age (comparable parent material !?)



- Change over time in physical and chemical properties...

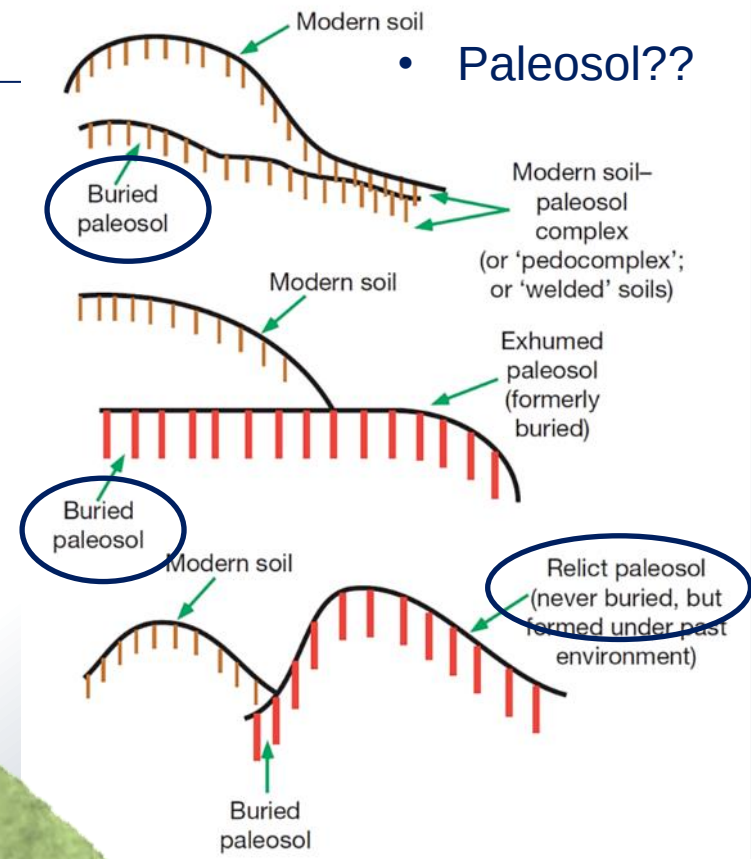
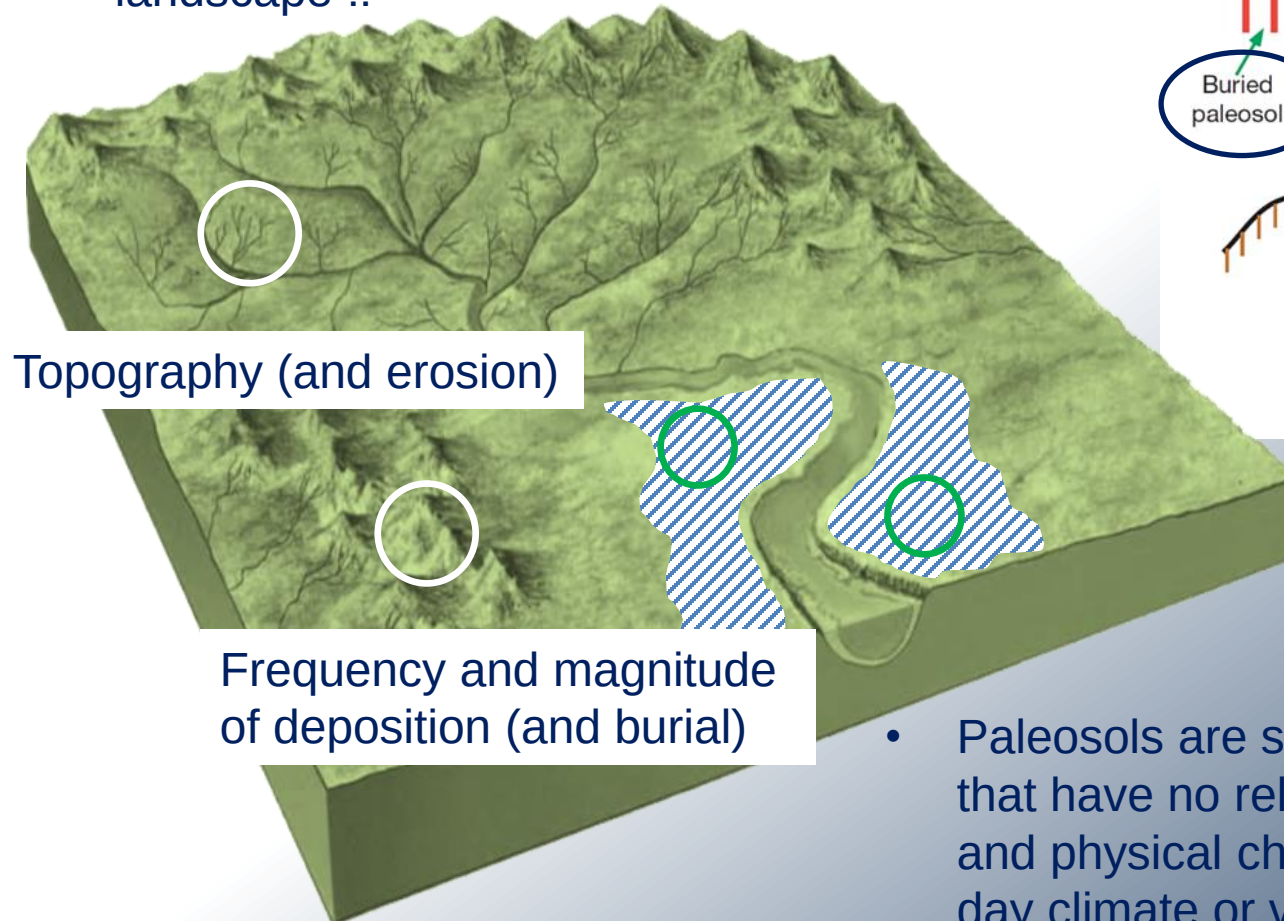
- Thickness
- Horizons
- Colour
- Chemistry
- Biology

- Relation between time and properties = relative age!!



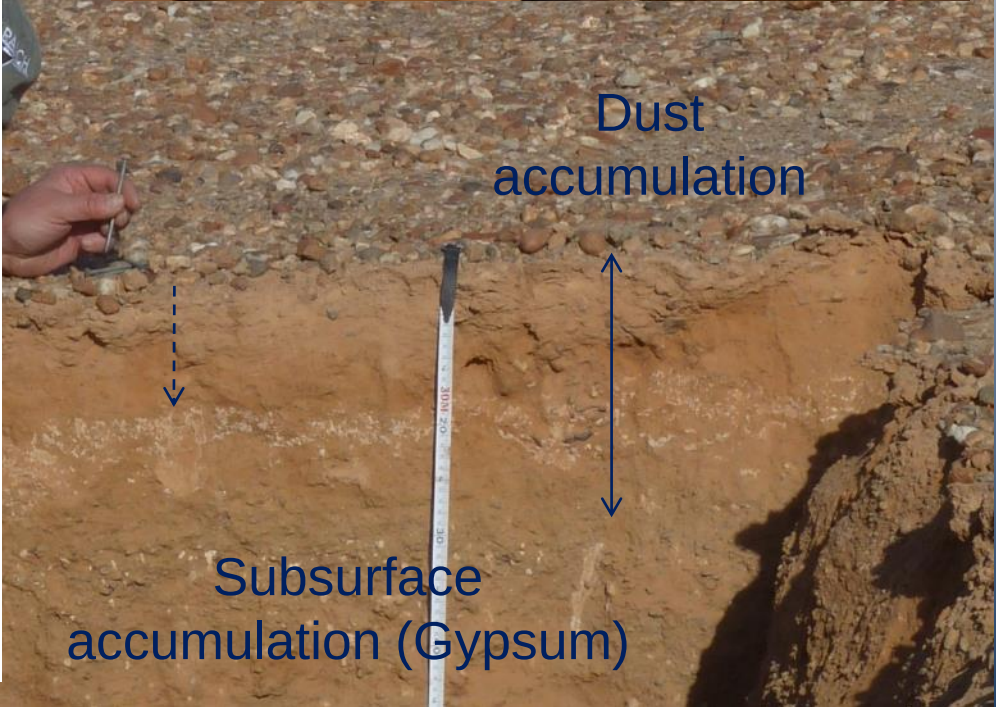
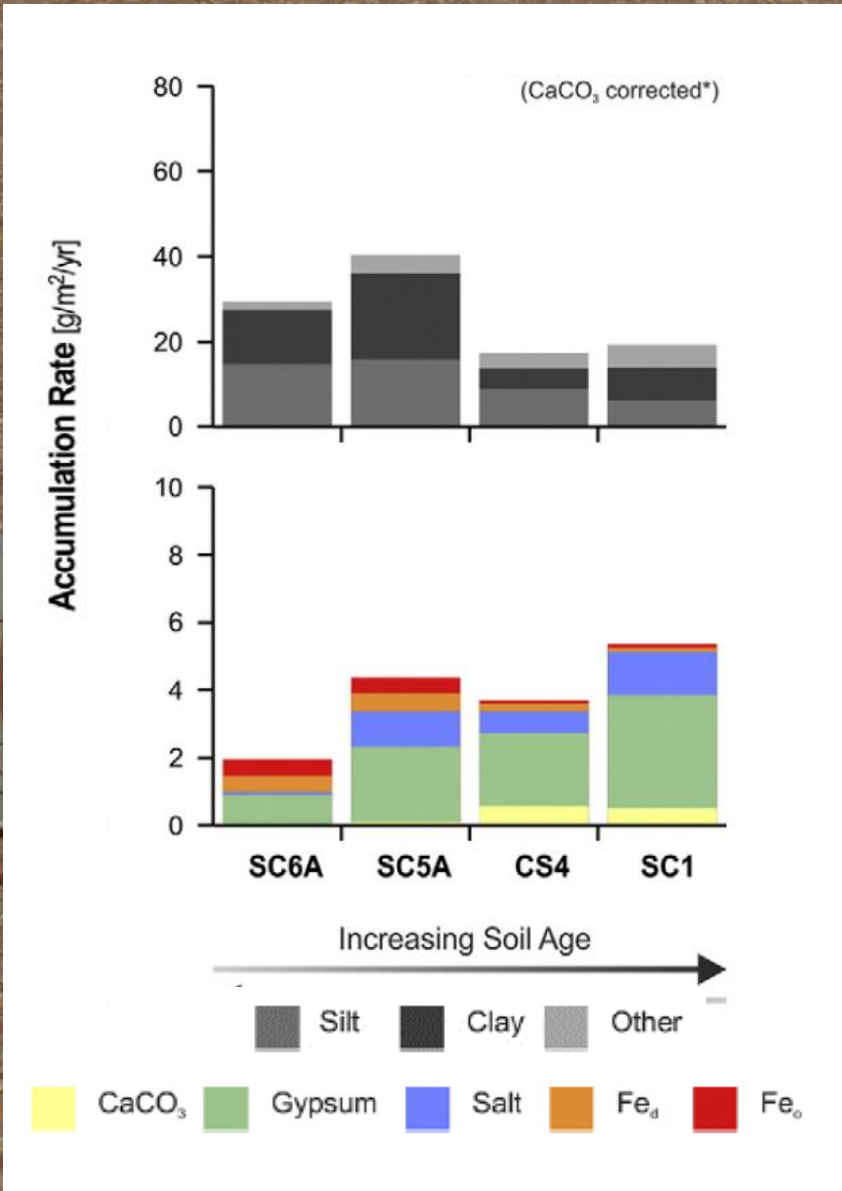
Soils and the landscape

- Where can soils form *and* **preserve**?
What are limiting factors?
- Well-developed soil reflects formation in a morpho-dynamically (relatively) **stable** landscape !!

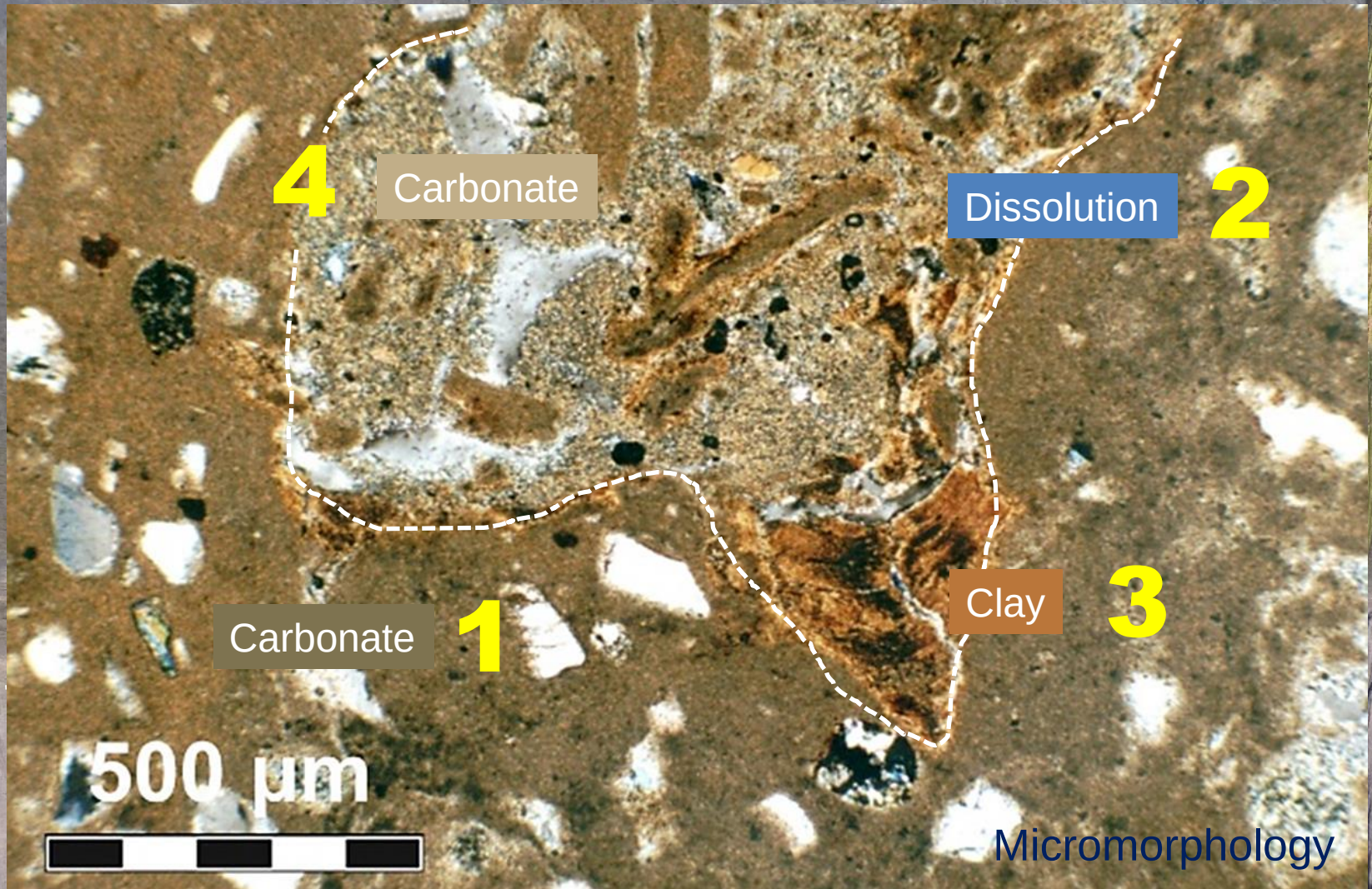


- 
- Former soil preserved by burial (geology)
 - Paleosols are soils formed long periods ago that have no relationship in their chemical and physical characteristics to the present-day climate or vegetation (soil science)

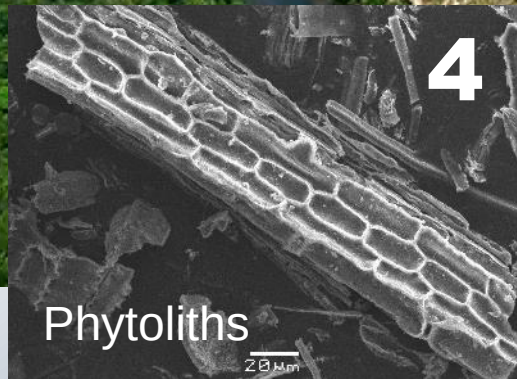
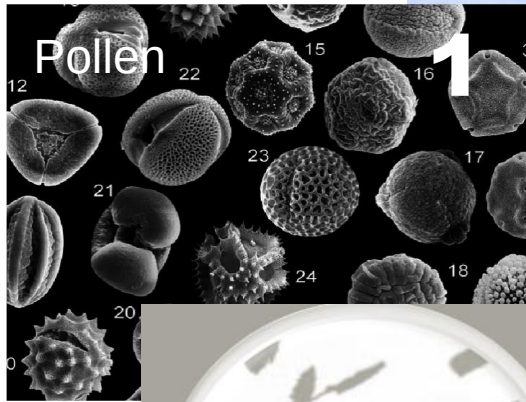
Soils and environmental change



Soils and environmental change



Paleosols and Paleoenvironment



SW Amazonian rainforest..
Untouched, pristine forest ?



Sustainable forest use since
about 6000 yrs

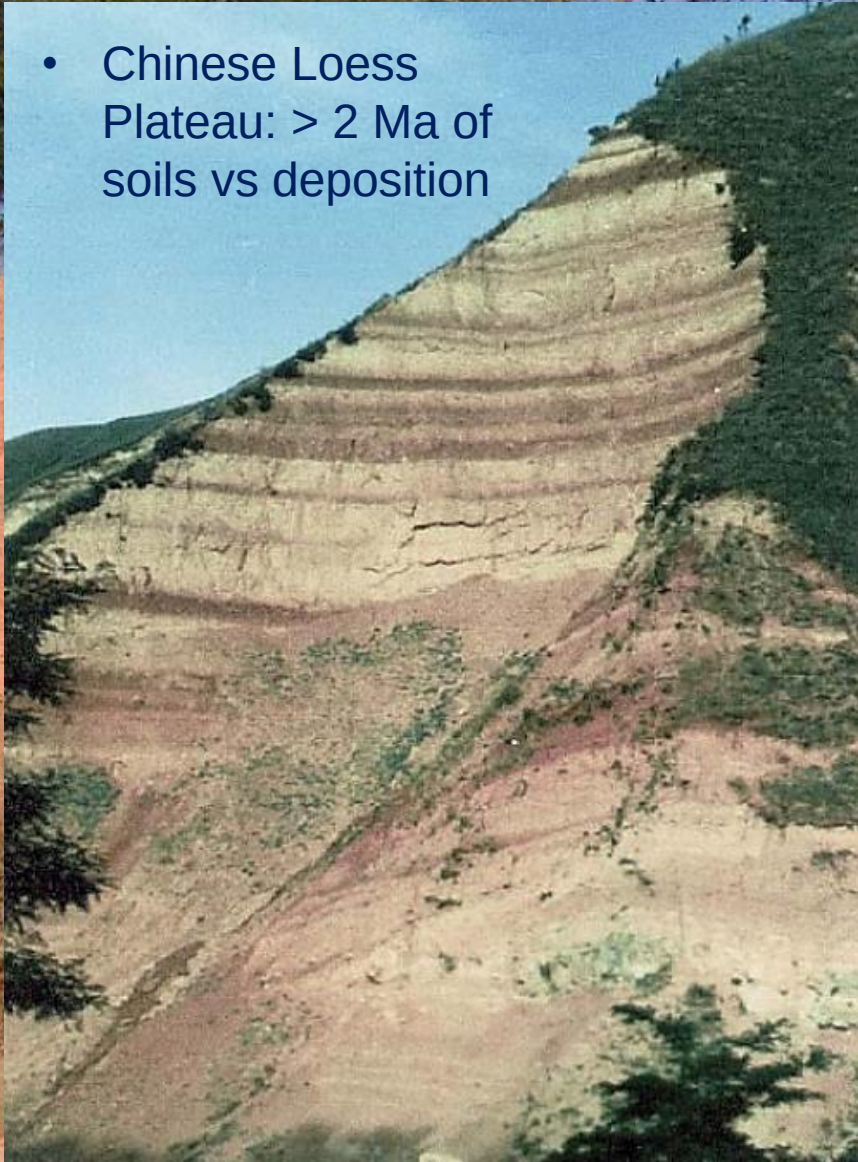
DNA

5

- Phytoliths: silica structures in plants – resist decay

Paleosols and Paleoenvironment

- Chinese Loess Plateau: > 2 Ma of soils vs deposition



1. Buried, past landsurface (“window in time”)
2. Environmental- and landscape reconstruction (“archive”)

Soils and the landscape – Summary...

- Soils form when / where landscape is **stable** (i.e. erosion / deposition are absent or slow)
- They provide a tool to understanding depositional sequences (**stratigraphy!**)
- They take time to form – tools for **relative dating** of landforms
- They are **past surfaces** and store information on what happened on these surfaces
- They represent archives for **reconstructing environmental changes**
- Buried and preserved paleosols are **windows in time**

3 minutes...



Weathering Landscapes – Deep time perspectives: Soils vs regolith



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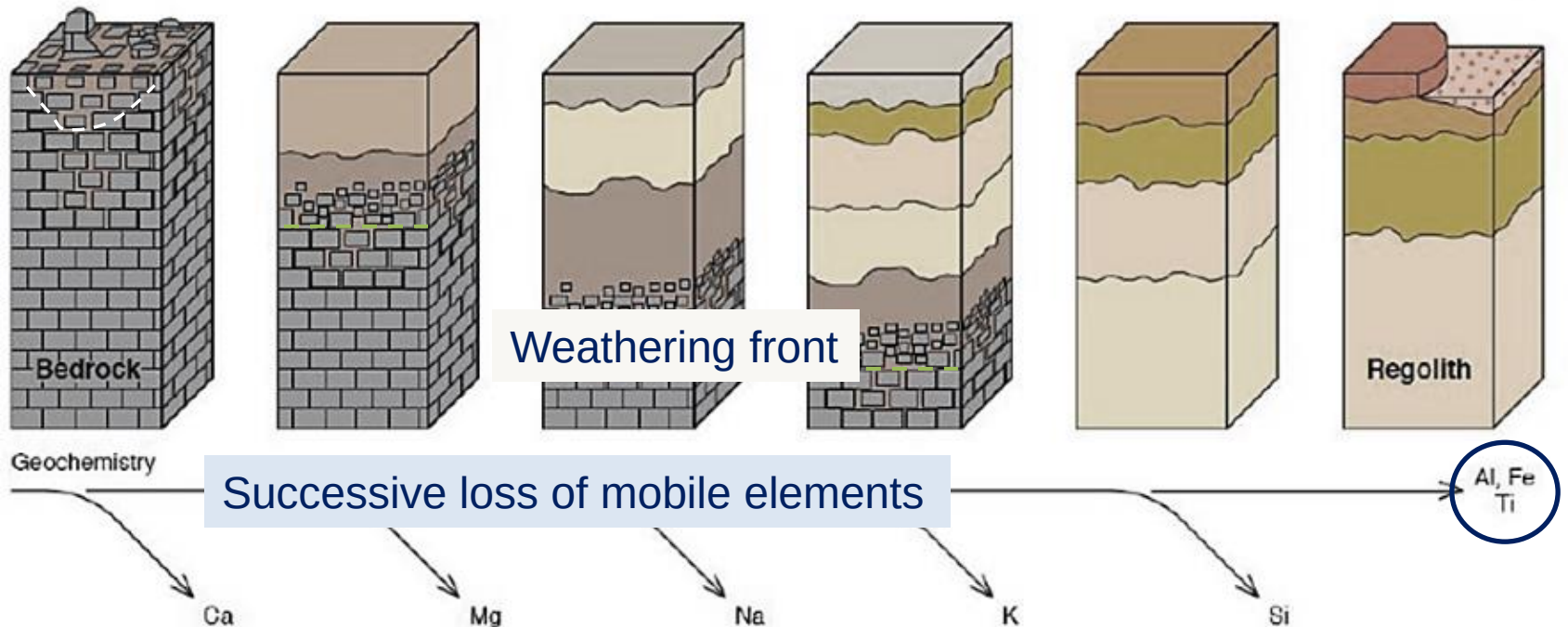
Dr. Alissa Flatley

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Long-term weathering

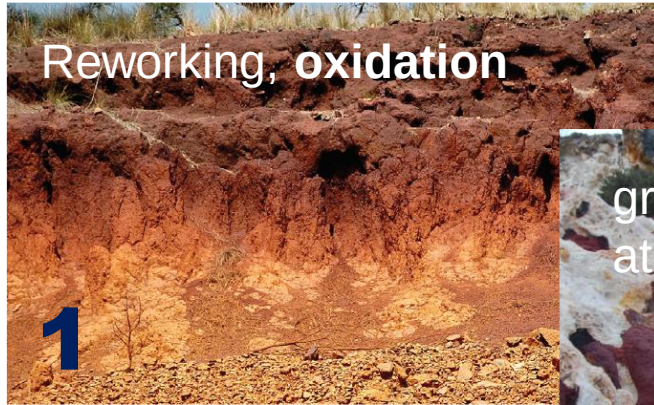
Weathering Intensity / Time →

Soil formation... a mixture of organic matter, minerals, gases, liquids, and organisms that together support life



- „Regolith - everything between fresh (un-weathered) rock and fresh air...“:
- layer of loose, heterogeneous superficial deposits/material covering solid rock, e.g. dust, soil, broken rock etc. (in-situ and transported)

Weathering Profiles



Reworking, oxidation

- Vertical assemblage of weathering zones



ground water and atmosphere

Groundwater...



ground water

Pallid Zone

Mottled Zone

Karamiquicham 2014

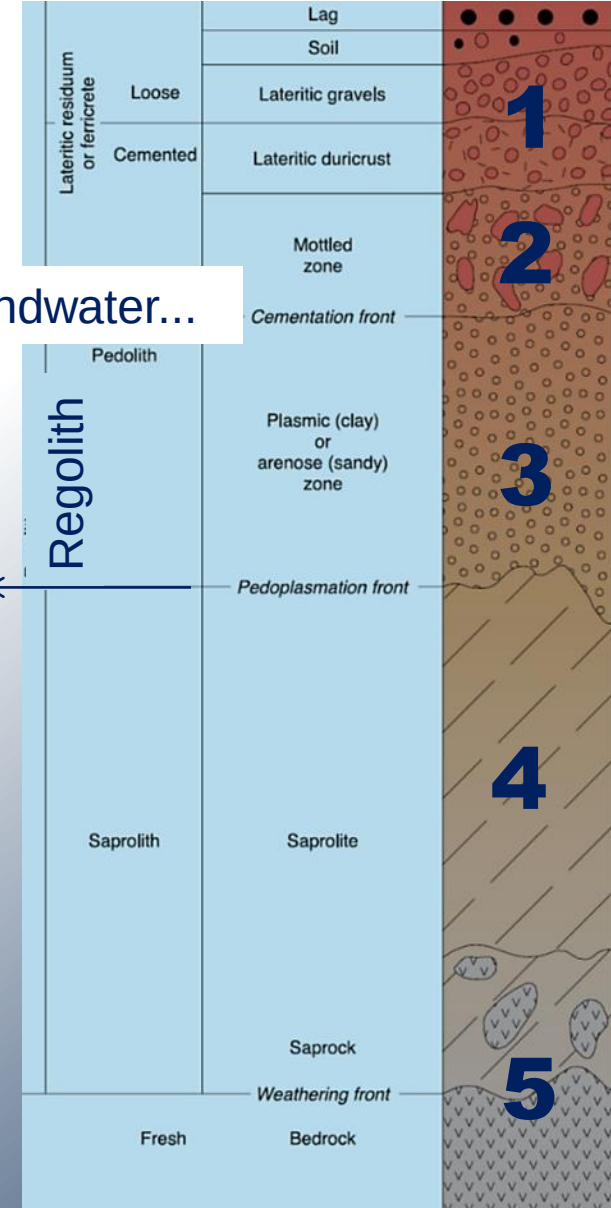


Core stones



Autochthonous chemical weathering

Saprolite Zone



- Profile is a complex response to climatic and geologic controls

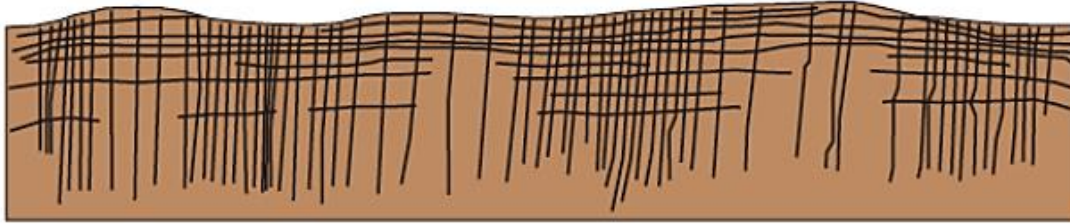
Weathering Profiles

Weathering profile in
Hamersley Ranges, Pilbara

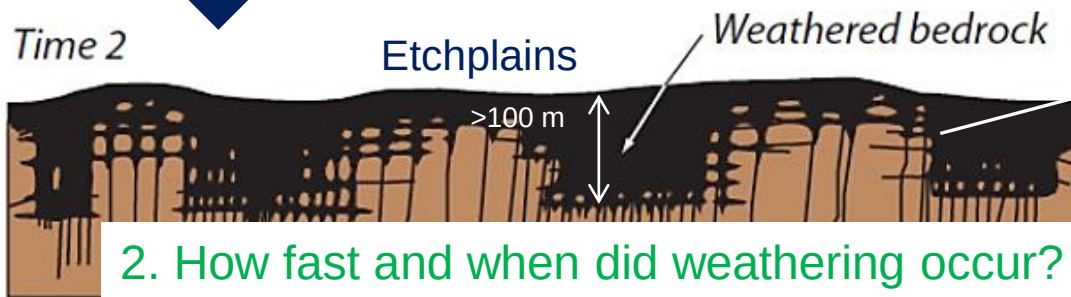


Weathering and Landscapes

Time 1 Tropical climate... (and tectonic stability/time)

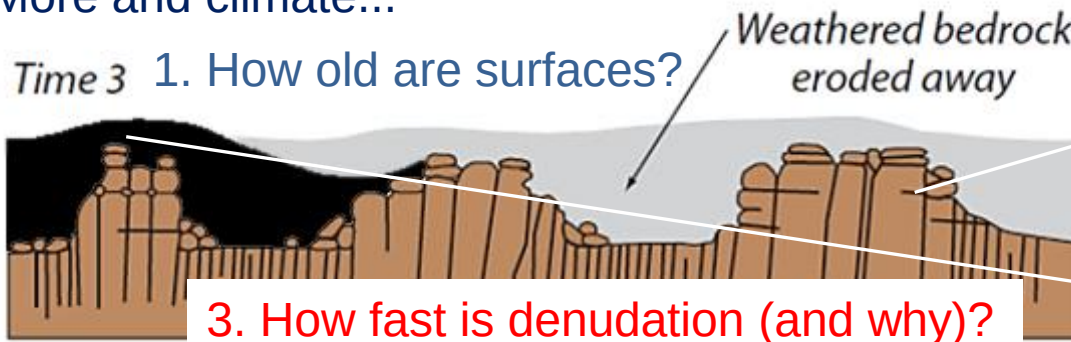


Time 2



More arid climate...

Time 3 1. How old are surfaces?



- Etchplains (peneplains) were thought of as developing in two major phases: (i) protracted deep weathering (ii) brief episode of stripping weathering products (denudation)

Weathering front relief

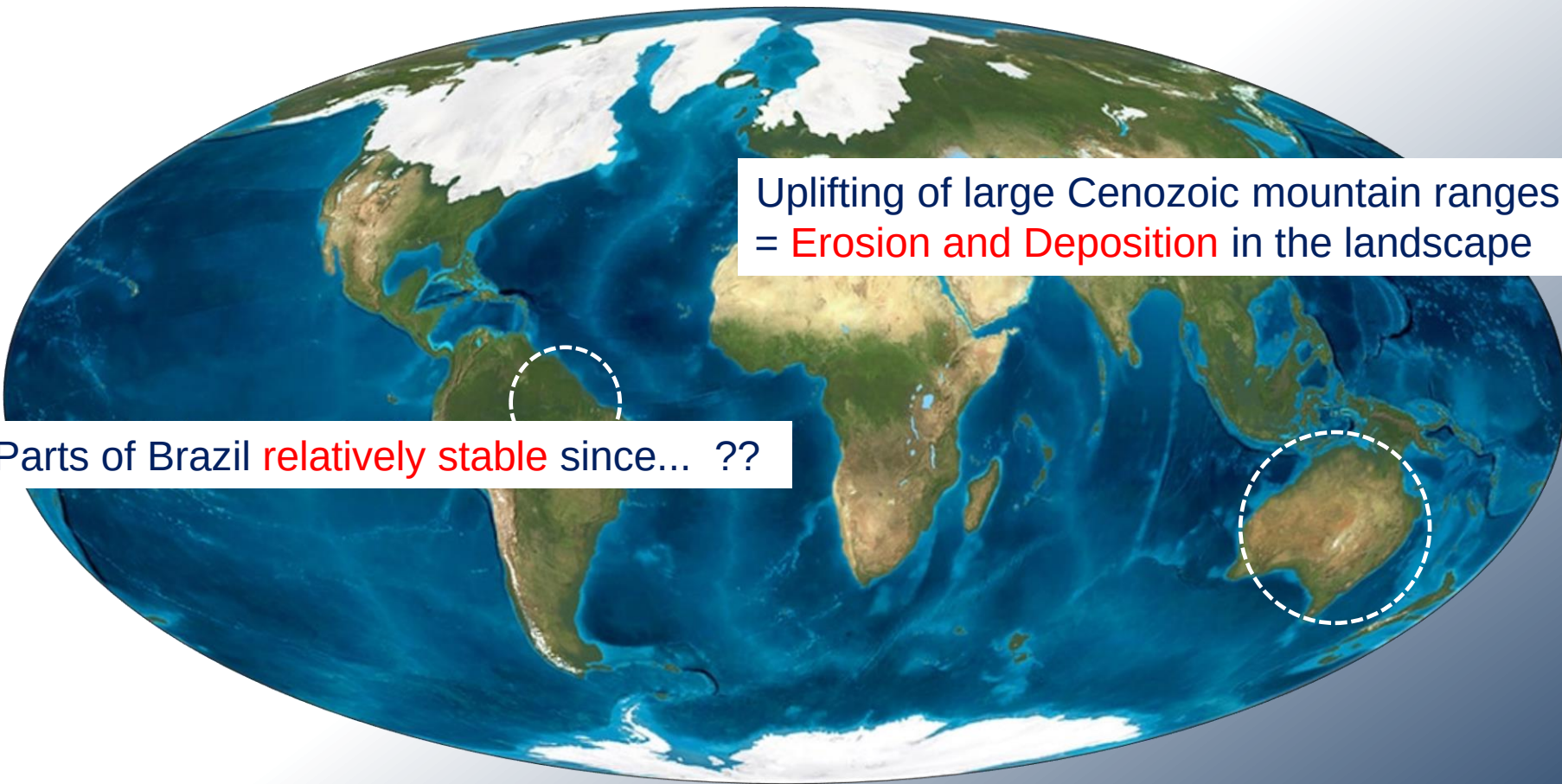
- Reasons for change from weathering to stripping?
- Complete or incomplete stripping...

Remnants of resistant areas in weathering front:
Inselbergs

Remnant peneplains

Long-term weathering – where on Earth...?

Northern Hemisphere glaciation 0.02 Ma
= **Erosion and Deposition** in the landscape

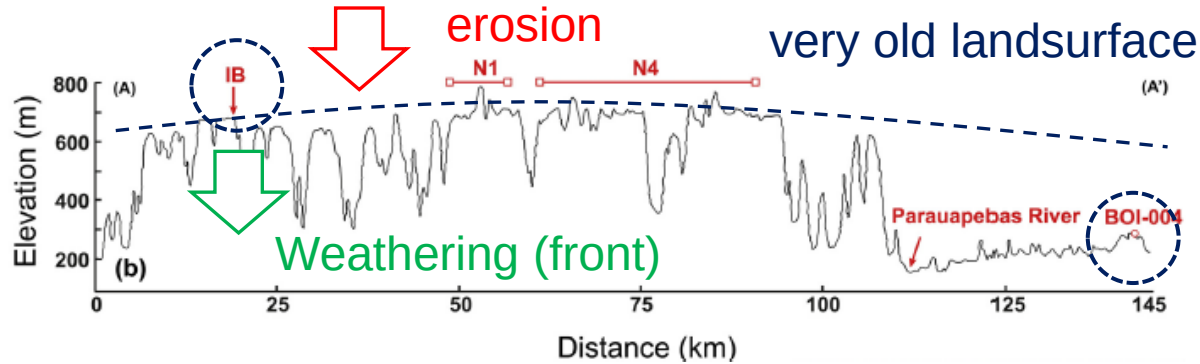


Uplifting of large Cenozoic mountain ranges
= **Erosion and Deposition** in the landscape

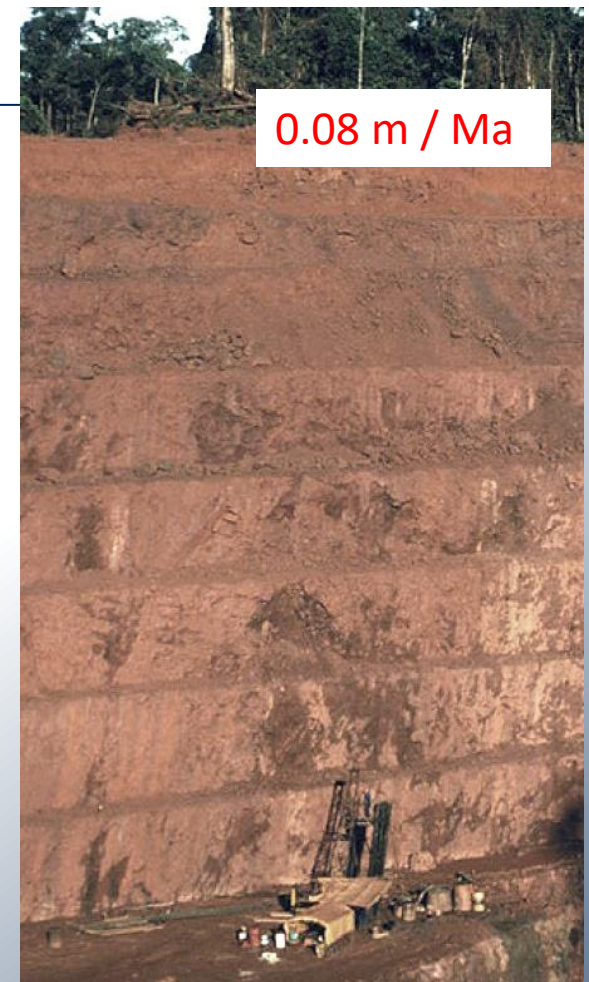
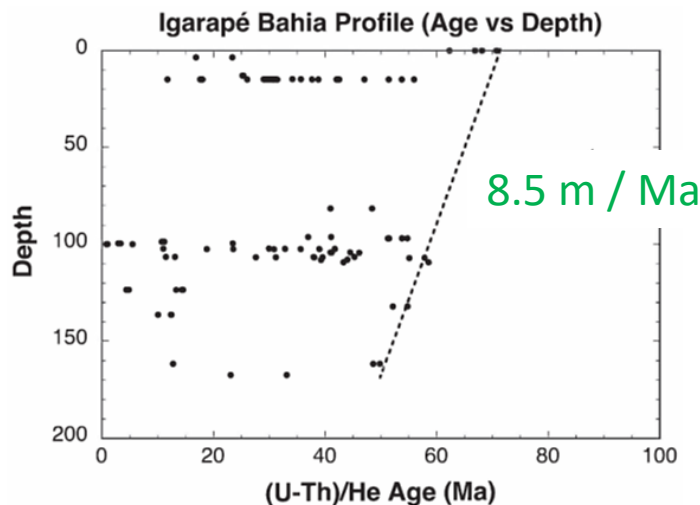
Parts of Brazil **relatively stable** since... ??

Large parts of Australia tectonically **relatively stable** since... ??

Weathering and Landscapes



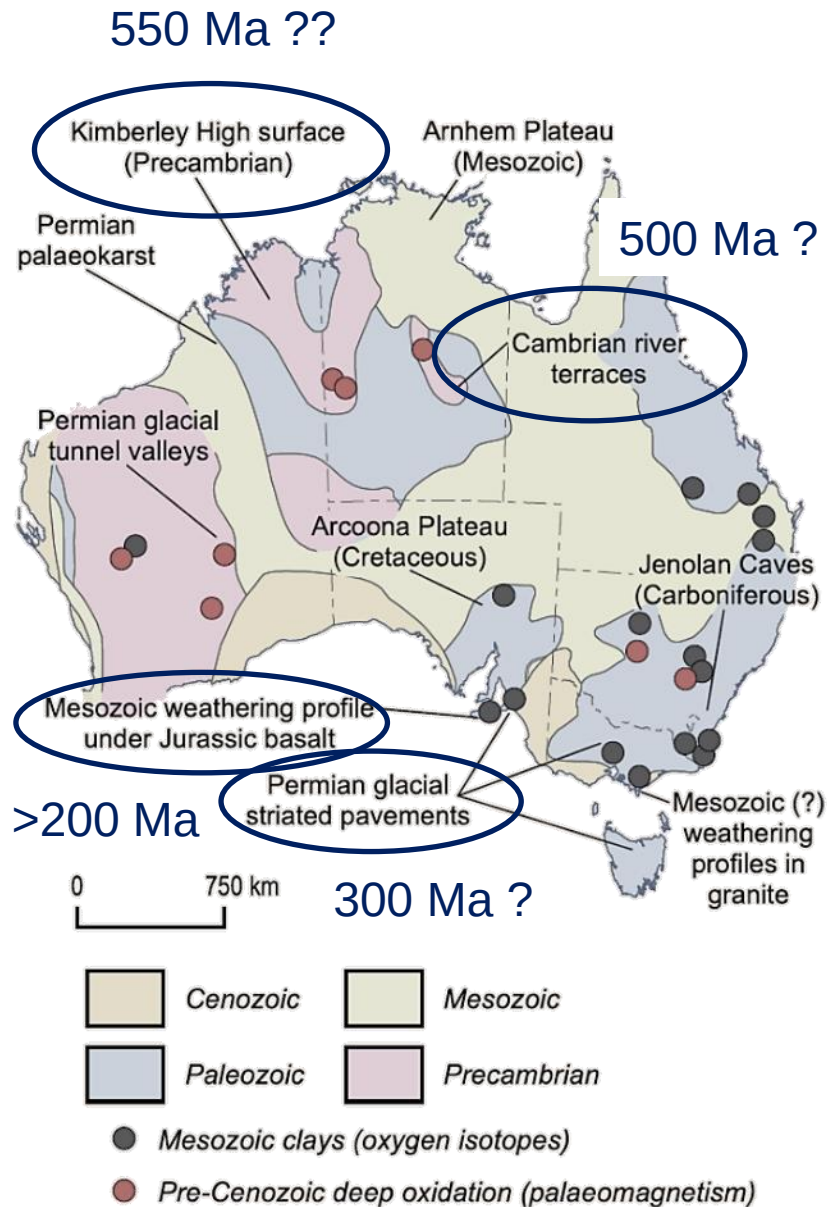
- Various dating methods for measuring erosion (=exposure), weathering (= clay neoformation)
- High surface: history of weathering spanning from ca. 80 Ma to the present; low surface consistently younger than 10 Ma



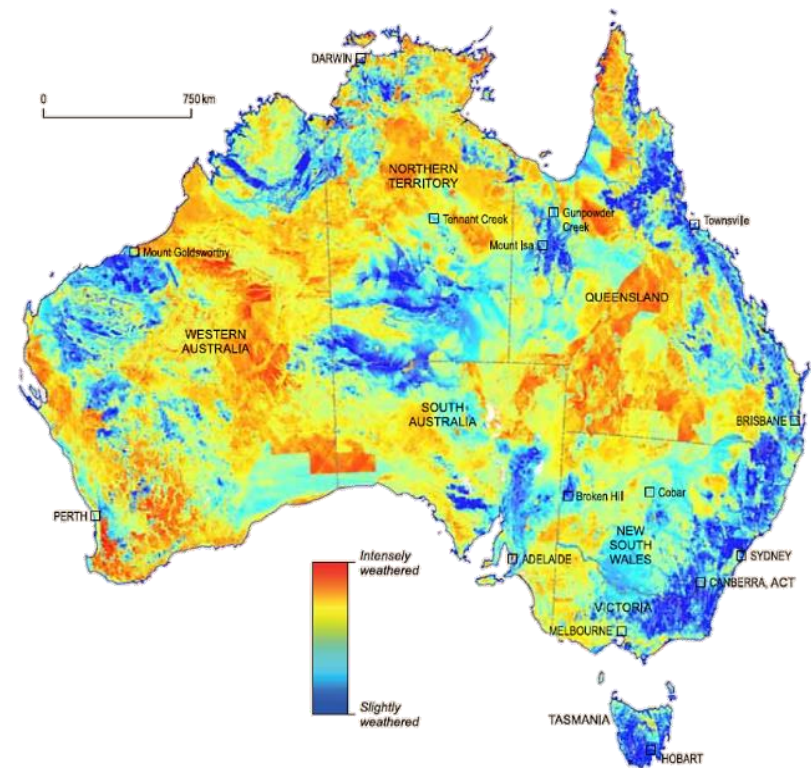
- Carajas Plateau (Igarapé Bahia, Brazil)

- **Denudation** – sum of processes that cause the wearing away of the Earth's surface leading to a reduction in elevation and relief

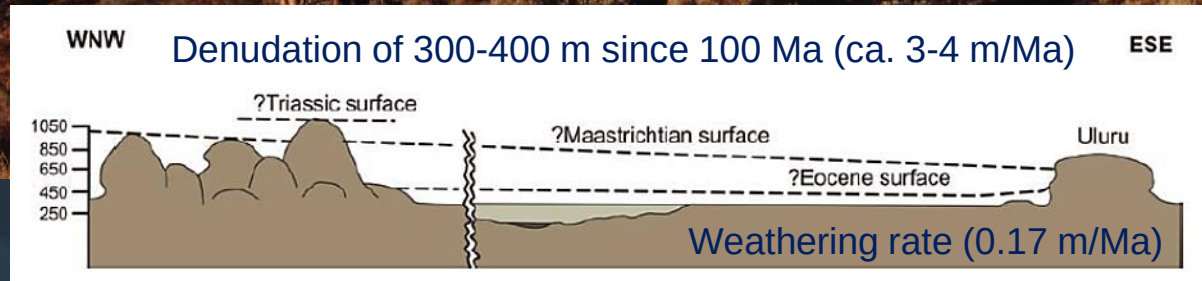
Australia's oldest land surfaces...



- Is there evidence for (i) long subaerial exposure (i.e. weathering) and (ii) very old surfaces in Australian landscapes?
- Regolith thickness (max ca. 100 m) vs weathering intensity...



Landscape Denudation

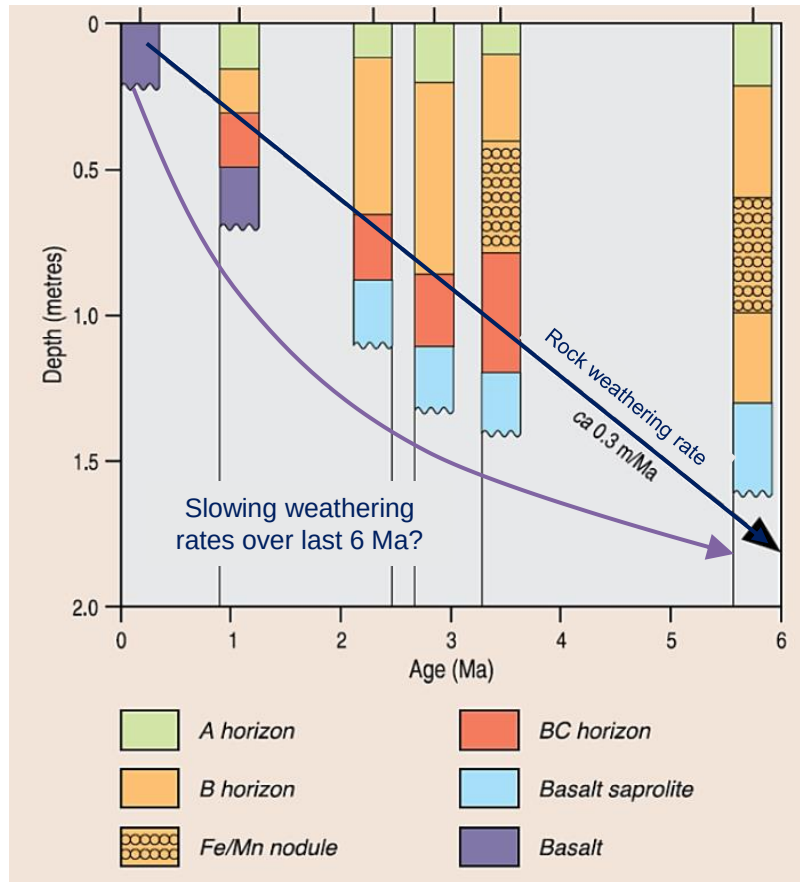


- Inselberg... remnant part of an old surface
- Has weathering slowed – and/or denudation intensified?

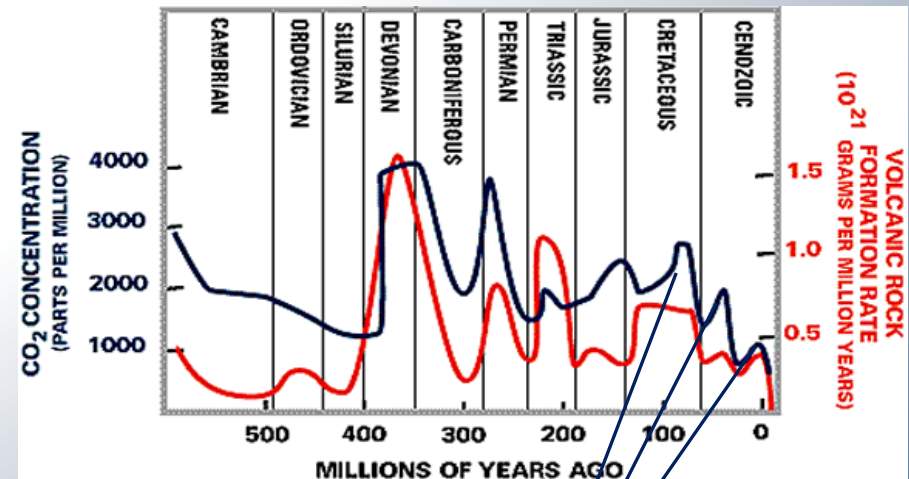
- Australia today (e.g. last few 100 ka): 0.2–7 m / Ma: (i) survival of very old (e.g. 500 Ma) land surfaces very unlikely, (ii) denudation varies spatially and temporally



Weathering rates and dates...



- 30 m/100 Ma... (100 m/330 Ma)
- CO₂ is crucial in increasing weathering intensity!! Therefore, changes in CO₂ in Earth history = changes in weathering intensity...!!



- peaks in tectonic / volcanic activity = peaks in CO₂ = peaks in weathering intensity ??

3 minutes...

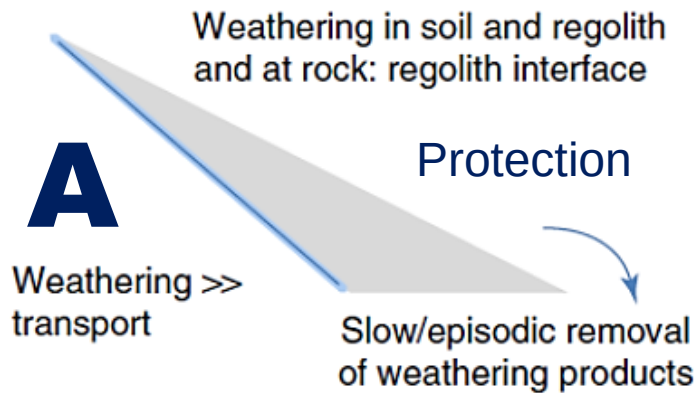


Regolith production & Landscape



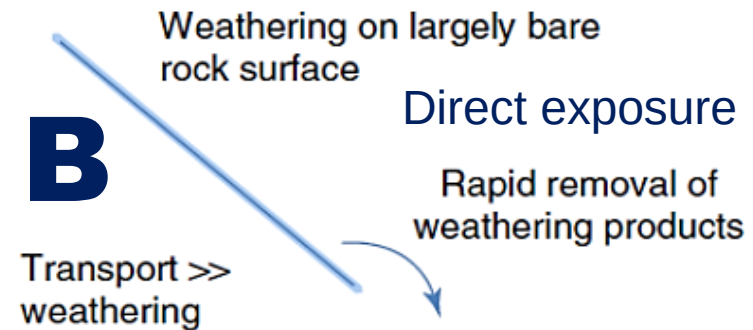
- What dominates landscape evolution in the long run...
Weathering or erosion/transport...?

„Transport-limited“



- Weathered material (regolith) accumulates, removal determines slope (landscape) evolution

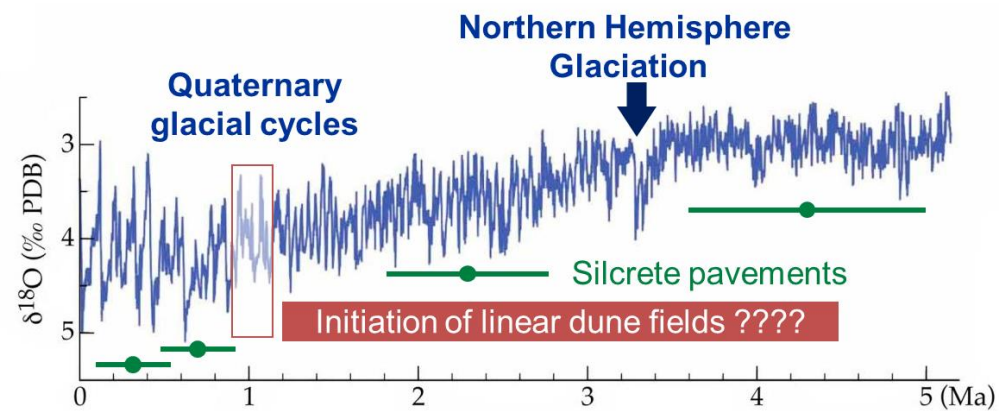
„Weathering-limited“



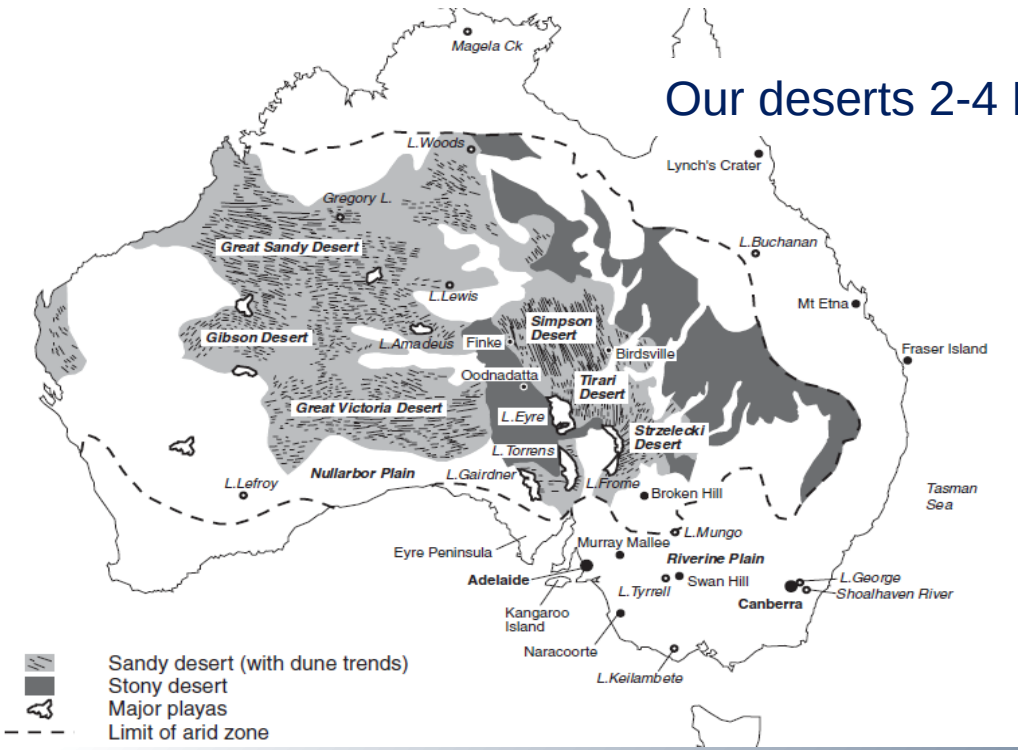
- Weathered material (regolith) constantly removed, weathering type / speed determines slope (landscape) evolution

What makes the difference?

Australian landscape and climate...



Transport-limited and humid



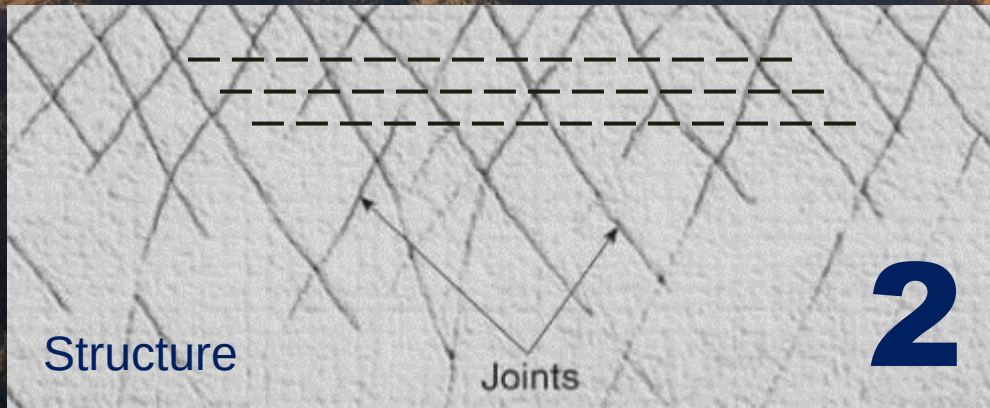
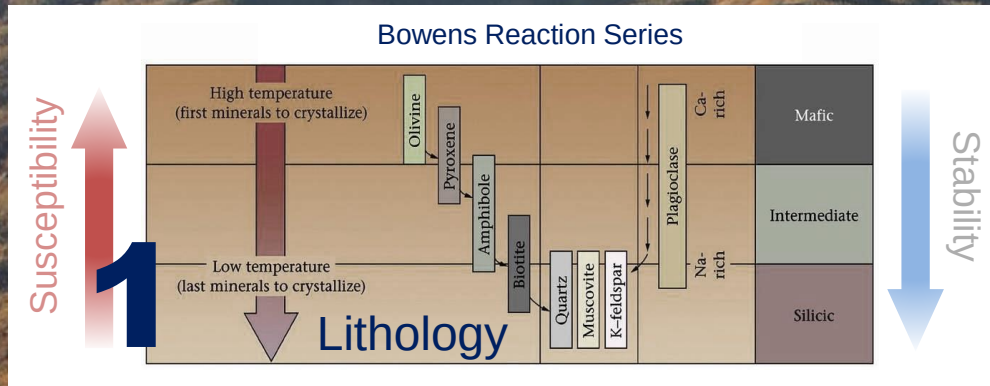
Weathering-limited and dry

Weathering-limited landscapes

- All rocks weather – but not the same way, and rate **depends on stability / resistance** (rock strength control)
- Long-term **differential weathering** and the presence of resistant bedrock layers...

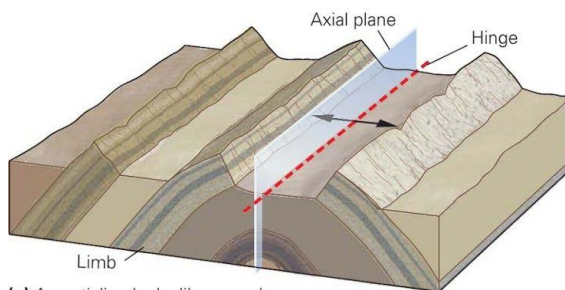
Resistant (Quartzite)

Soft (Shales)

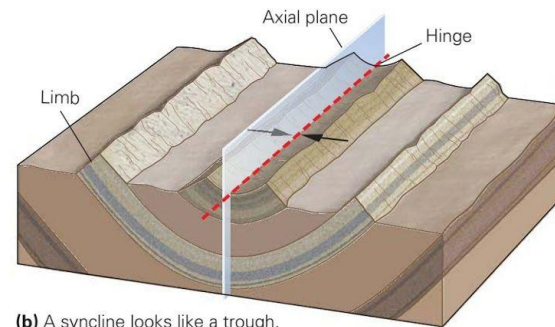


Flinders Ranges,
South Australia

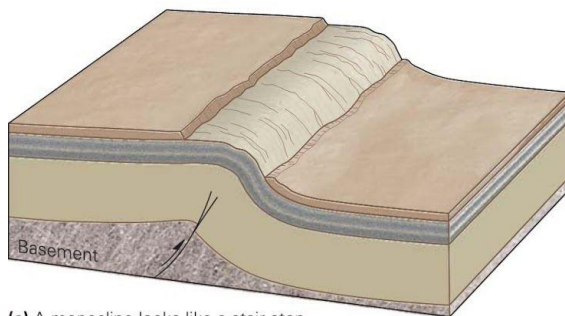
Structural landforms



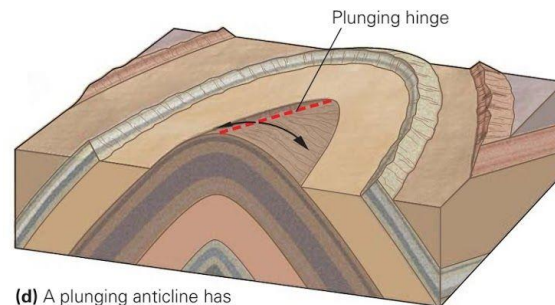
(a) An anticline looks like an arch. The beds dip away from the hinge.



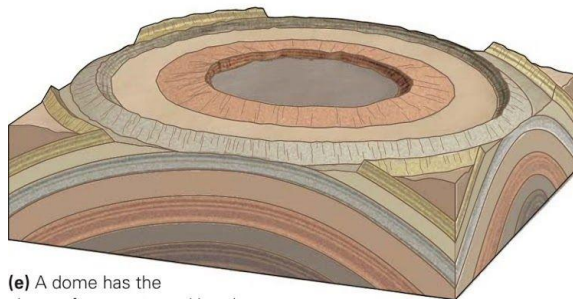
(b) A syncline looks like a trough. The beds dip toward the hinge.



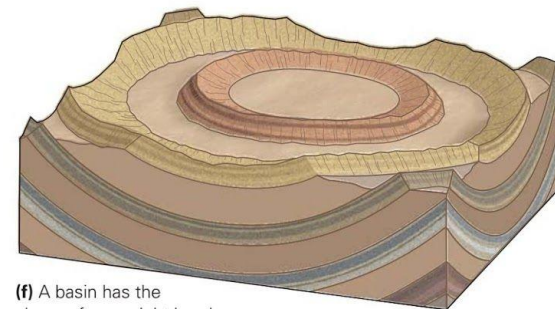
(c) A monocline looks like a stair step, and is commonly draped over a fault block.



(d) A plunging anticline has a tilted hinge.



(e) A dome has the shape of an overturned bowl.



(f) A basin has the shape of an upright bowl.

Structural landforms



Monument Valley, USA

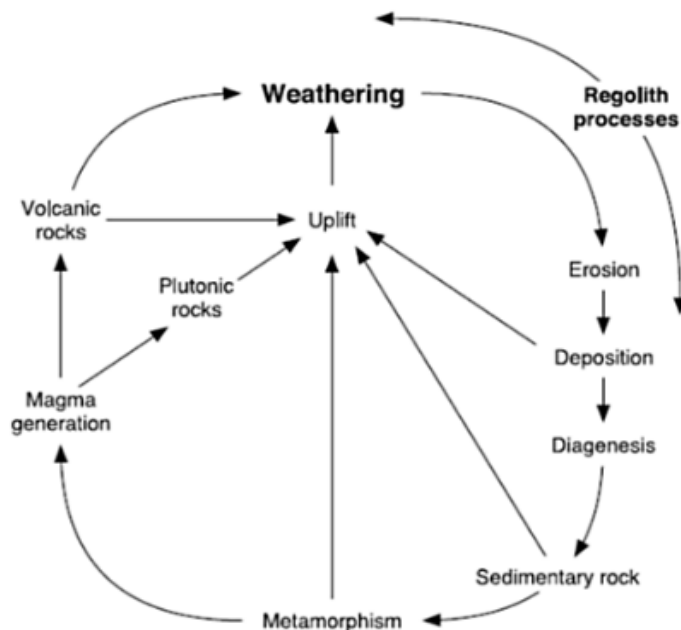
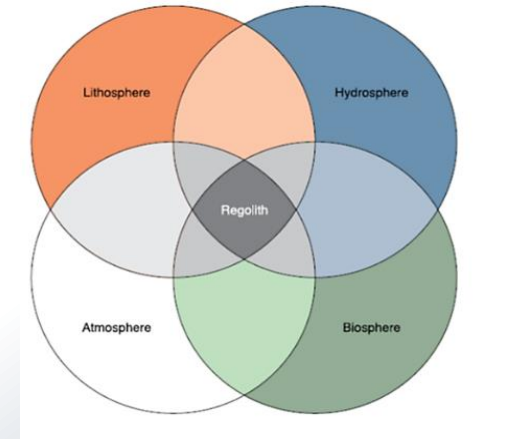
Structural landforms



<http://www.geologypage.com/2016/05/devils-tower.html>

Summary „Weathering & Landscape“

- “... at the heart of some exceptionally beautiful landscapes” – not just in the tropics...
- ... creates complex landscapes controlled by (i) range of weathering processes, and (ii) weathering factors



- ... has created deep weathering profiles and regolith mantle over geological timescales
- ... depends on rock strength when regolith mantle is absent
- ... and erosion under more recent conditions have exposed residual landscapes