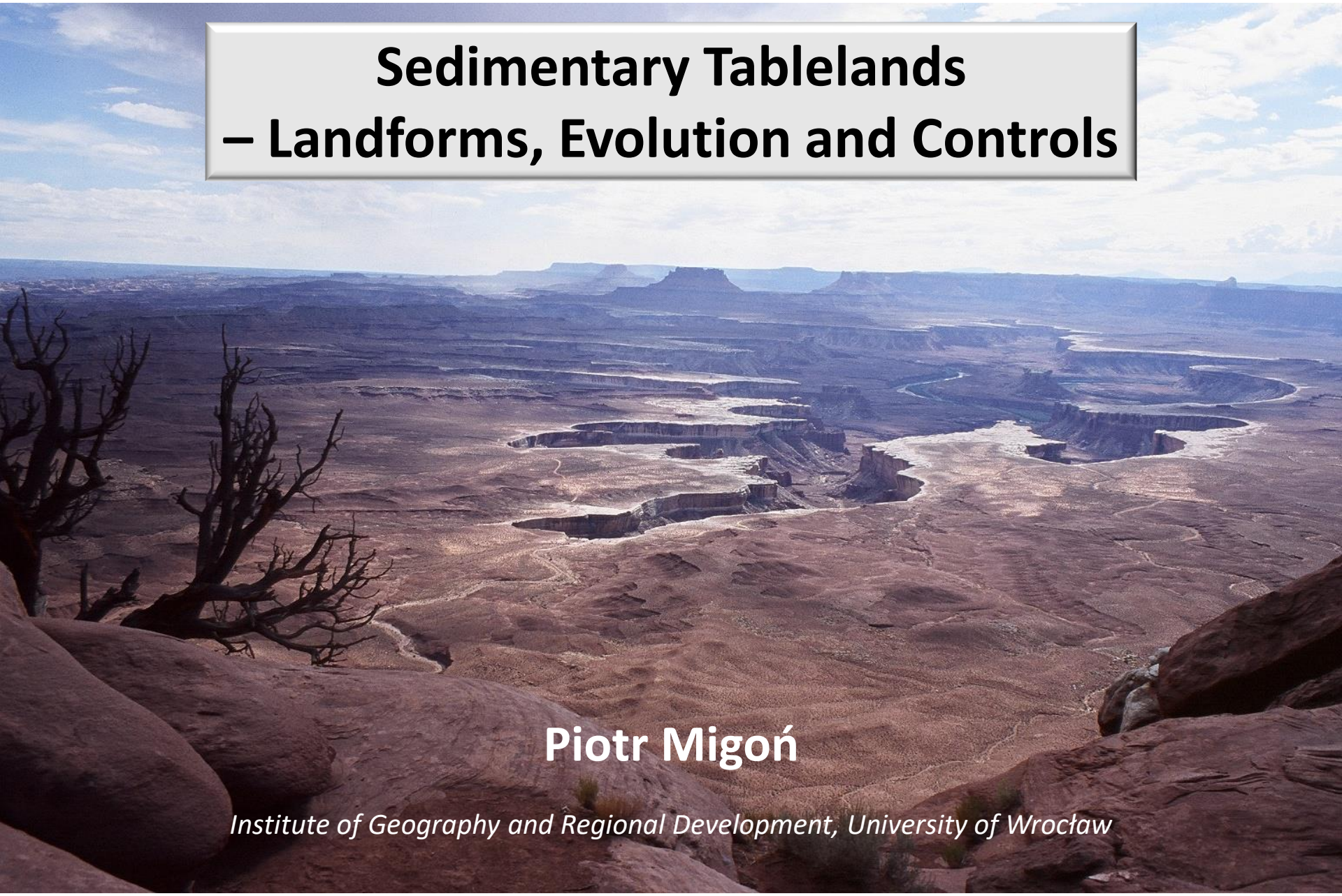


Sedimentary Tablelands – Landforms, Evolution and Controls

Piotr Migoń

Institute of Geography and Regional Development, University of Wrocław

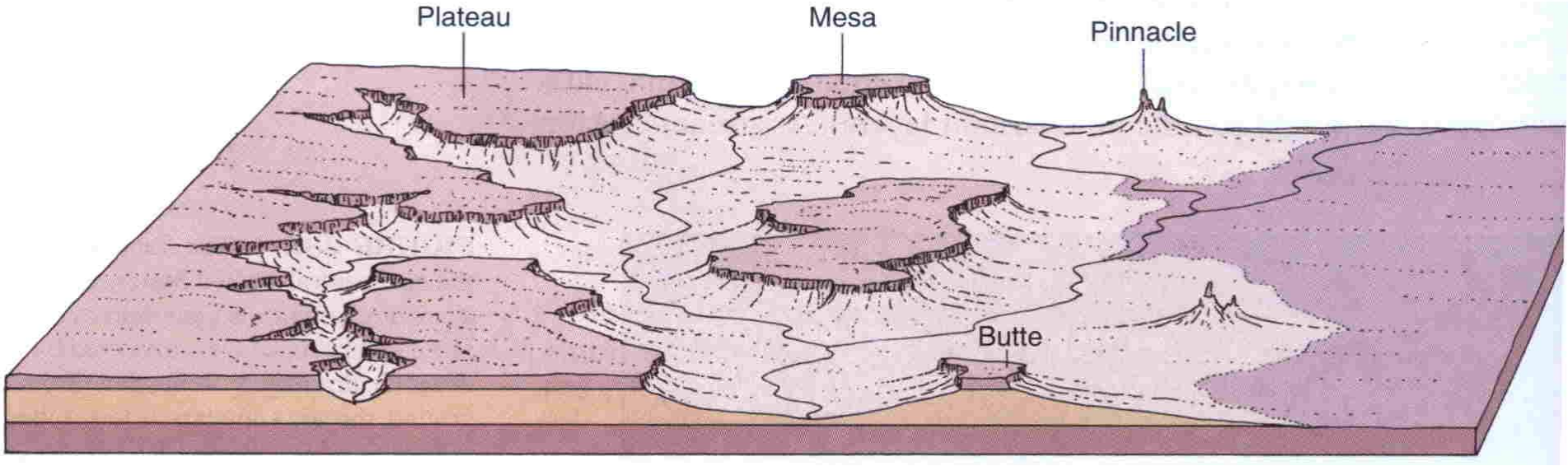
INNOLEC (Innovation Lectures), Masaryk University, Brno, 12 April 2023

Outline

1. Tablelands – key geological characteristics *) with focus on clastic successions
2. Regional landscapes
3. Specific medium-size landforms
4. Geomorphic evolution – main traits
5. Surface processes
6. Patterns of slope evolution
7. Subterranean processes
8. Timing of escarpment retreat
9. Conclusions

What are **Tablelands**?

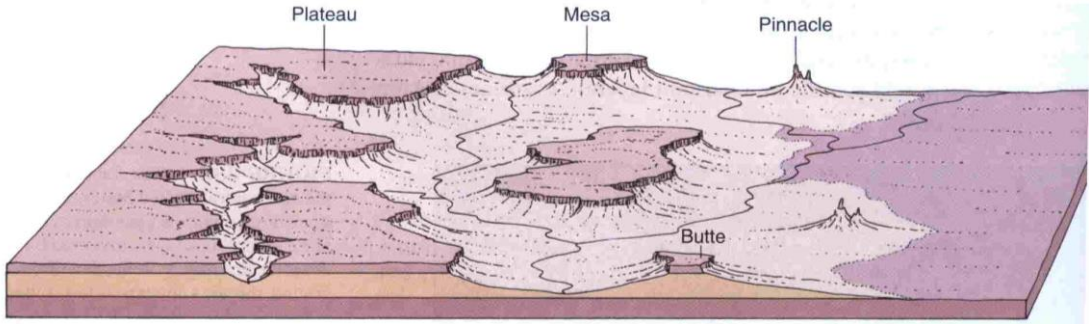
- landscape appearance is the answer



What are **Tablelands**?

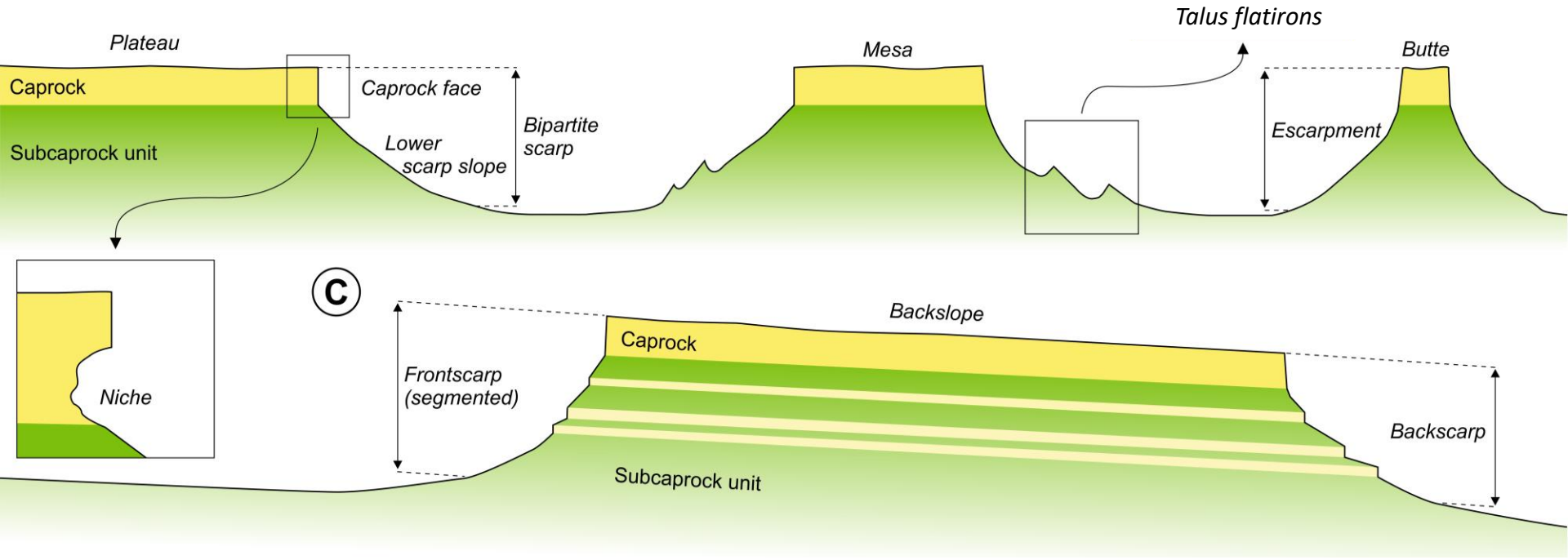
- but geology controls the landscape

Layered sedimentary successions



Layered sedimentary successions may involve different lithologies

Unifying theme → rock series of different properties in vertical alternation



Strong
(resistant)

Weak
(less resistant)

Diversity of clastic successions

1 Multitude of sedimentary environments

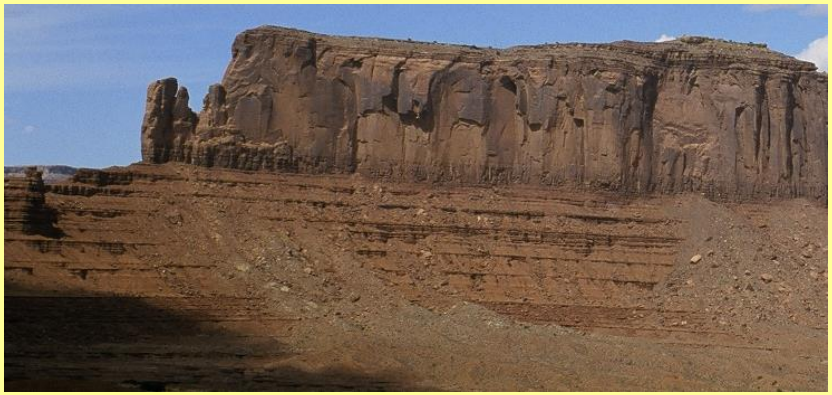
- non-marine
  - fluvial
  - deltaic
  - lacustrine
  - aeolian
- transitional
- marine

2 Classification by grain size

ClasticTexture (particle size)		Sediment Name	Rock Name
Coarse (over 2 mm)		Gravel (Rounded particles)	Conglomerate
		Gravel (Angular particles)	Breccia
Medium 1/16 to 2 mm)		Sand (If abundant feldspar is present the rock is called **Arkose**)	Sandstone
Fine (1/16 to 1/256 mm)		Mud	Siltstone
Very fine (less than 1/256 mm)		Mud	Shale or Mudstone

http://www.geologyin.com/2014/12/sedimentary-textures-and-classification.html

3 Alternations in vertical succession



⇐ coarser, massive

⇐ finer, thinly bedded

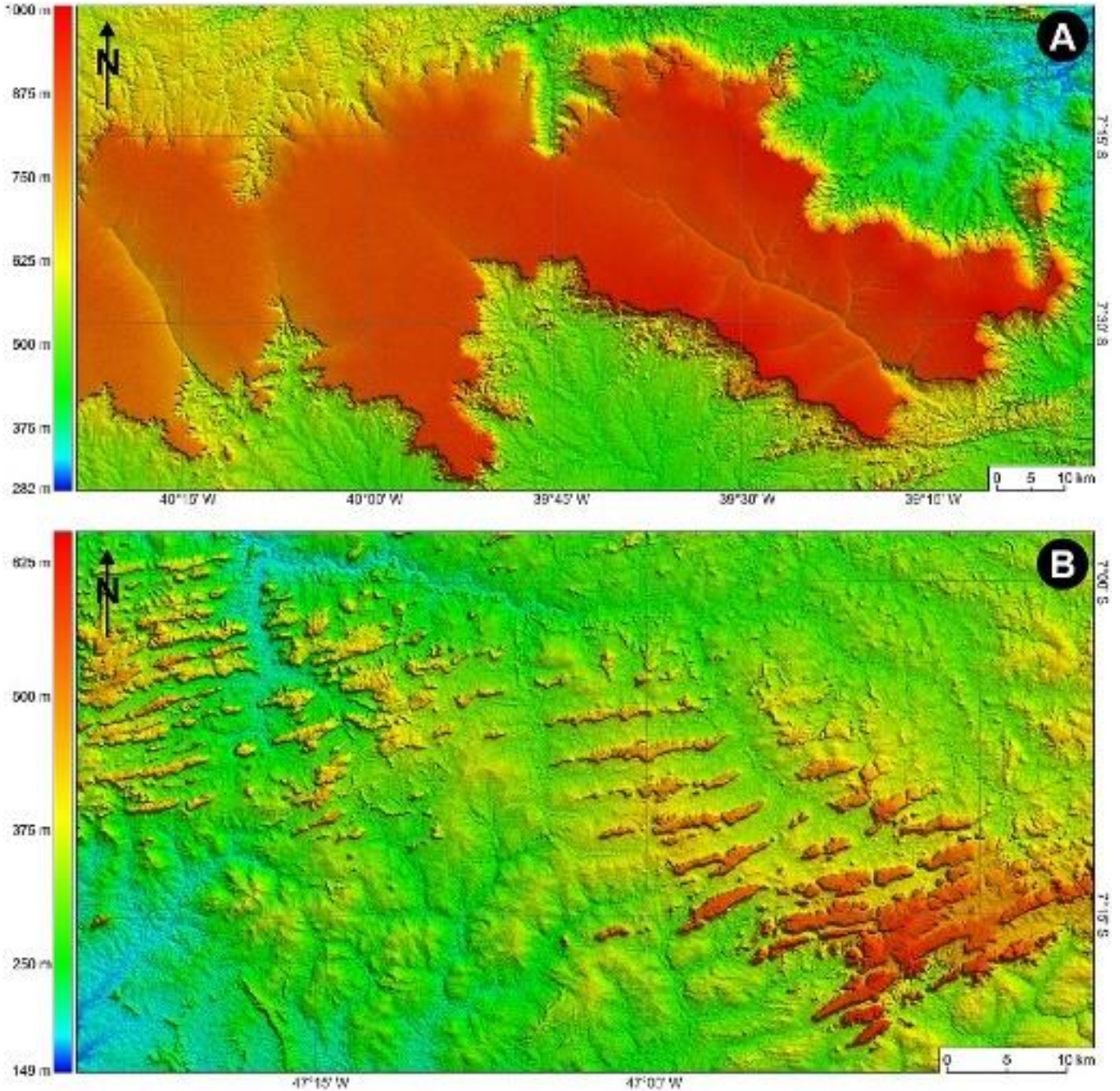
Regional landscapes

- plains and plateaus in flat-lying successions → structural levels separated by scarps

Colorado Plateau, USA

Regional landscapes

- plains and plateaus in flat-lying successions → but the extent of dissection varies



Regional landscapes

- homoclinal ridges and escarpments in tilted successions


Saharan Desert, Morocco


Broumovske stěny

Regional landscapes

- locally more complex structures (more deformation)

Breached anticline of Makhtesh Hagadol, Israel

Geological controls on more local scale

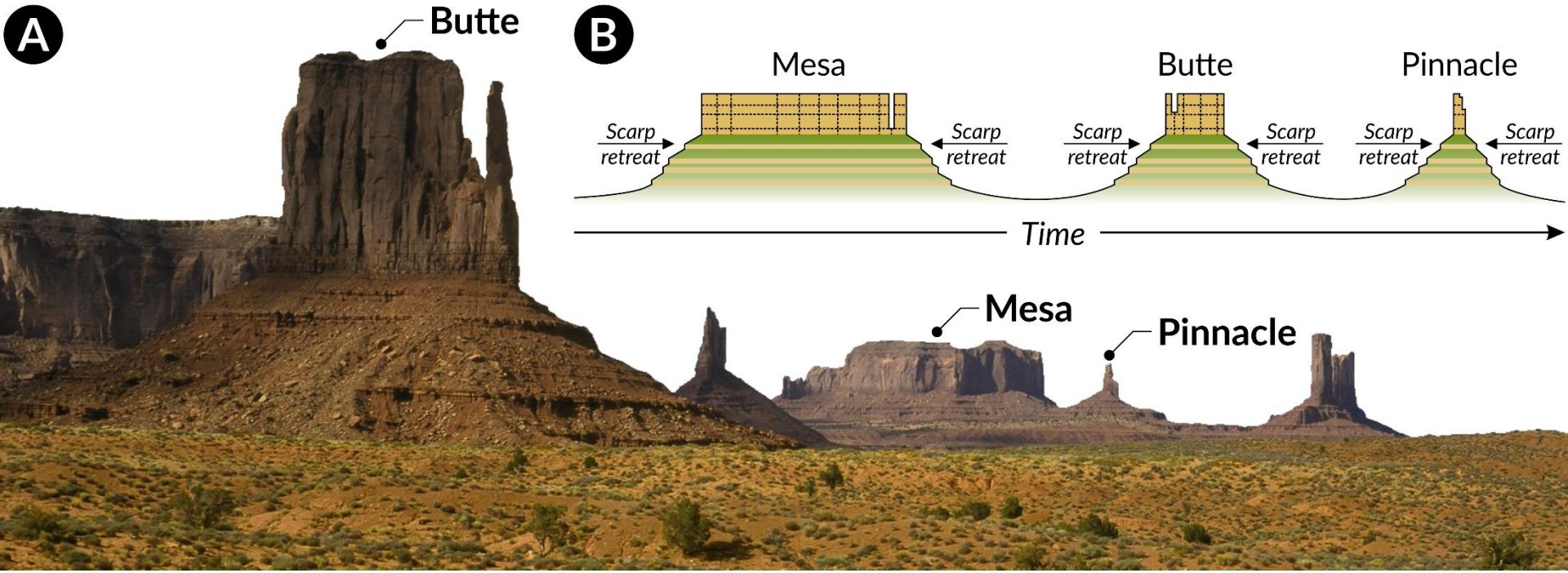
- joints (fractures)

Teplické skalní město

http://itras.cz/fotogalerie/teplicke-skaly/velke/jenka-libor-teplice-003.jpg

Monument Valley, USA

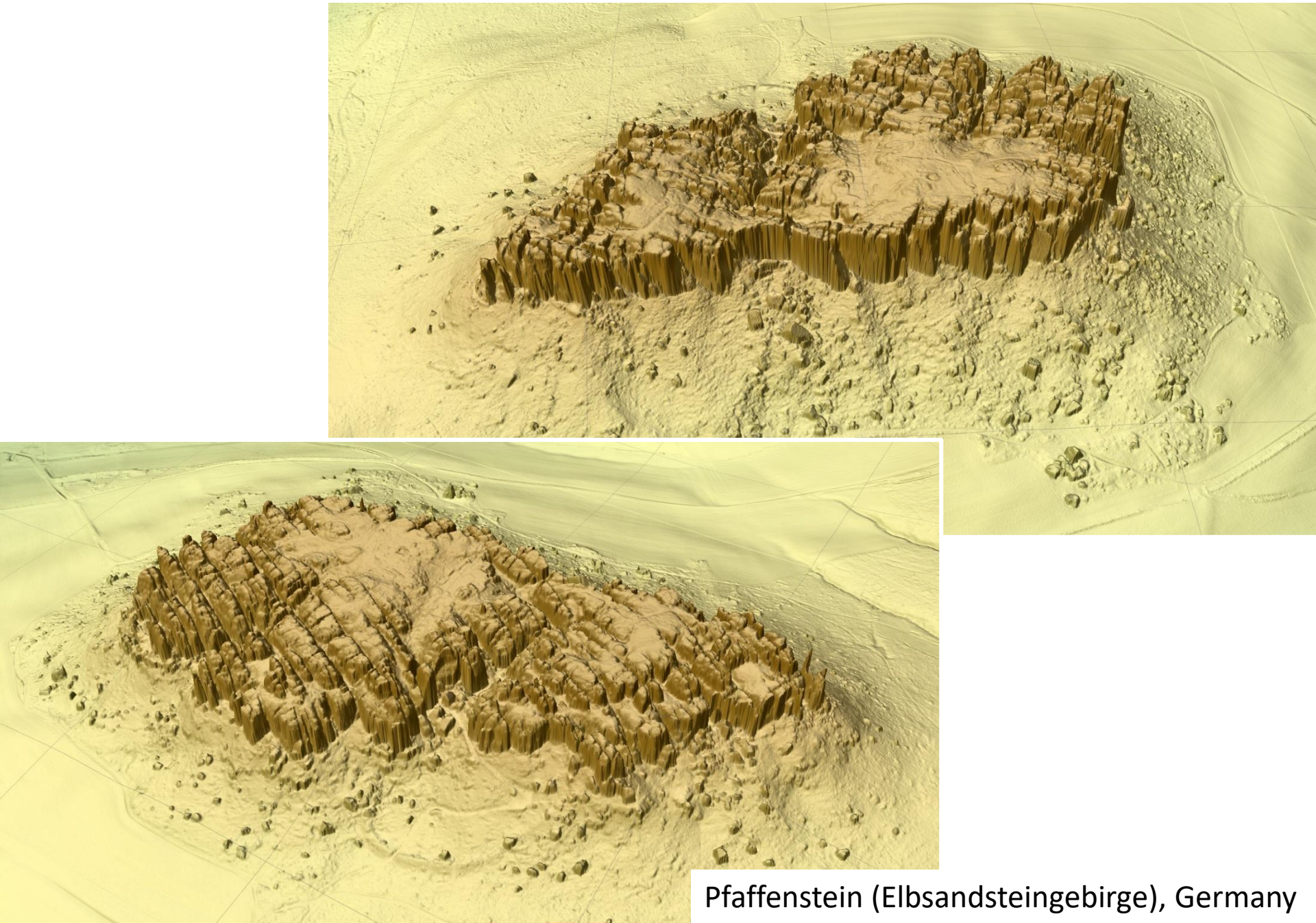
Specific medium-size landforms – residual hills



Specific medium-size landforms – residual hills: mesa

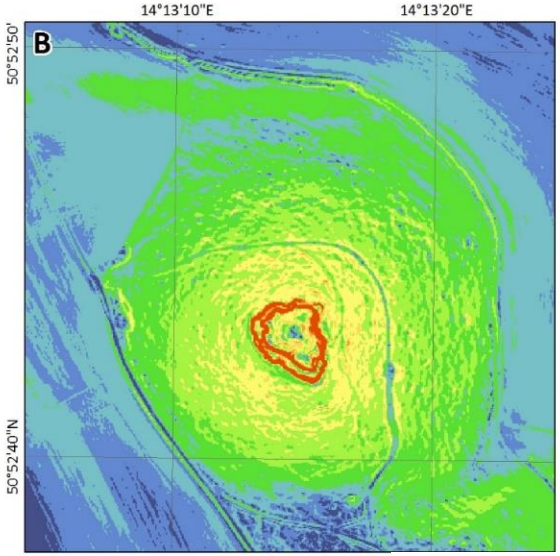
Quirl (Elbsandsteingebirge), Germany

Specific medium-size landforms – residual hills: mesa

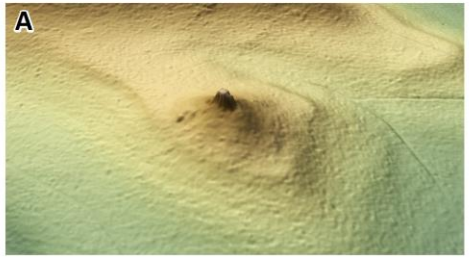


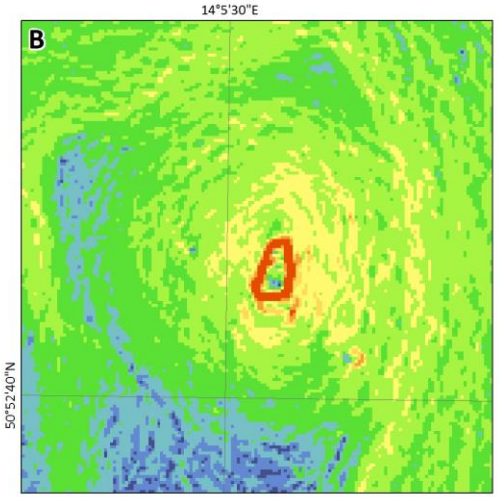
Pfaffenstein (Elbsandsteingebirge), Germany

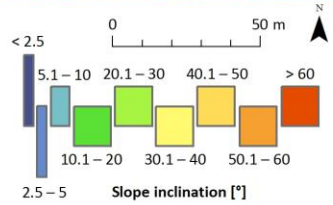
Specific medium-size landforms – residual hills: butte and pinnacle



Zirkelstein (Elbsandsteingebirge), Germany



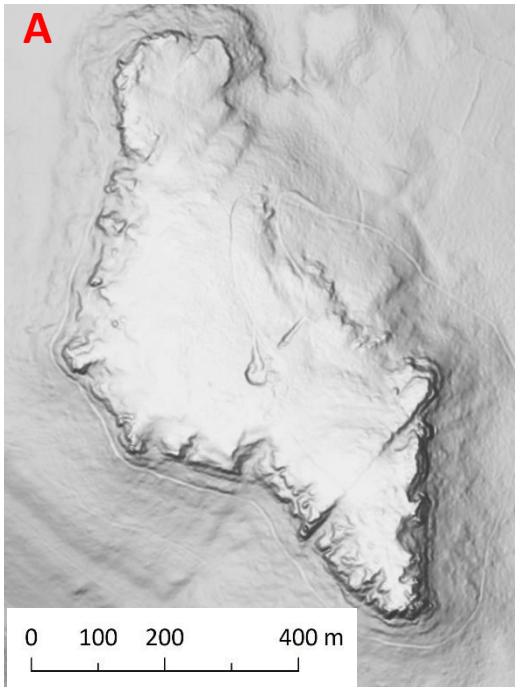


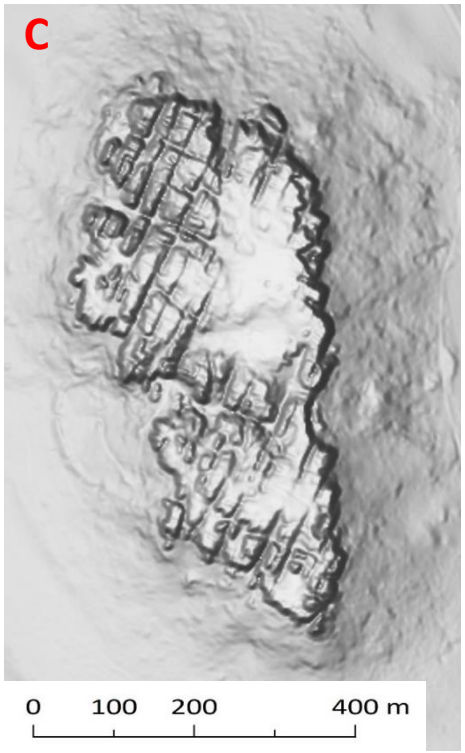


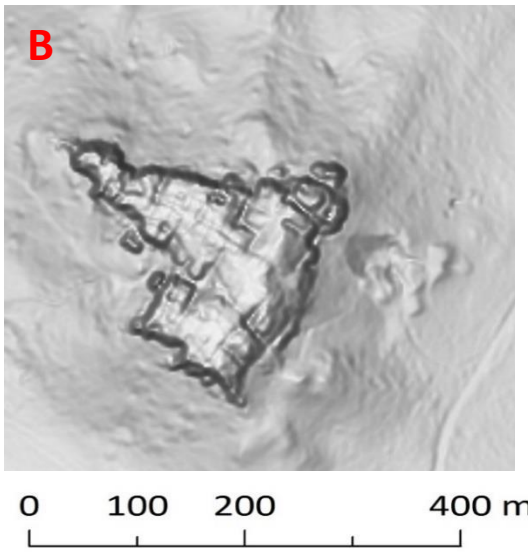
Spitzstein (Elbsandsteingebirge), Germany

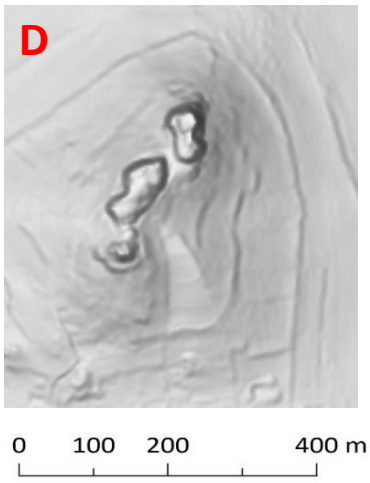
Specific medium-size landforms – residual hills

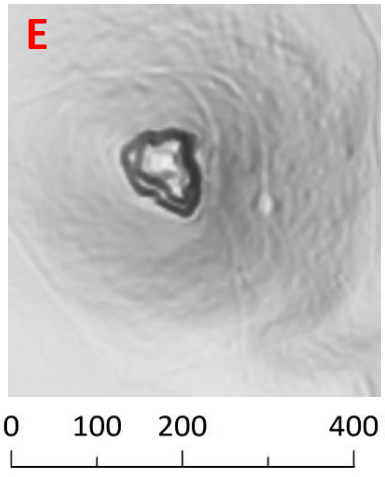
→ do they represent an evolutionary sequence?

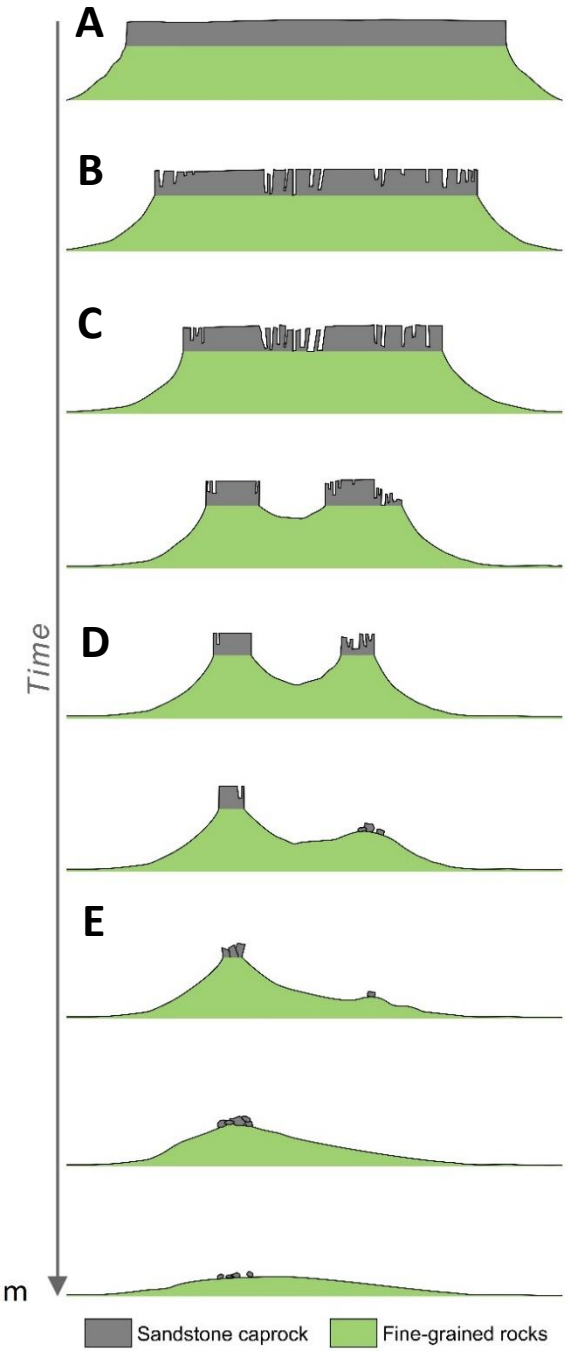






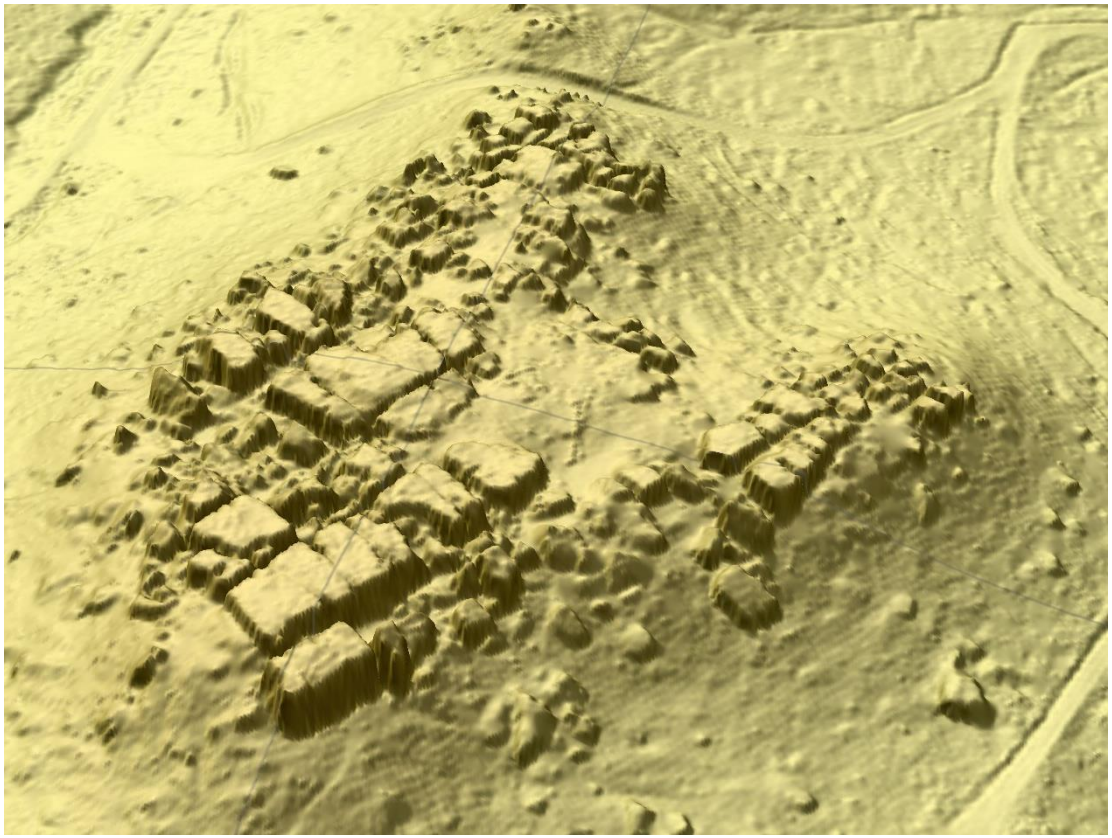


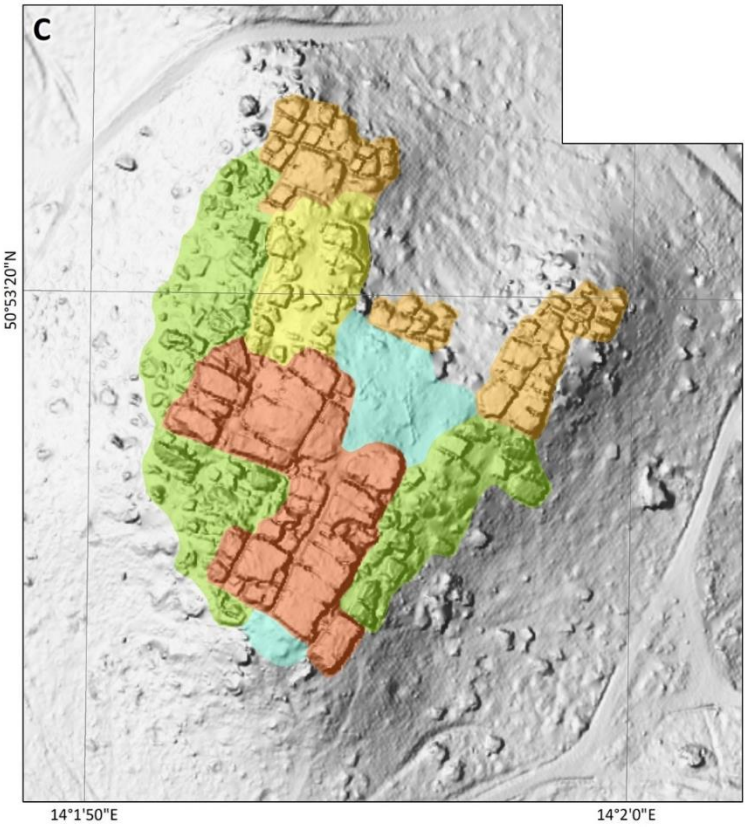




Specific medium-size landforms – residual hills

→ do they represent an evolutionary sequence?





Summit part of rock city, with tunnels and covered passages, caprock compartments in situ.

Marginal and lower parts of rock city, no tunnels and covered passages, caprock compartments in situ.

Ruiniform relief

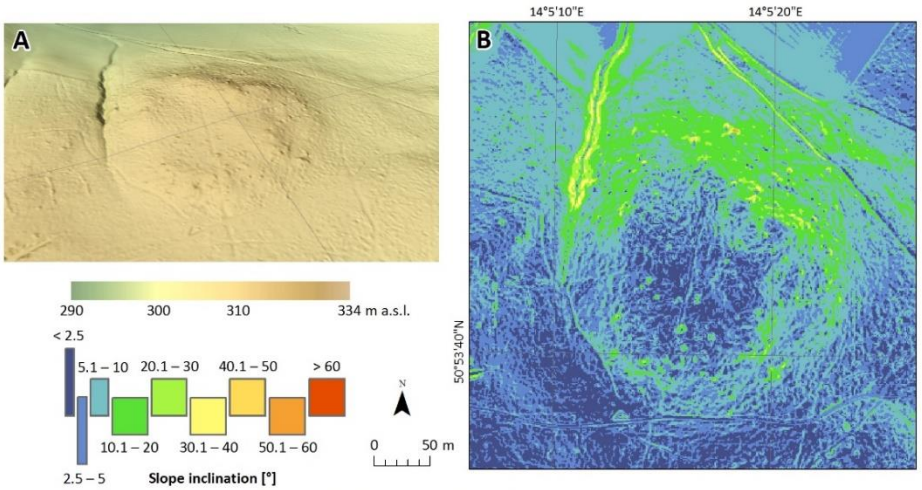
Displaced caprock compartments and blocky chaos

Rock platforms

Labyrinth (Elbsandsteingebirge), Germany

Specific medium-size landforms – residual hills

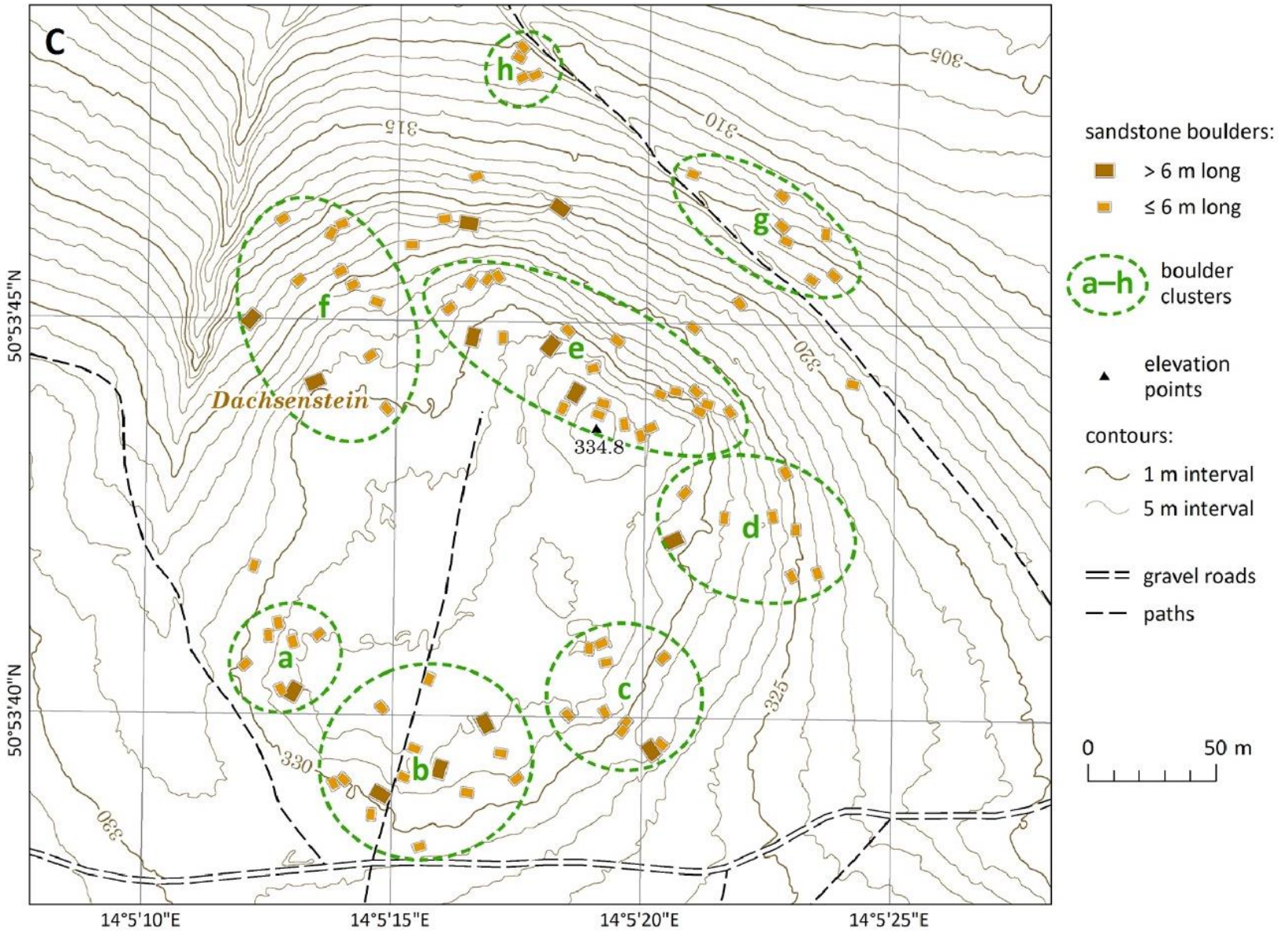
→ do they represent an evolutionary sequence?



Zeisighübel/Dachsenberg (Elbsandsteingebirge), Germany

Specific medium-size landforms – residual hills

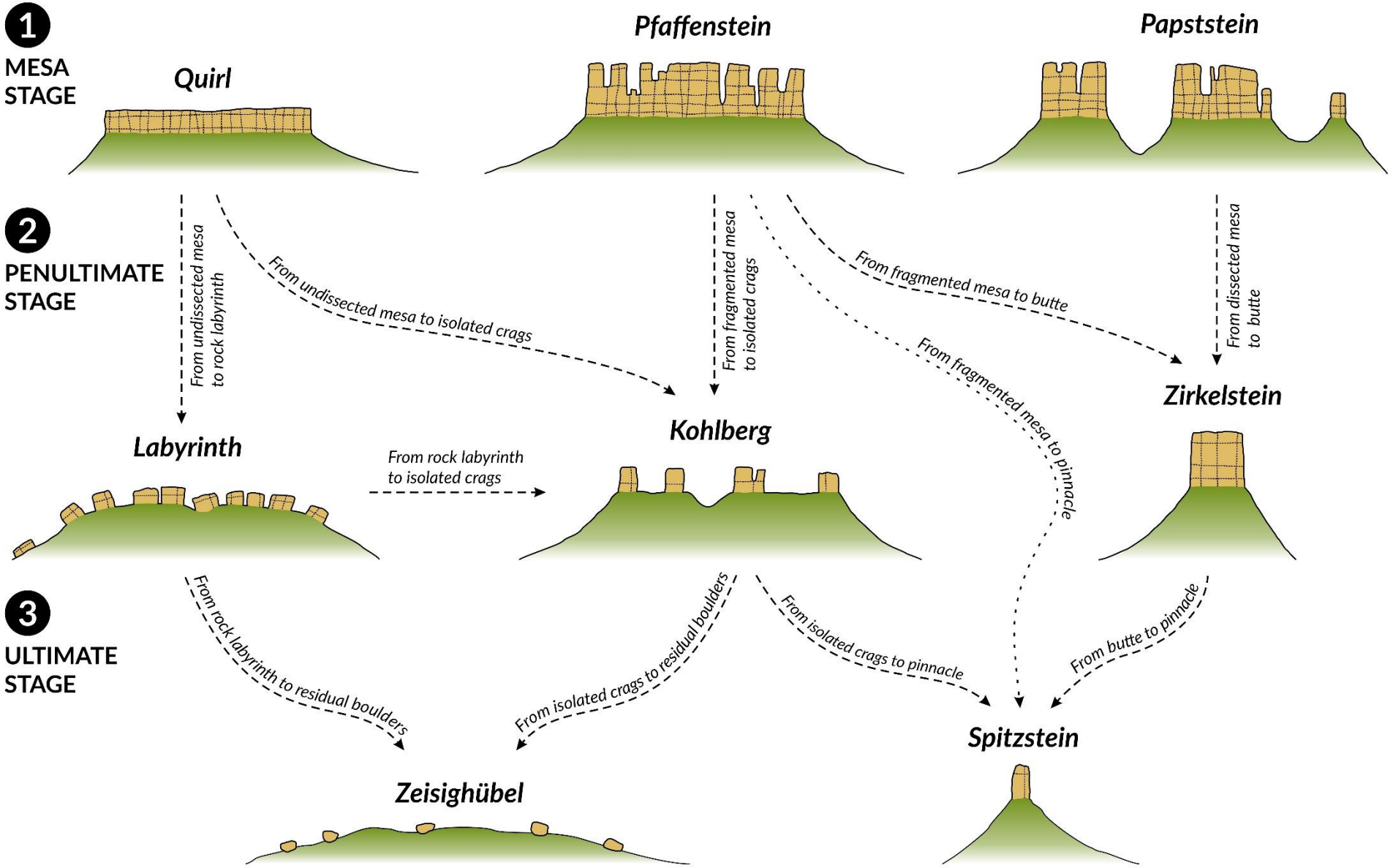
→ do they represent an evolutionary sequence?



Zeisighübel/Dachsenberg (Elbsandsteingebirge), Germany

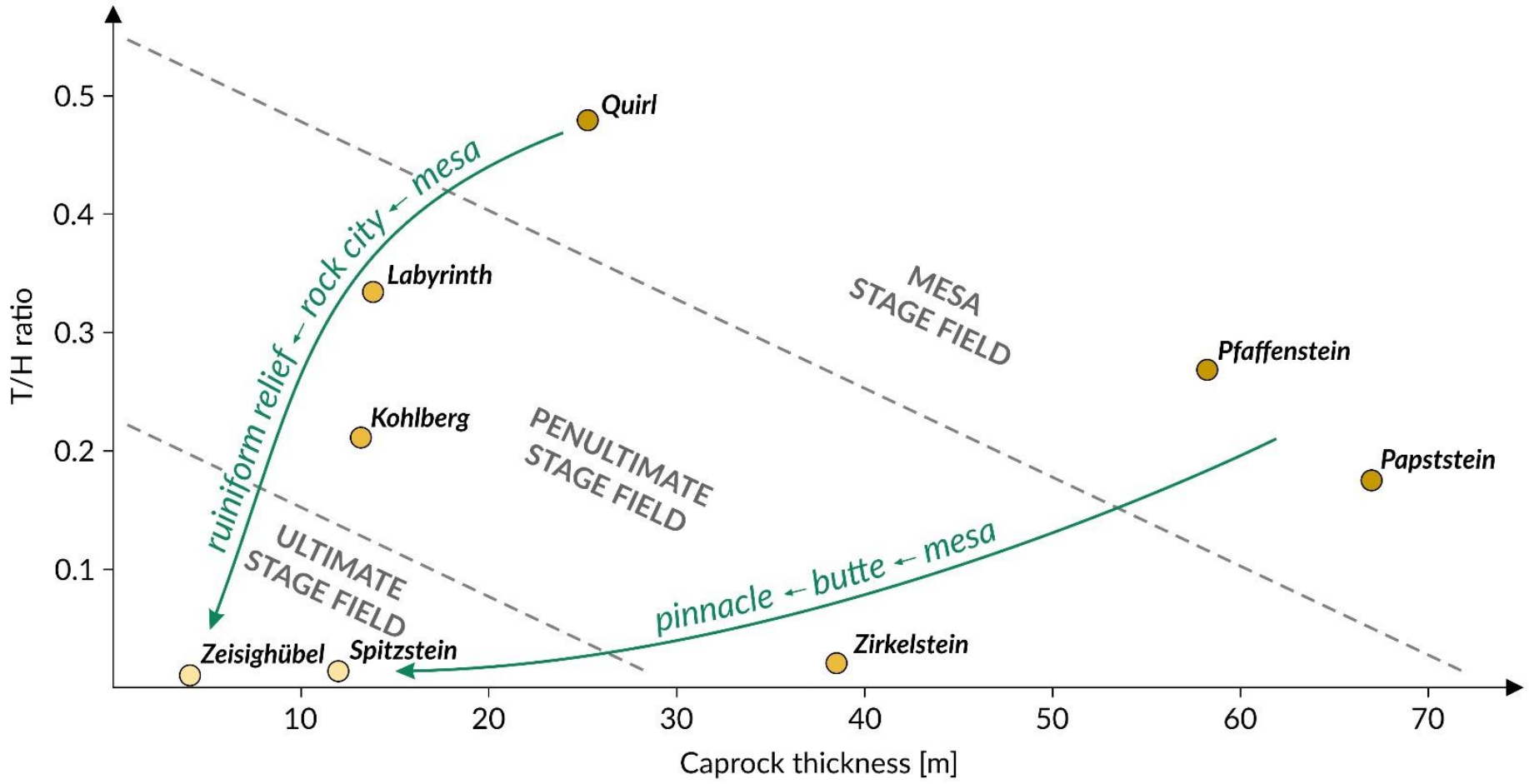
Specific medium-size landforms – residual hills

→ do they represent an evolutionary sequence?



Specific medium-size landforms – residual hills

→ do they represent an evolutionary sequence? → **(at least) two pathways**



T/H ratio: T – top surface (area), H – base area

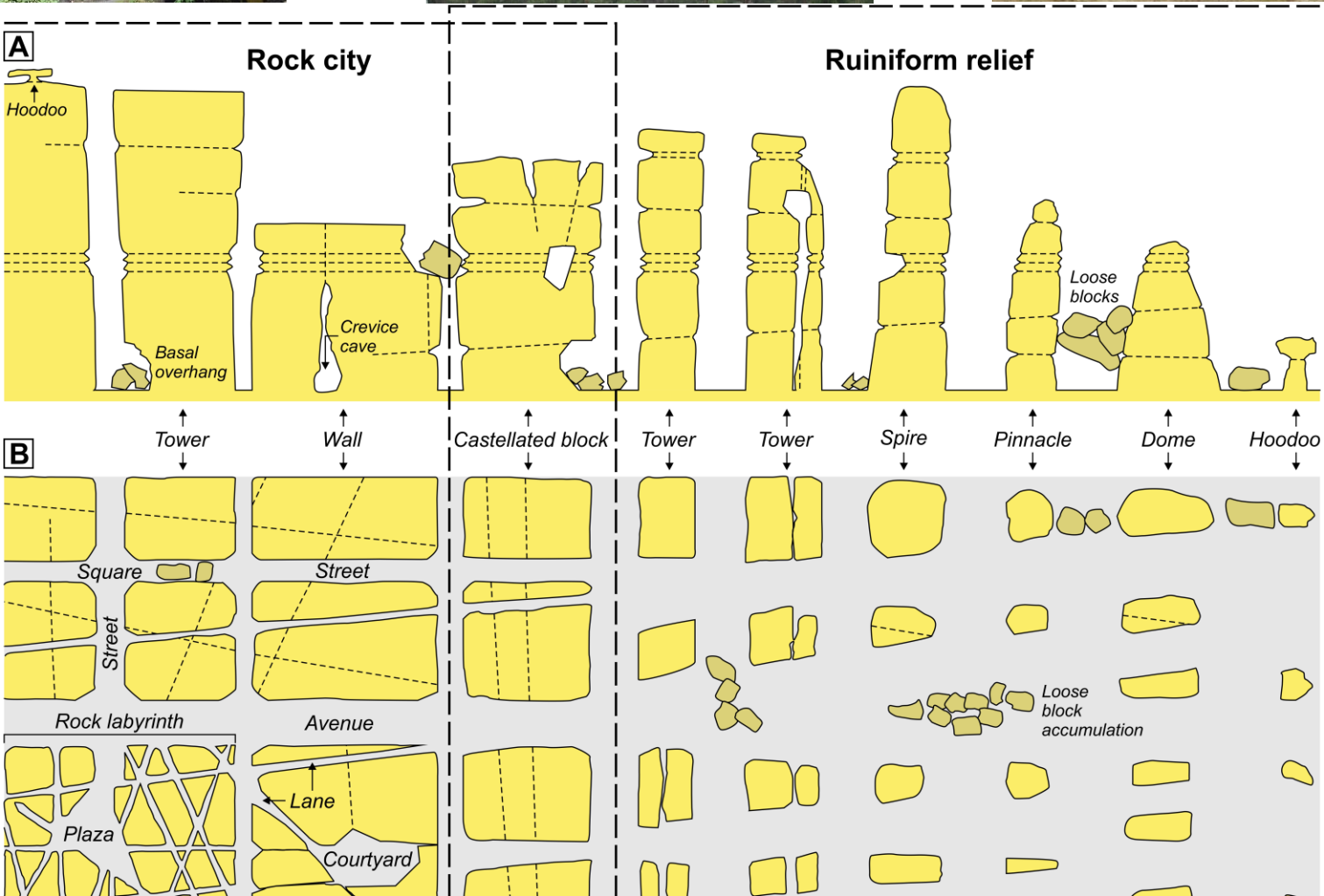
Specific medium-size landforms – rock cities and ruiniform relief


Teplické skalní město


Cete Cidades (NE Brazil)


Cete Cidades (NE Brazil)

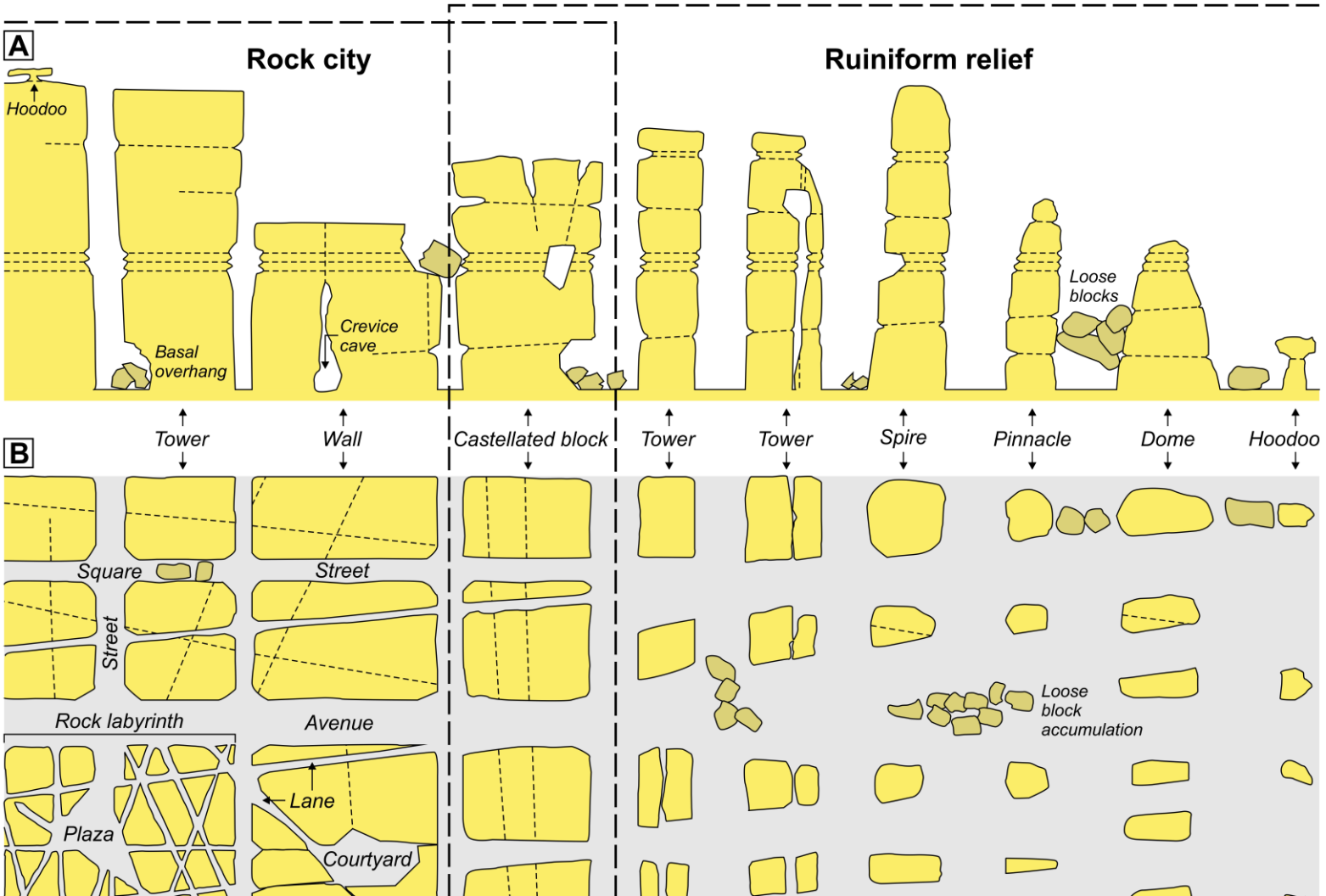
Specific medium-size landforms – rock cities and ruiniform relief



Specific medium-size landforms – rock cities and ruiniform relief

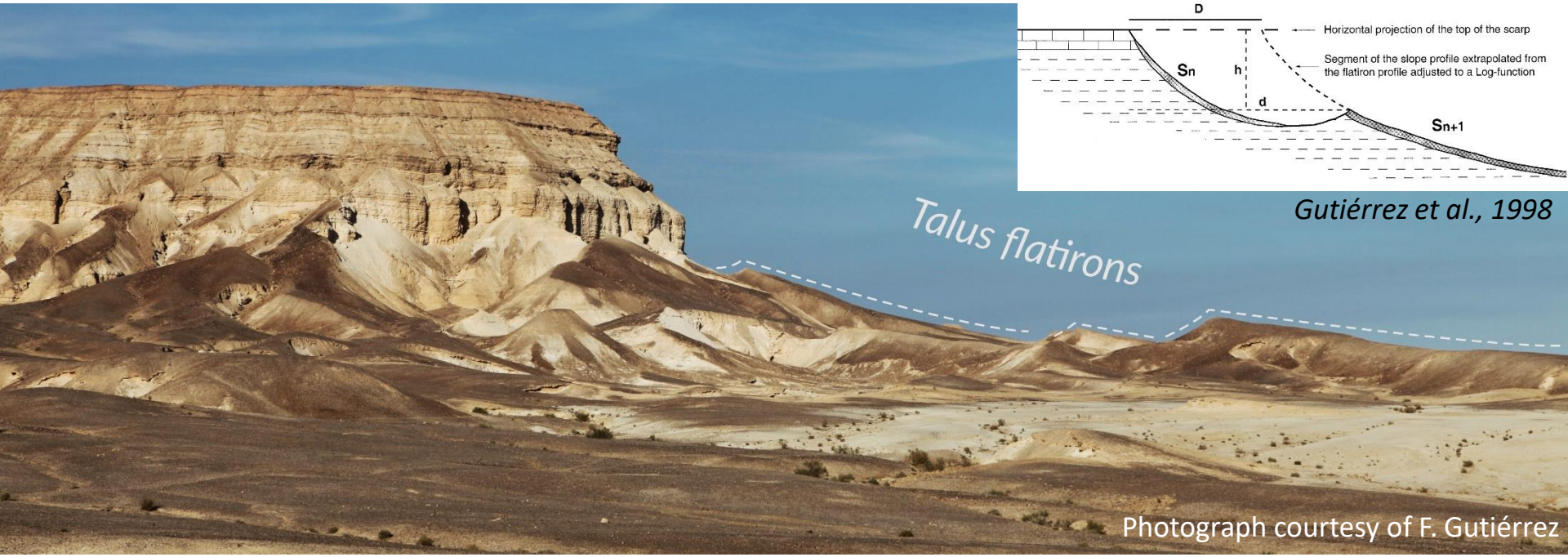
Rock cities – category of rock-cut erosional relief, with closely spaced rock blocks separated by an interconnected network of joint-aligned thoroughfares (avenues, streets, lanes) → visual resemblance to urban landscape (townscape)

Ruiniform relief – is made of rock-cut residuals, typically heavily weathered, dispersed over a terrain and hence, lacking evident resemblance to urban landscape



Long-term geomorphic evolution

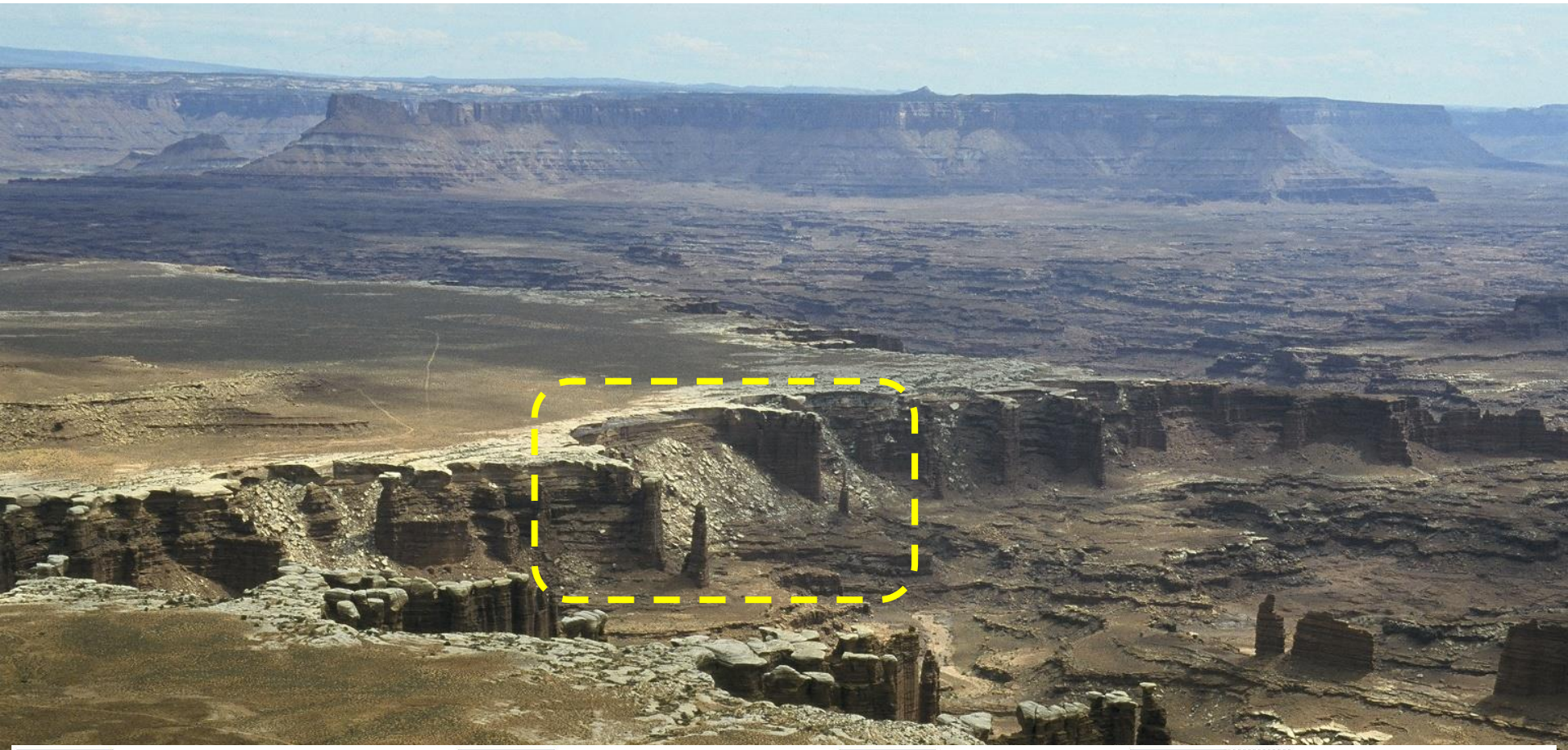
- tableland dissection and escarpment retreat as two major pathways

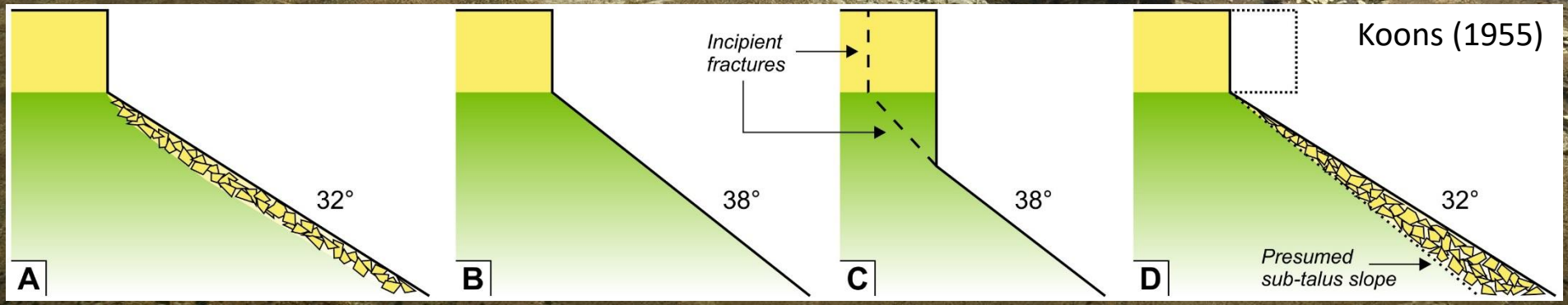


- but by what means specifically?

Sandstone-capped escarpments – how they retreat?

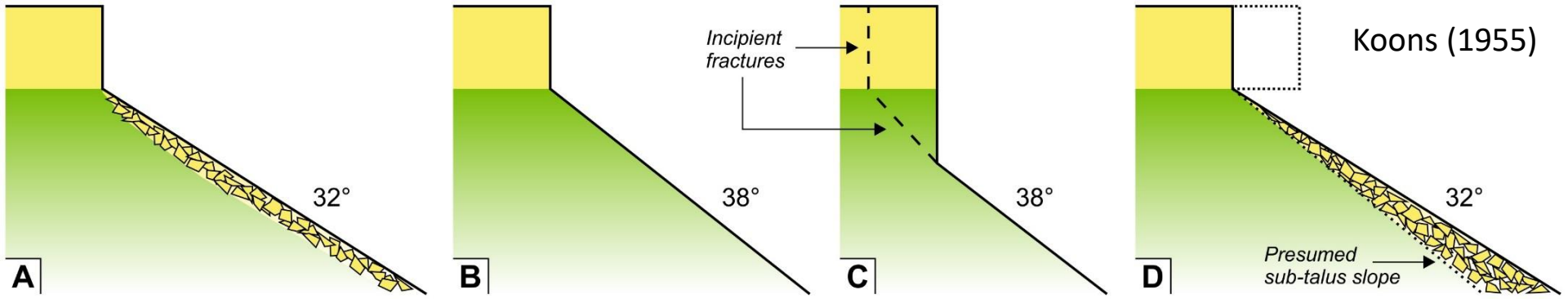
- rock fall scenario





Sandstone-capped escarpments – how they retreat?

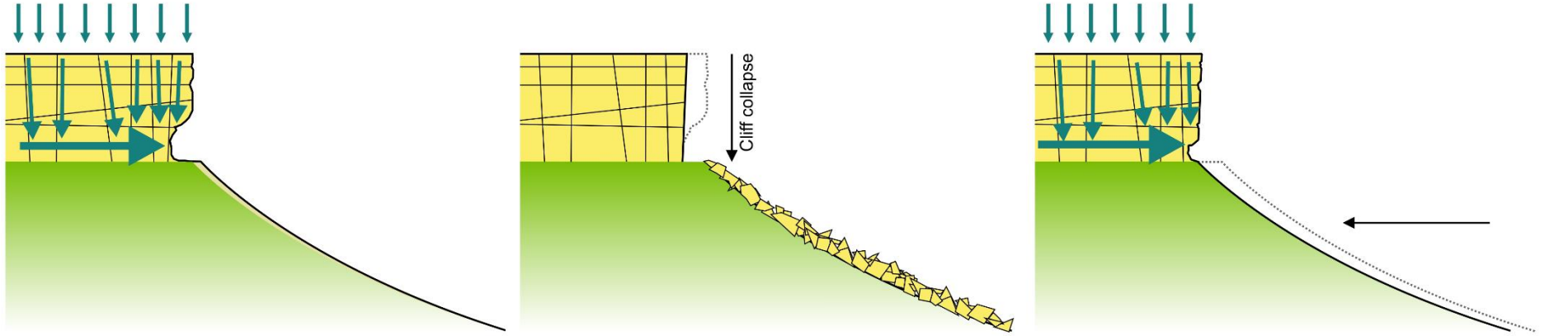
- rock fall scenario



Sandstone-capped escarpments – how they retreat?

- groundwater sapping and rock fall scenario

Laity & Malin (1985), Howard & Kochel (1988): *Seepage-induced sapping and the resultant cliff face collapse*




Danxiashan, China


Petrified Forest NP., USA

Stołowe Mountains (SW Poland) – which scenario applies?

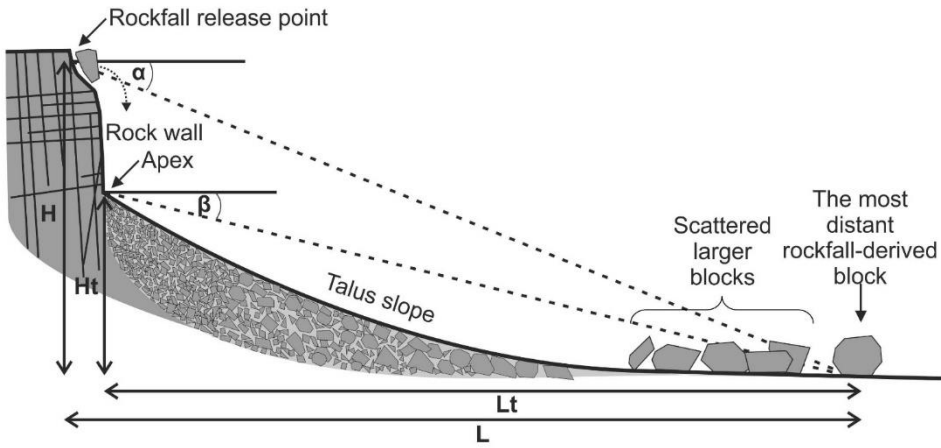
Are these boulders rock fall-derived?

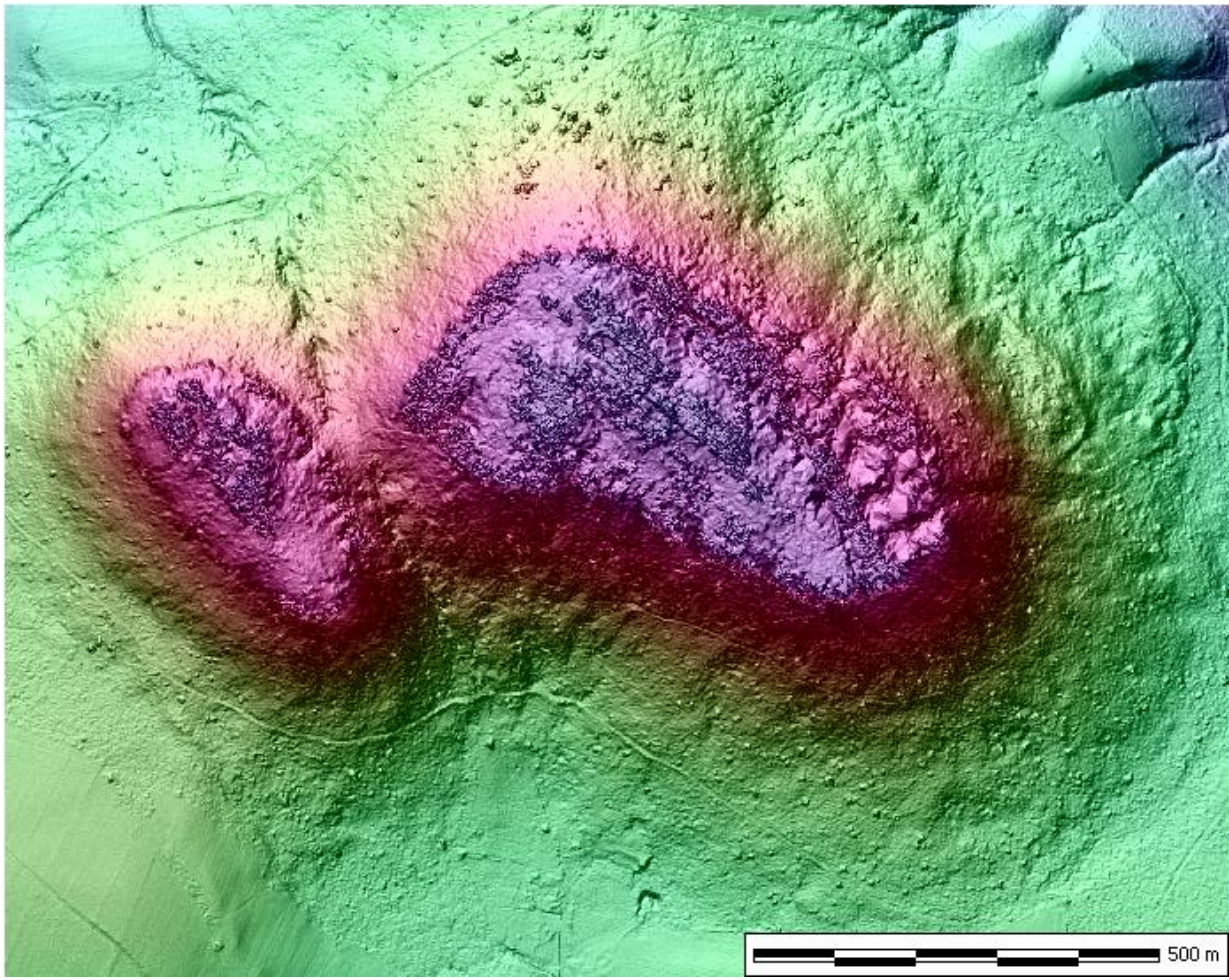
Stołowe Mountains (SW Poland) – which scenario applies?

How far can boulders detached from top parts of cliff faces travel?

Conefall 1.0 simulations

Test site	Simulated limit of talus	Actual limit of boulders
1	165	460
2	115	191
3	172	416
4	73	366
5	93	526
6	270	742
7	341	510
8	323	500





Stołowe Mountains (SW Poland) – which scenario applies?

- what the weathering history of boulders on slopes tells us?

Assumption 1: intact rock strength of near-surface part of the rock decreases due to weathering; hence longer weathering history means lower measured strength

Assumption 2: downslope variation in rock strength may be of significance

Schmidt hammer tests of intact rock strength of sandstone boulders

Hypotheses

Catastrophic (= instantaneous release)

Rock strength similar within the talus
or
Non-systematic downslope variation

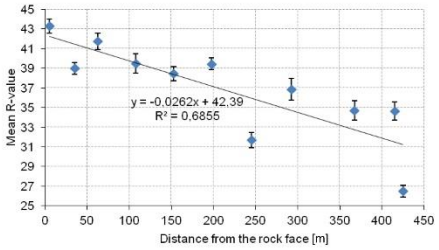
Non-catastrophic (= gradual release)

Diverse values of rock strength
and/or
Systematic downslope variation

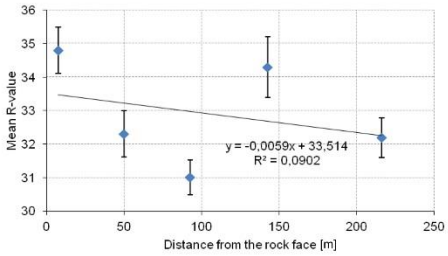
Stołowe Mountains (SW Poland) – which scenario applies?

- what the weathering history of boulders on slopes tells us?

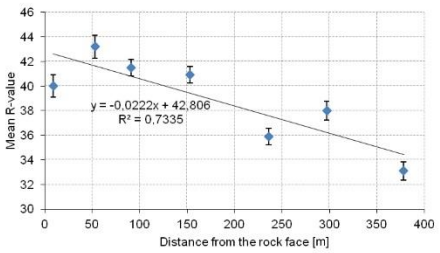
Profile 1 - Szczeliniec Wielki



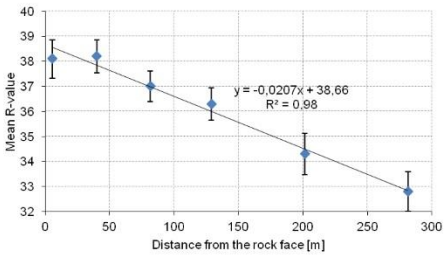
Profile 2 - Szczeliniec Mały



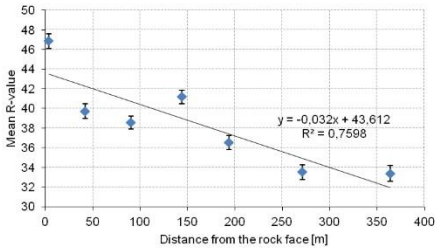
Profile 3 - Narożnik



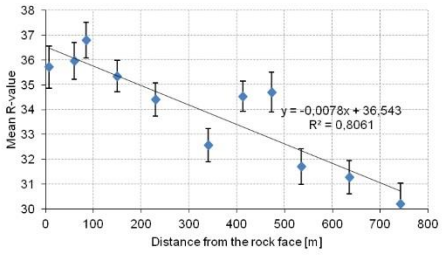
Profile 4 - Urwisko Batorowskie



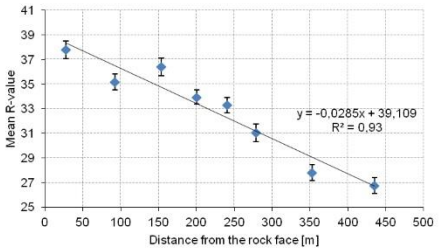
Profile 5 - Skalniak



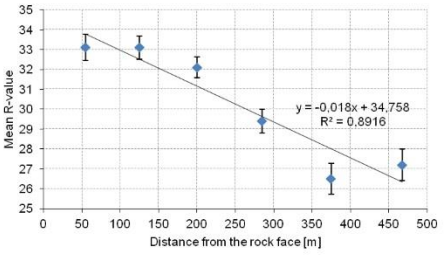
Profile 6 - Biała Skała



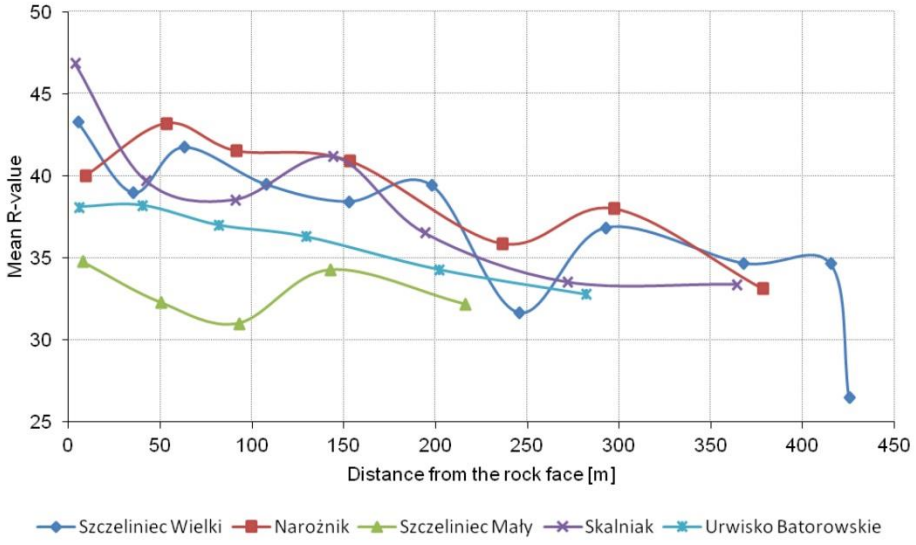
Profile 7 - Radkowskie Ściany



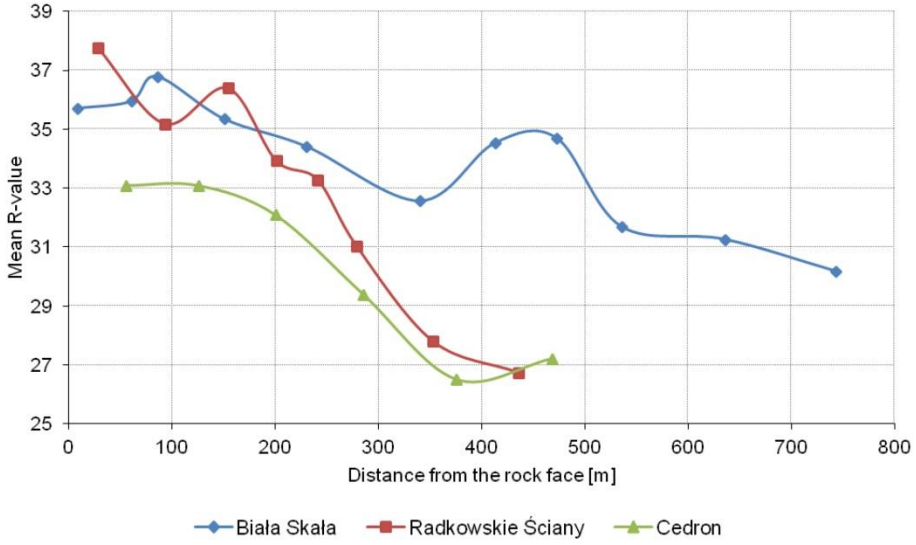
Profile 8 - Cedron



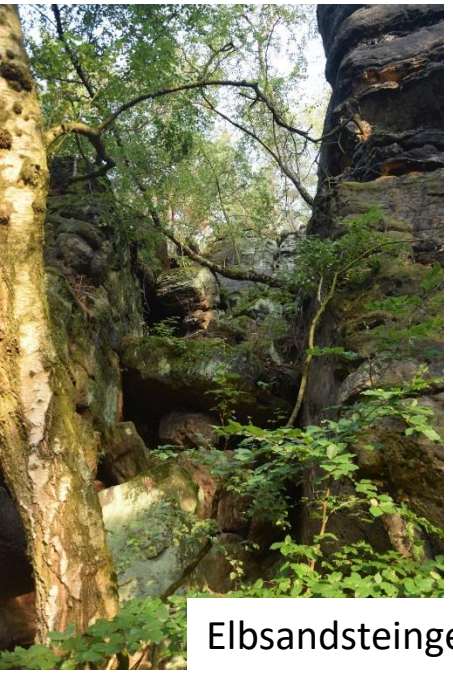
Profiles 1-5 summary

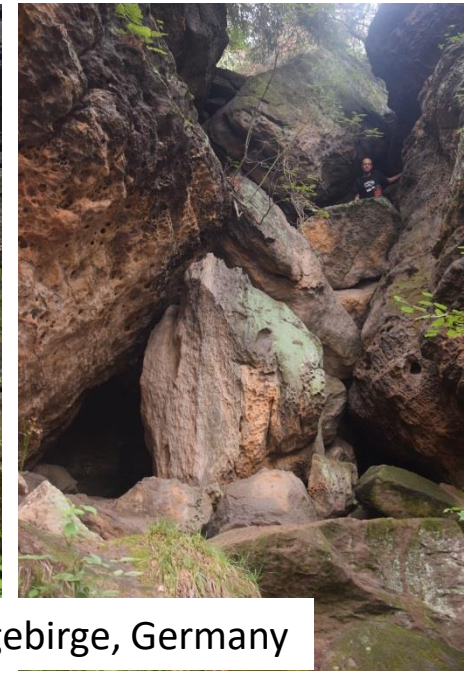


Profiles 6-8 summary



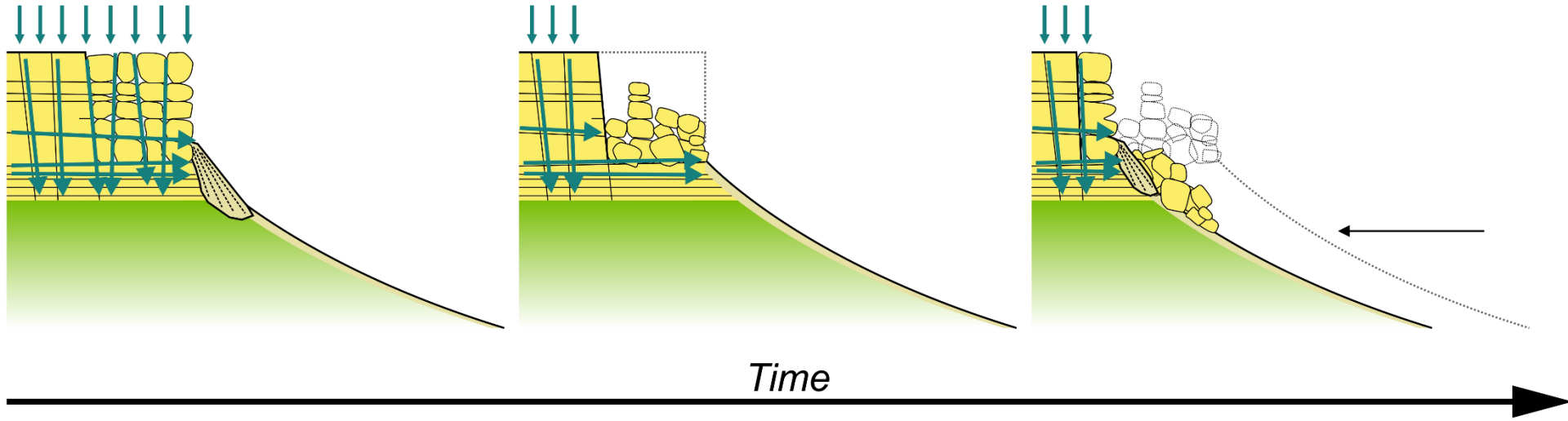
Sandstone-capped escarpments – in situ disintegration model





Elbsandsteingebirge, Germany

Stołowe Mountains, Poland



Explanations:

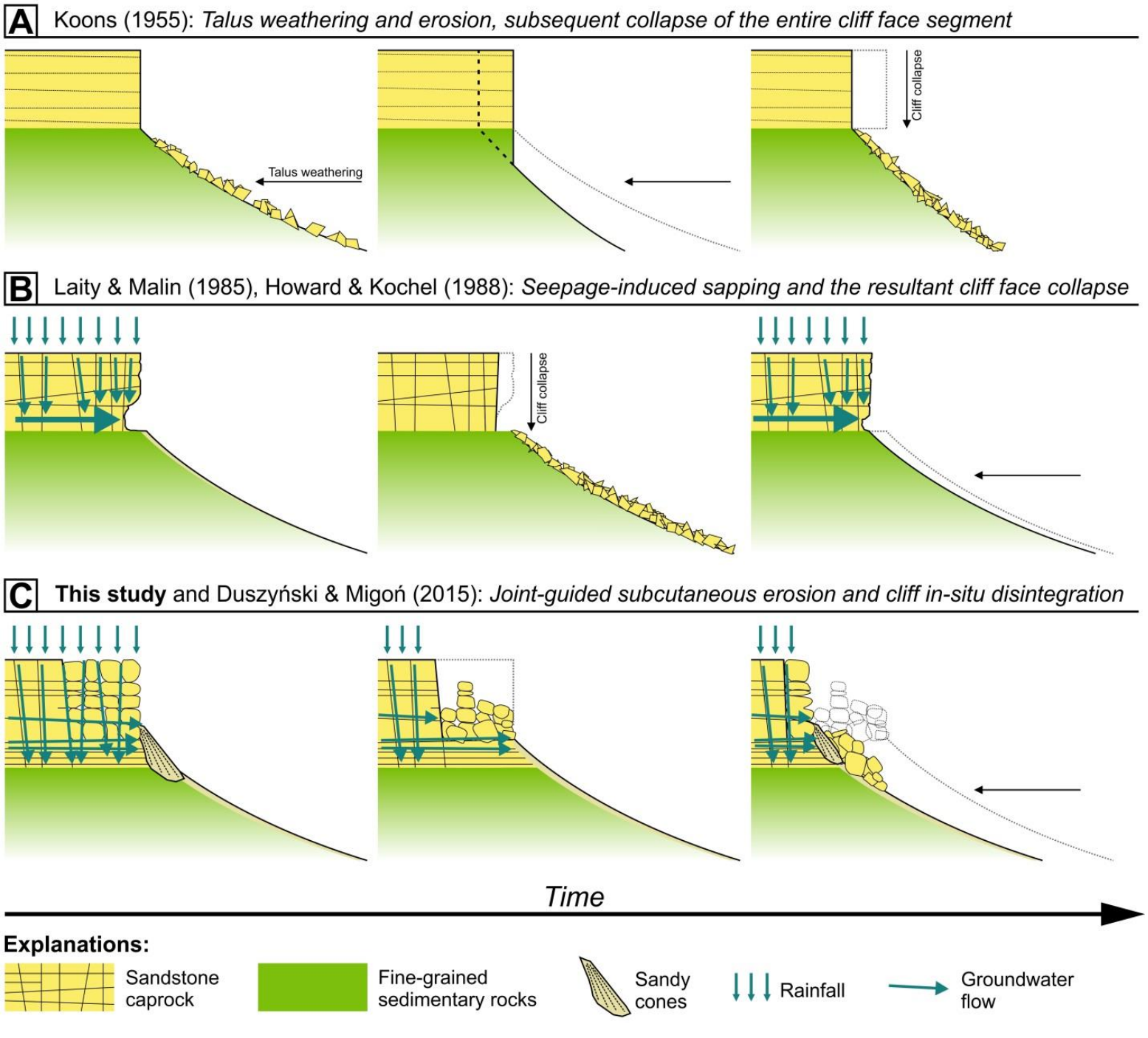
Sandstone caprock

Fine-grained sedimentary rocks

Sandy cones

Rainfall

Groundwater flow


A Koons (1955): Talus weathering and erosion, subsequent collapse of the entire cliff face segment
Talus weathering
Cliff collapse
B Laity & Malin (1985), Howard & Kochel (1988): Seepage-induced sapping and the resultant cliff face collapse
Cliff collapse
C This study and Duszyński & Migoń (2015): Joint-guided subcutaneous erosion and cliff in-situ disintegration
Time
Explanations:
Sandstone caprock
Fine-grained sedimentary rocks
Sandy cones
Rainfall
Groundwater flow

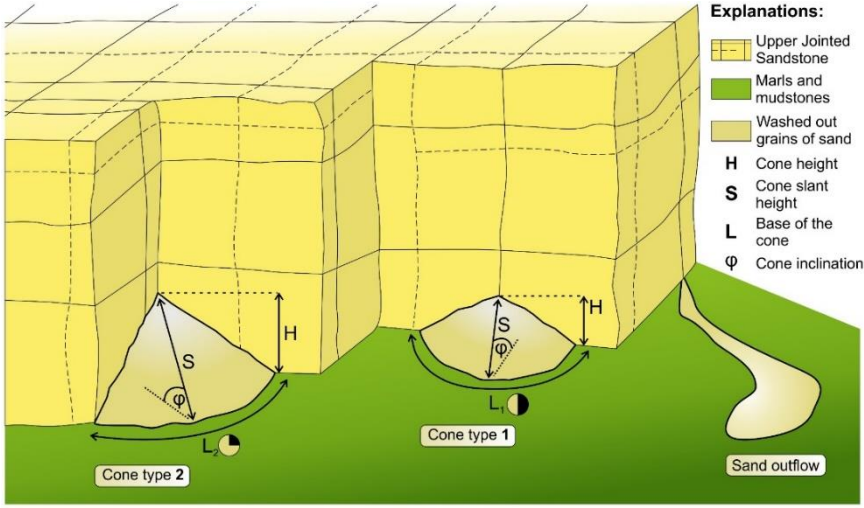
The role of subterranean processes → substantial sand removal from caprock

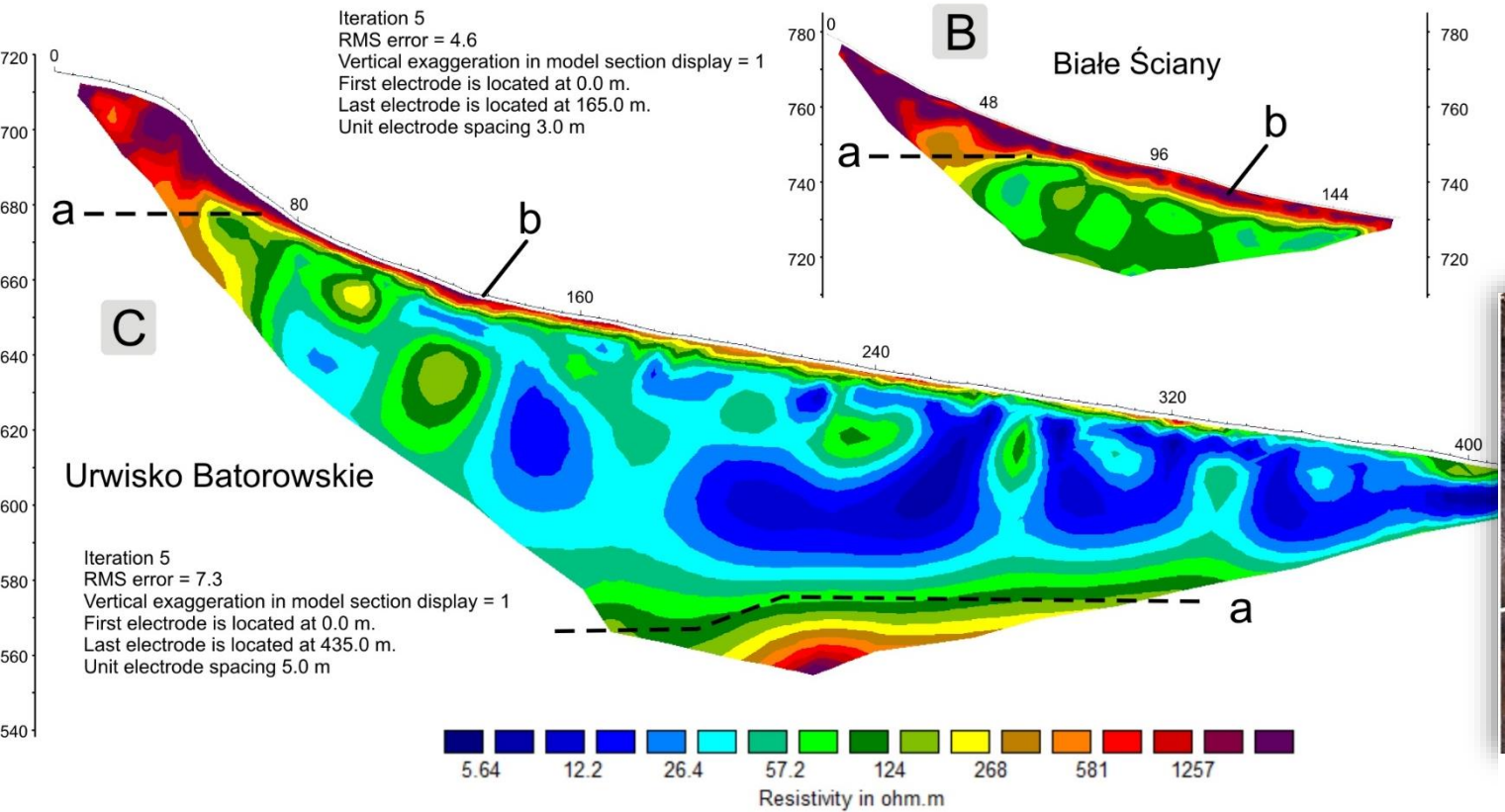
The role of subterranean processes → substantial sand removal from caprock

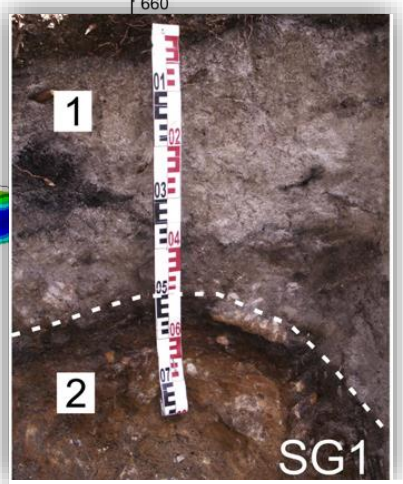
a) estimating the volume of sand stored in cones

b) estimating the volume of sand on slopes

c) monitoring contemporary undeground erosion







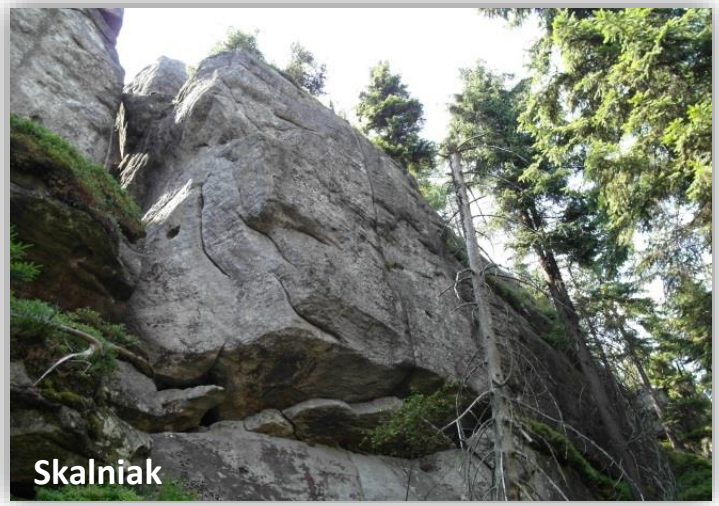
(Waroszewski et al., 2015)

The role of subterranean processes → substantial sand removal from caprock

Assumptions used in volumetric calculations:

0 – 150 m ⟶ **3 m**
150 – 300 m ⟶ **1.5 m**
300 – 400 m ⟶ **0.5 m**

Total volume of sandy slope covers: 22×10^6 m^3



The way of calculating sandstone plate volume: **The area** of particular plateau x **height** of the exposed section of sandstone plate (varying in the range of 10-30 m)

Total volume of sandstone plate remaining to the present day: 23×10^7 m^3

The role of subterranean processes → substantial sand removal from caprock

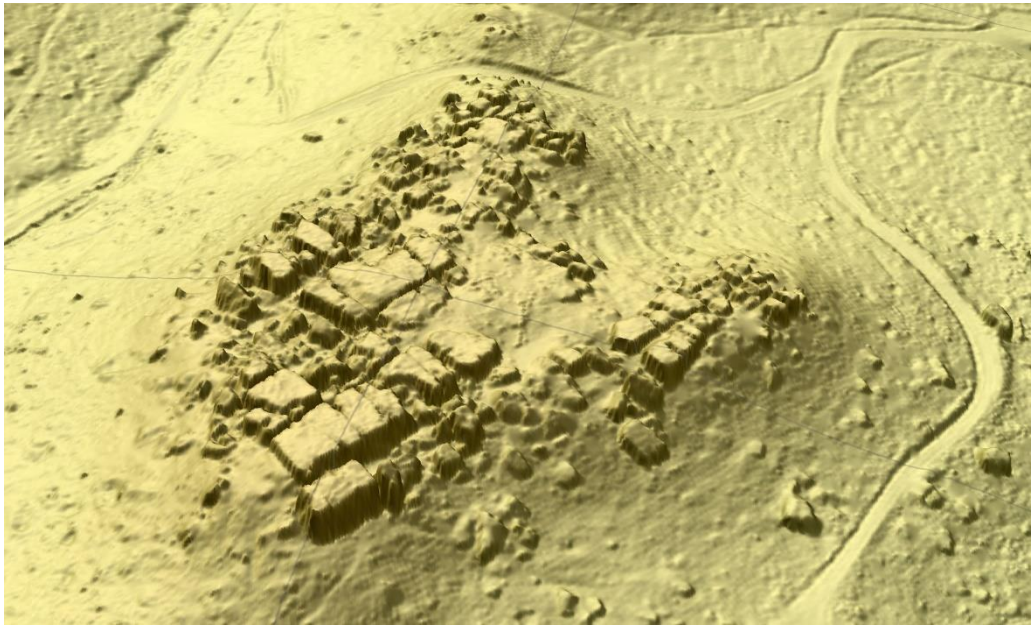
→ so what about the consequences for surface caprock morphology?

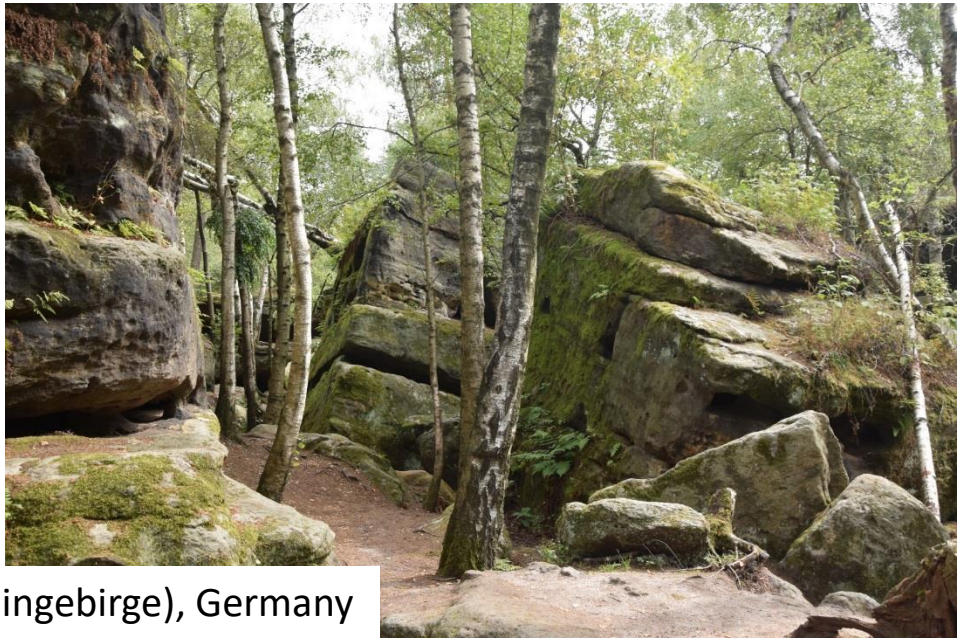
In situ disintegration of cliff lines

Breaking down of rock slabs and differential settling

The role of subterranean processes → substantial sand removal from caprock

→ so what about the consequences for surface caprock morphology?

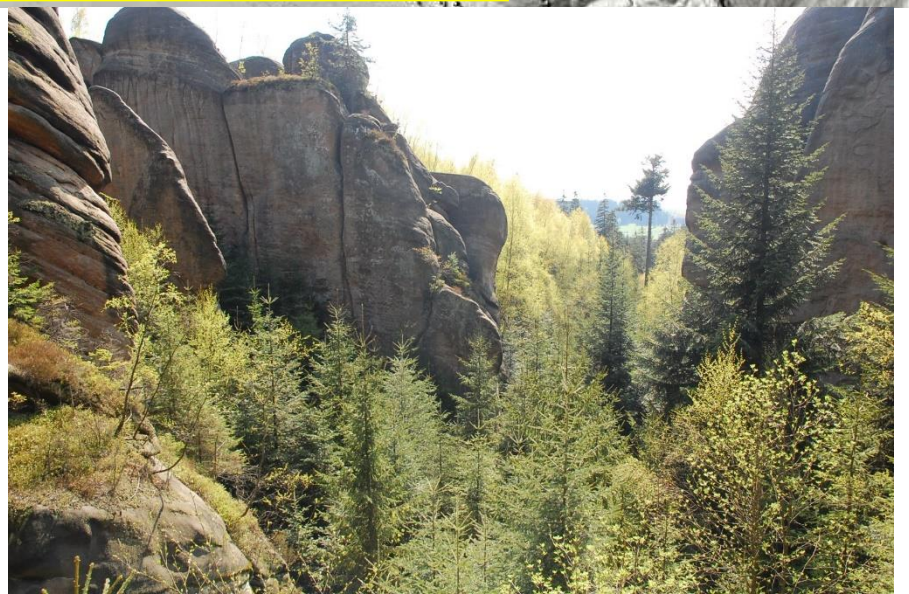




Labirynth (Elbsandsteingebirge), Germany

The role of subterranean processes → substantial sand removal from caprock

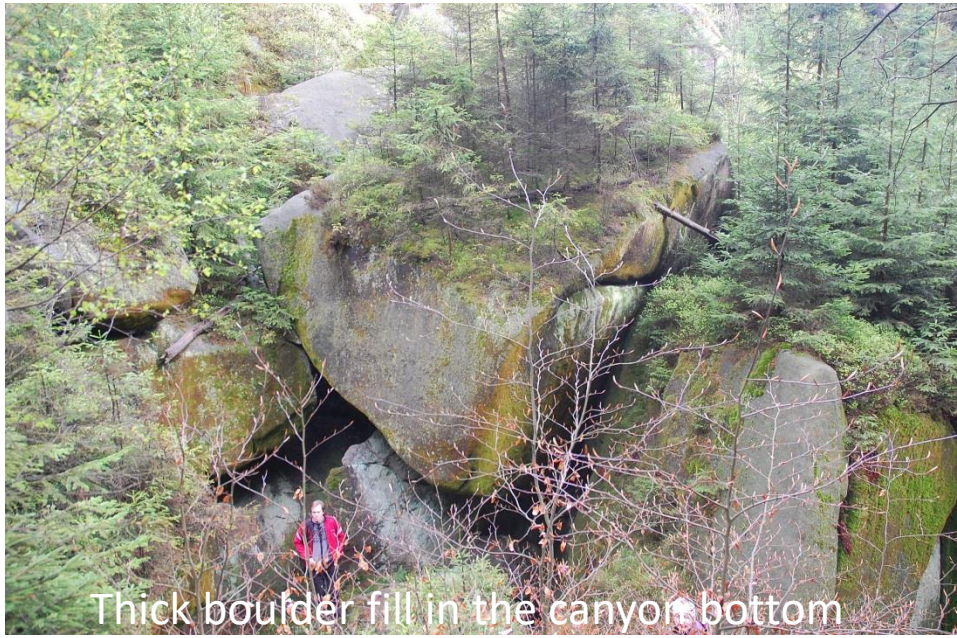
→ so what about the consequences for surface caprock morphology?



The role of subterranean processes → substantial sand removal from caprock

→ so what about the consequences for surface caprock morphology?


No evidence of downcutting

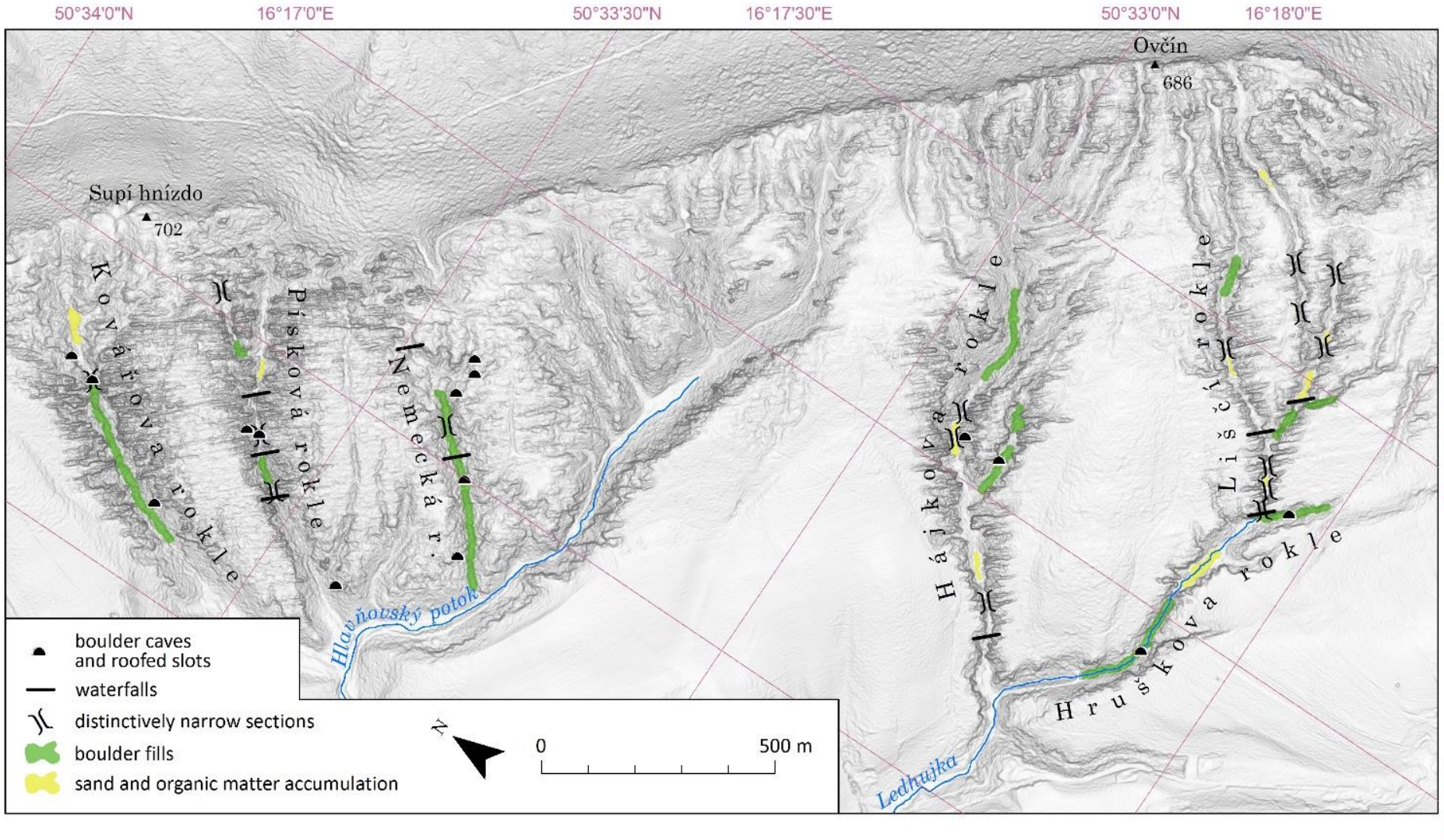

Thick boulder fill in the canyon bottom


Subterranean flow at the base of the fill


Scarce evidence of rock fall

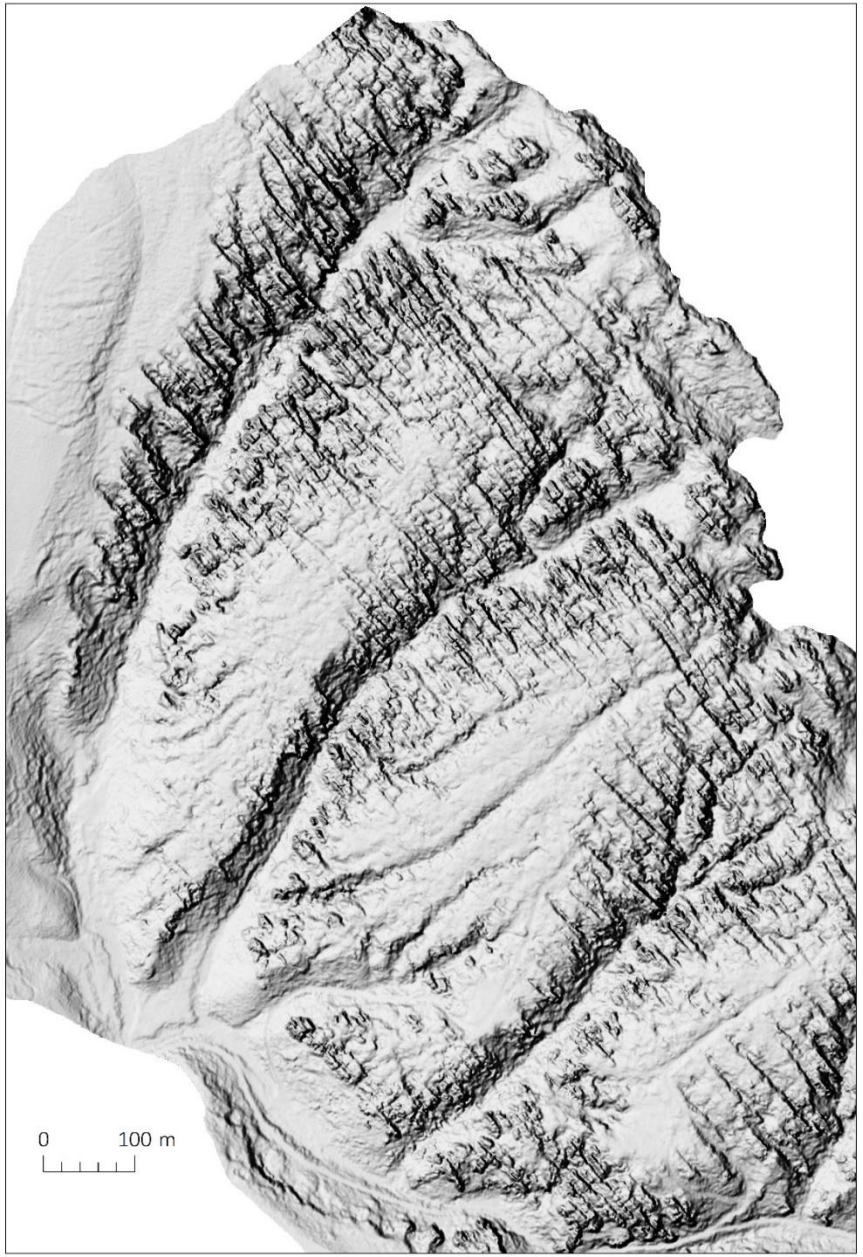
The role of subterranean processes → substantial sand removal from caprock

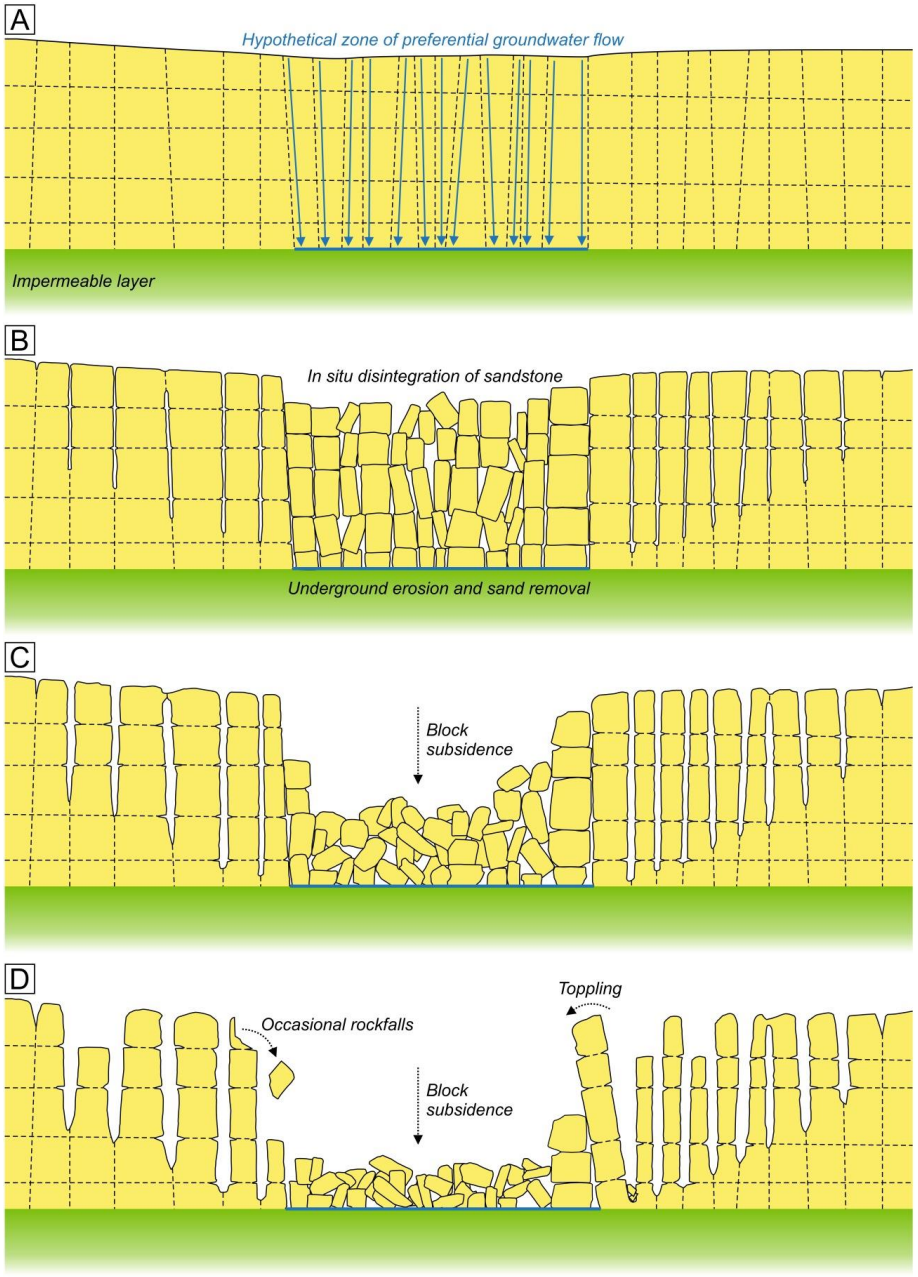
→ so what about the consequences for surface caprock morphology?



The role of subterranean processes → substantial sand removal from caprock

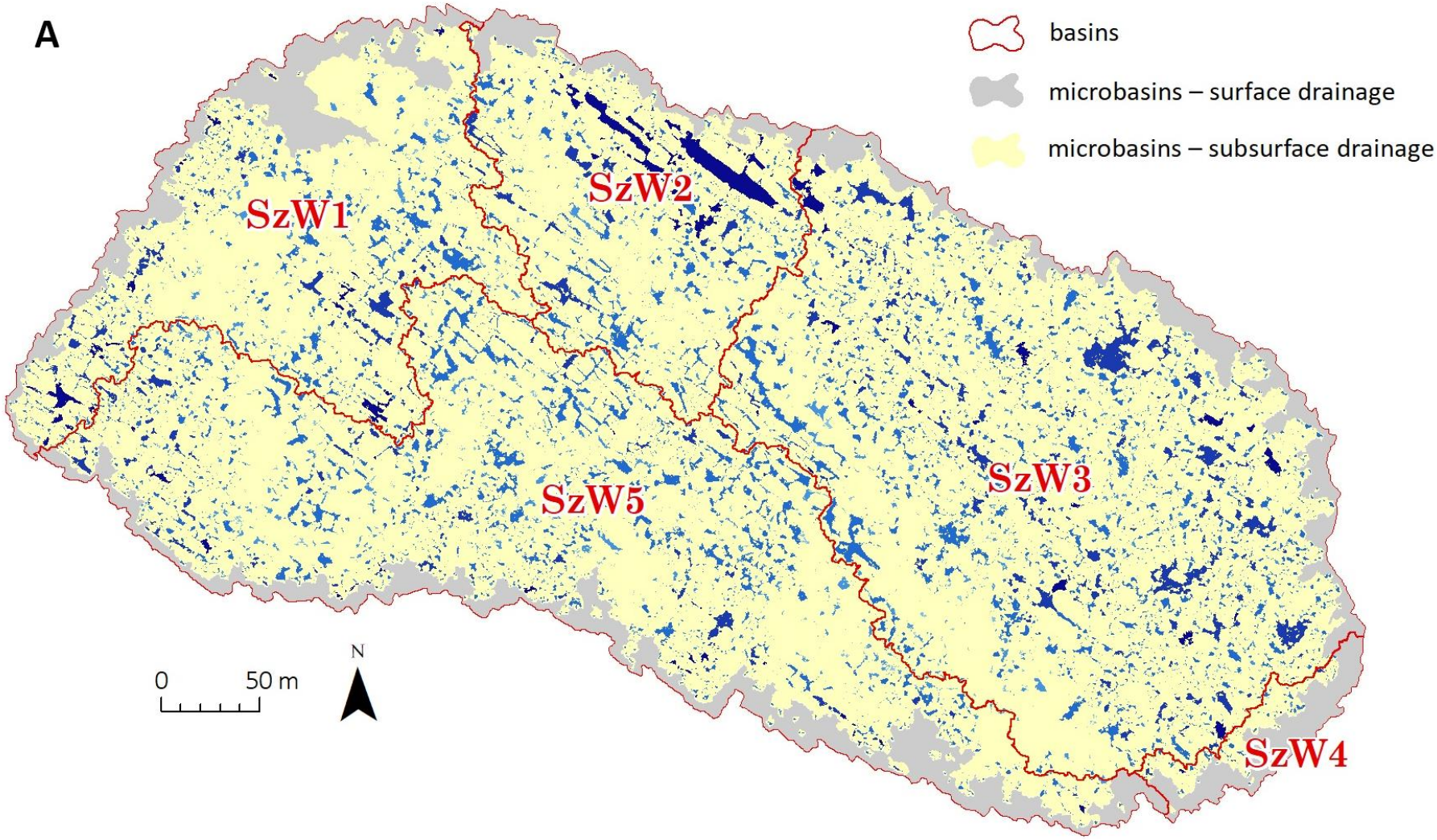
→ so what about the consequences for surface caprock morphology?





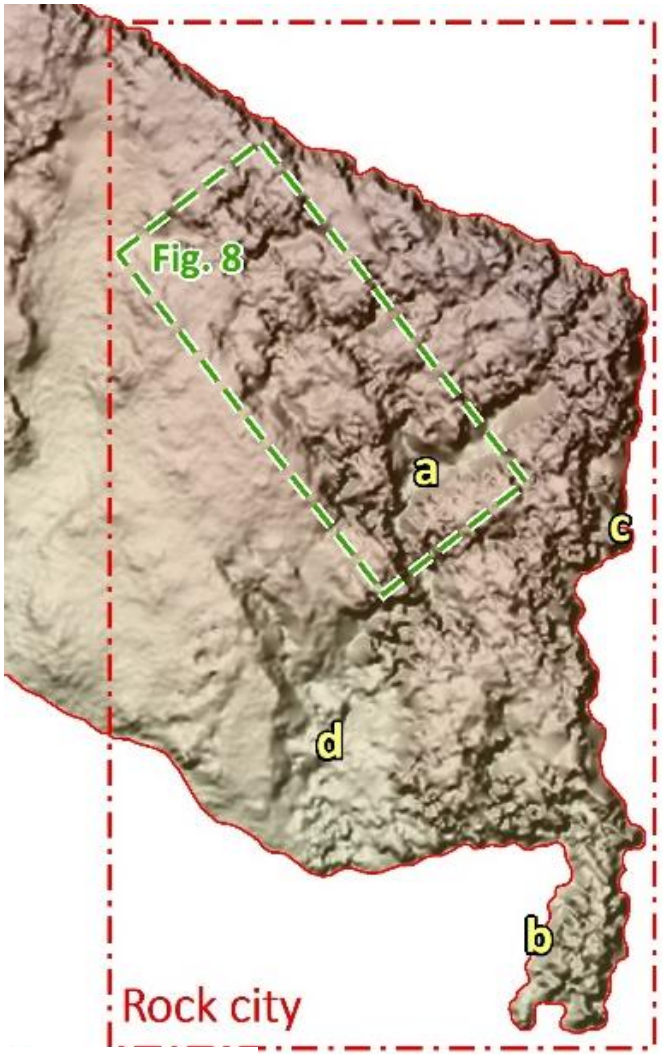
The role of subterranean processes → substantial sand removal from caprock

→ so what about the consequences for surface caprock morphology?

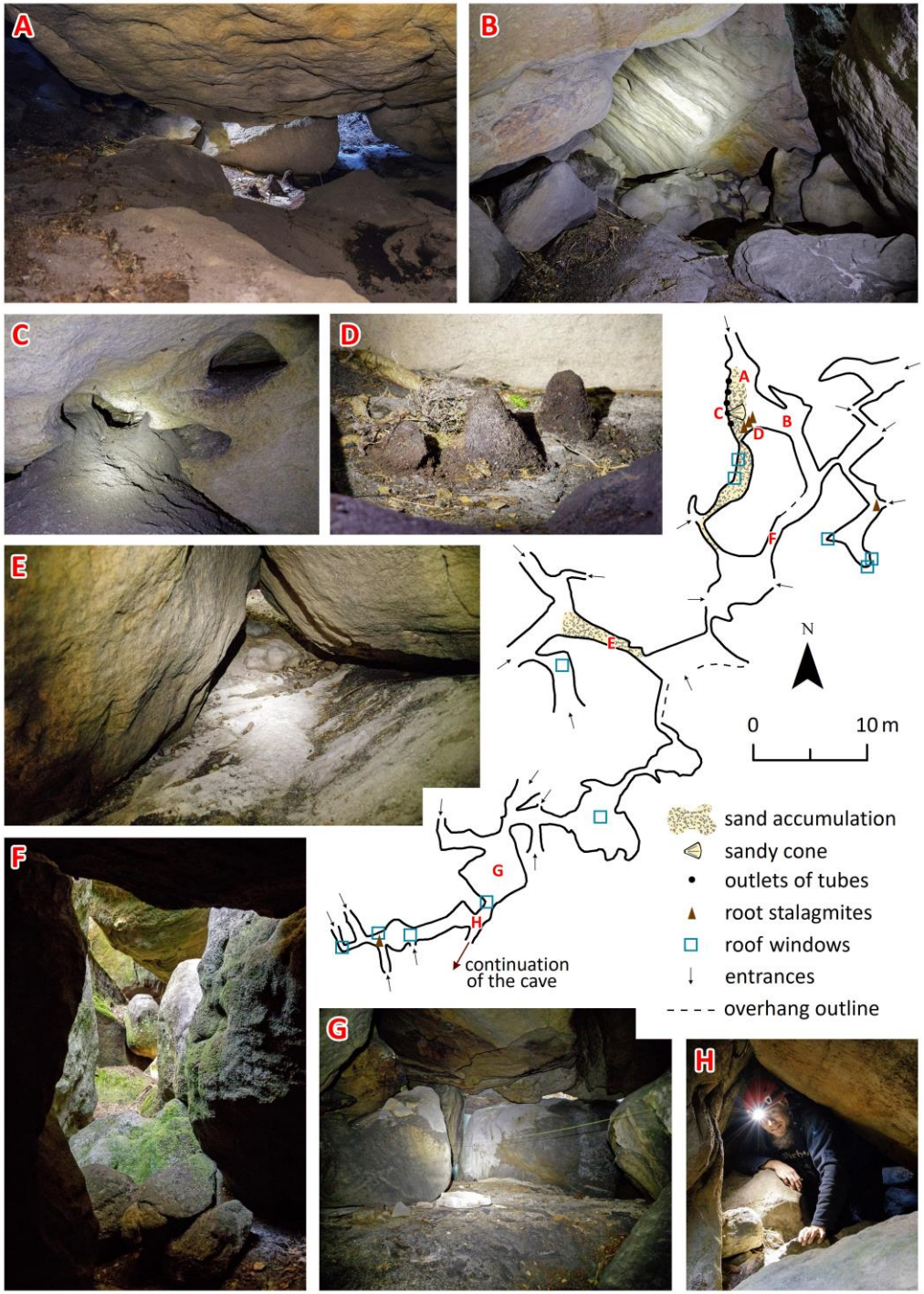


Closed depression within the caprock on the mesa of Szczeliniec Wielki

Rock city and caves within the caprock on the mesa of Hejda

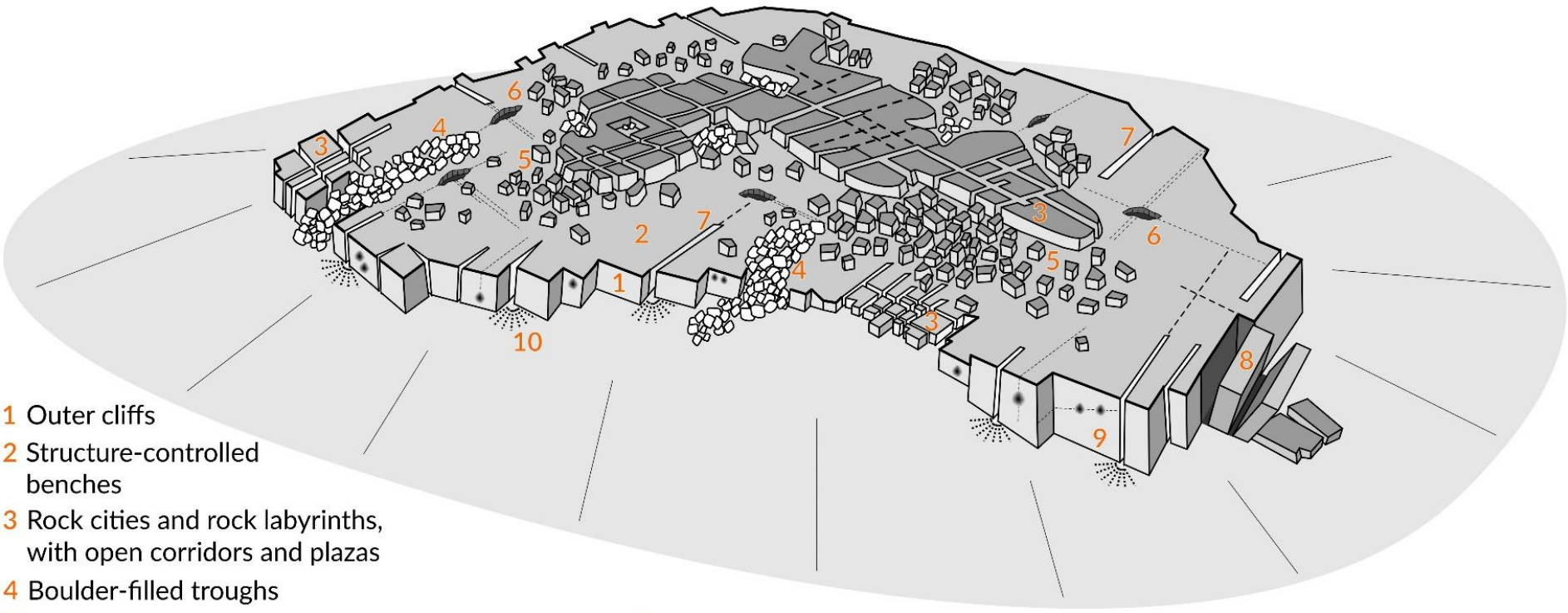


a – boulder-filled hollow
b – tilted towers
c – roofed slots
d – Pisečná Cave



The role of subterranean processes → substantial sand removal from caprock

→ so what about the consequences for surface caprock morphology?



1 Outer cliffs
2 Structure-controlled benches
3 Rock cities and rock labyrinths, with open corridors and plazas
4 Boulder-filled troughs
5 Blocky chaos and residual rock landforms (tors)
6 Pseudo-sinkholes
7 Open slots penetrating from outer cliffs inward
8 Tilted and collapsed blocks: large-scale slope instabilities
9 Outlets of tubes
10 Sandy cones

The role of subterranean processes → is this karst?

Karstic tubes through rock towers?

Cete Cidades (NE Brazil) – degraded dolines in ancient silicate karst?

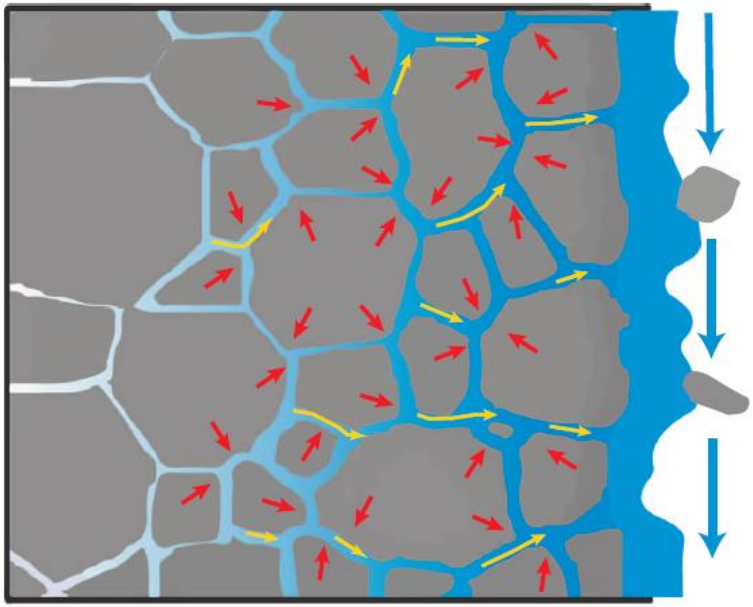
The role of subterranean processes → is this karst?

Quartzite tablelands of Venezuela

↓

True karst

<u>Arenization</u> (dissolution of cement in quartzite) as a critical process



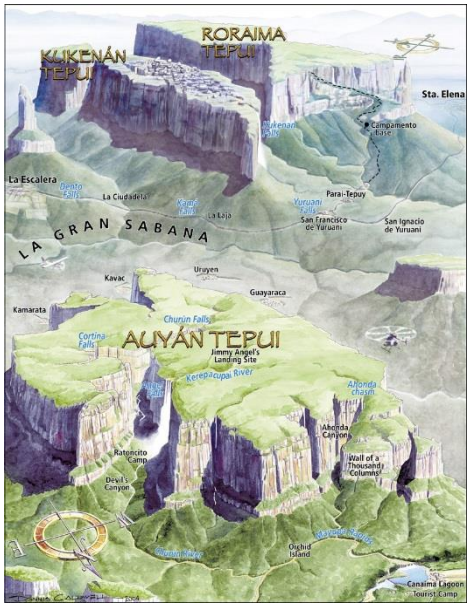
Dissolution at grain contacts

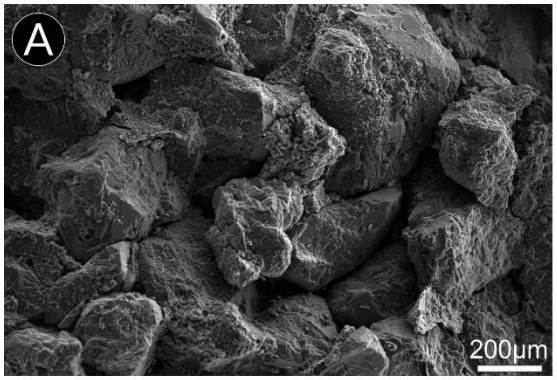
Diffusion transport along pore water

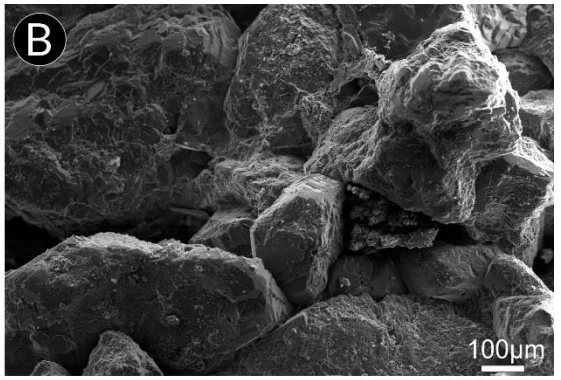
Advective flux of undersatured water (fracture/free surface)

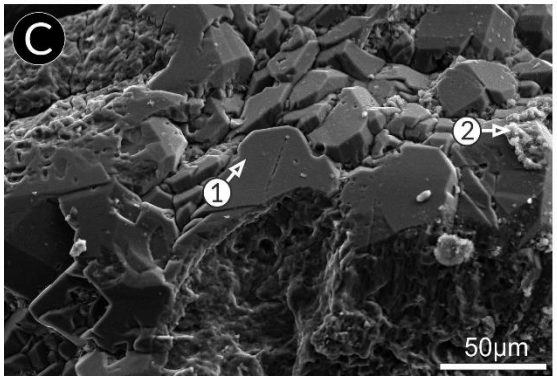
>>>>>>> SiO_2 concentration gradient

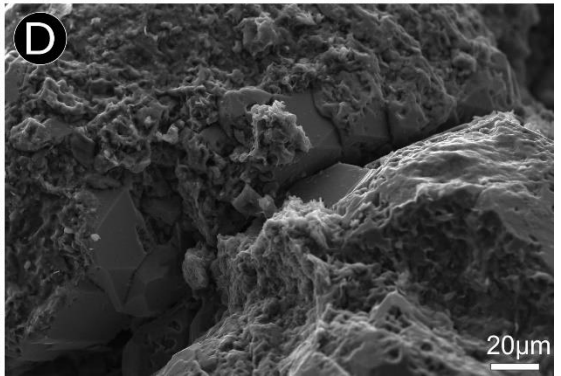
Source: Wray & Sauro (2017)



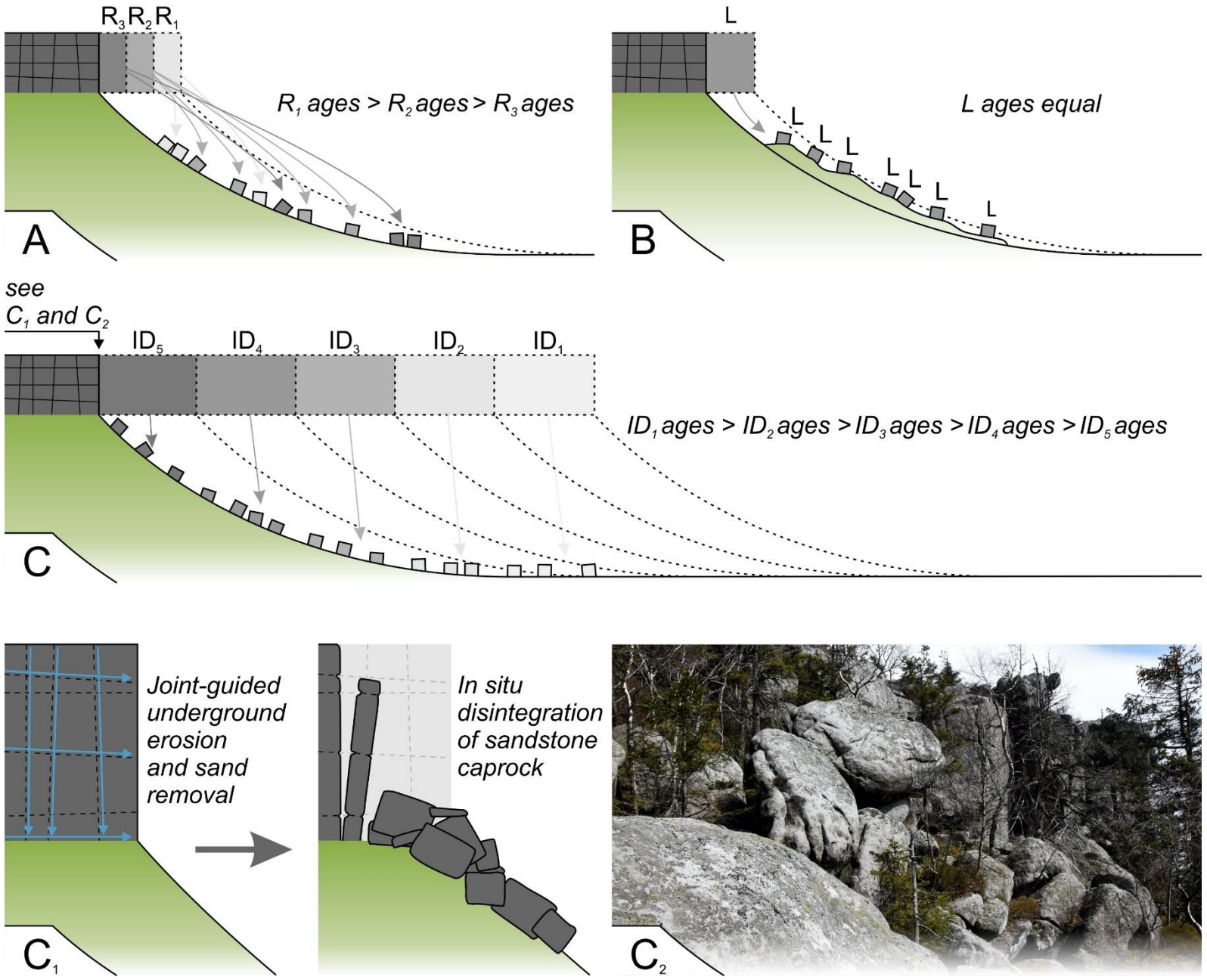




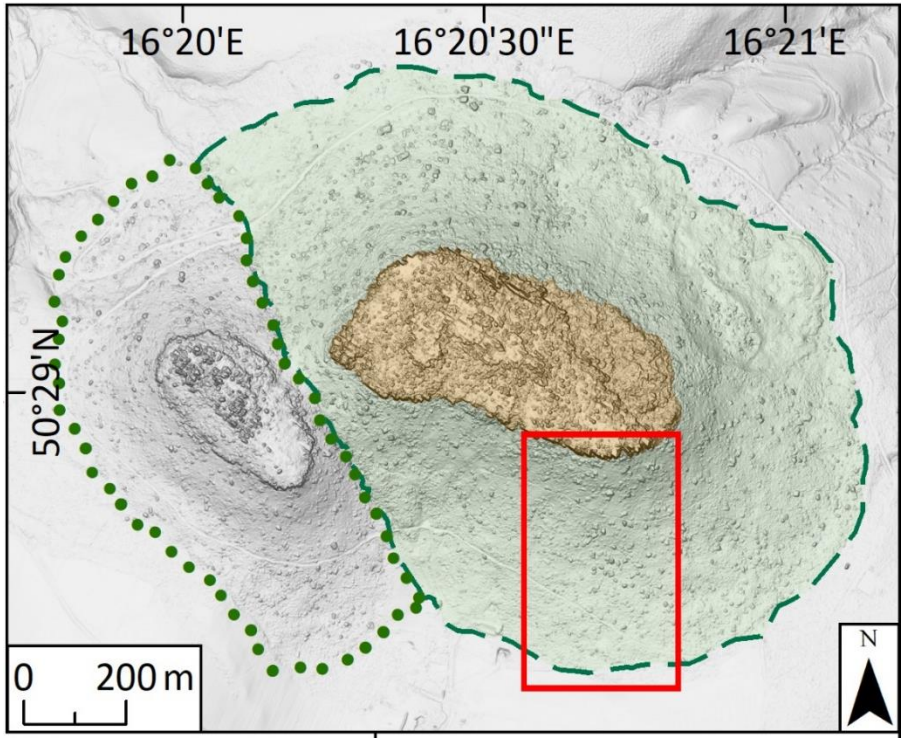


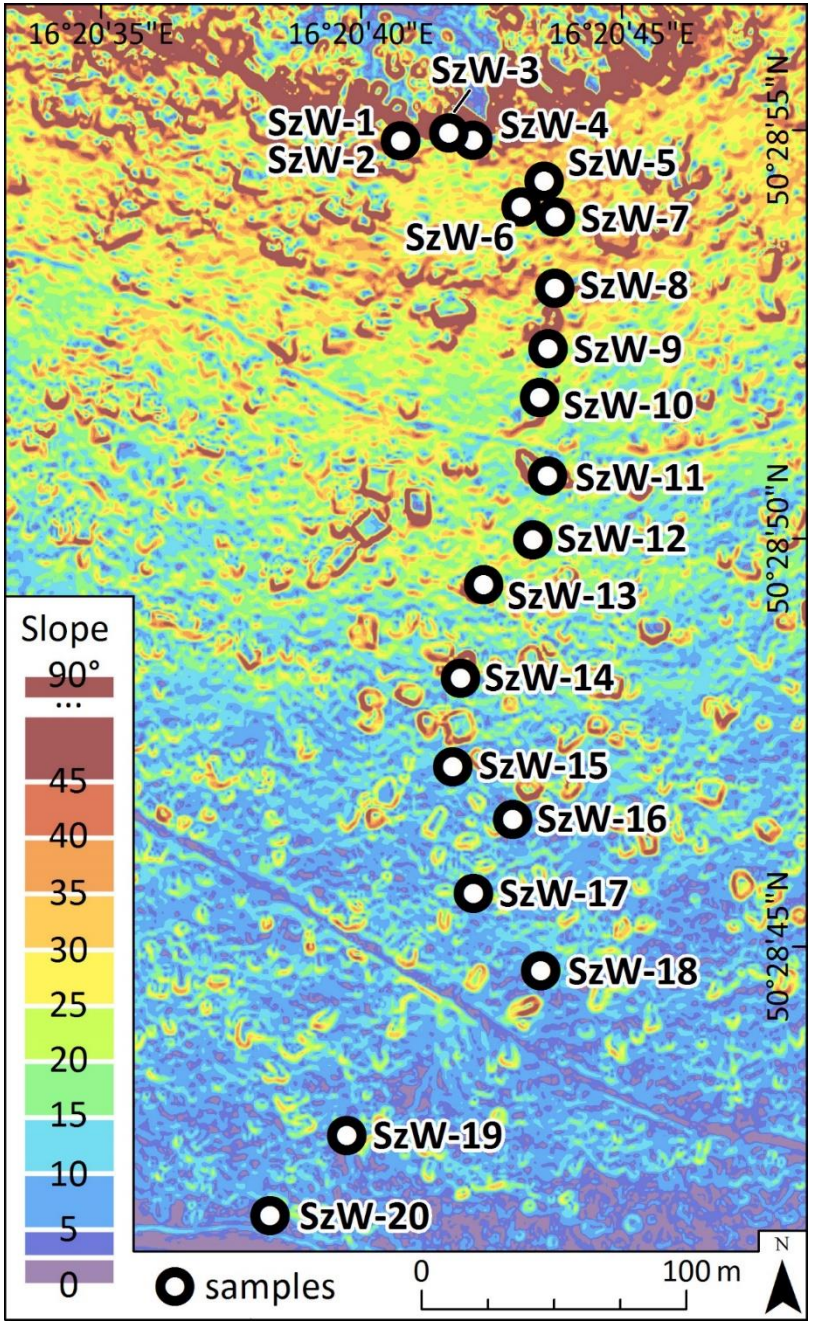


Sandstone-capped escarpments – what are rates of their retreat?

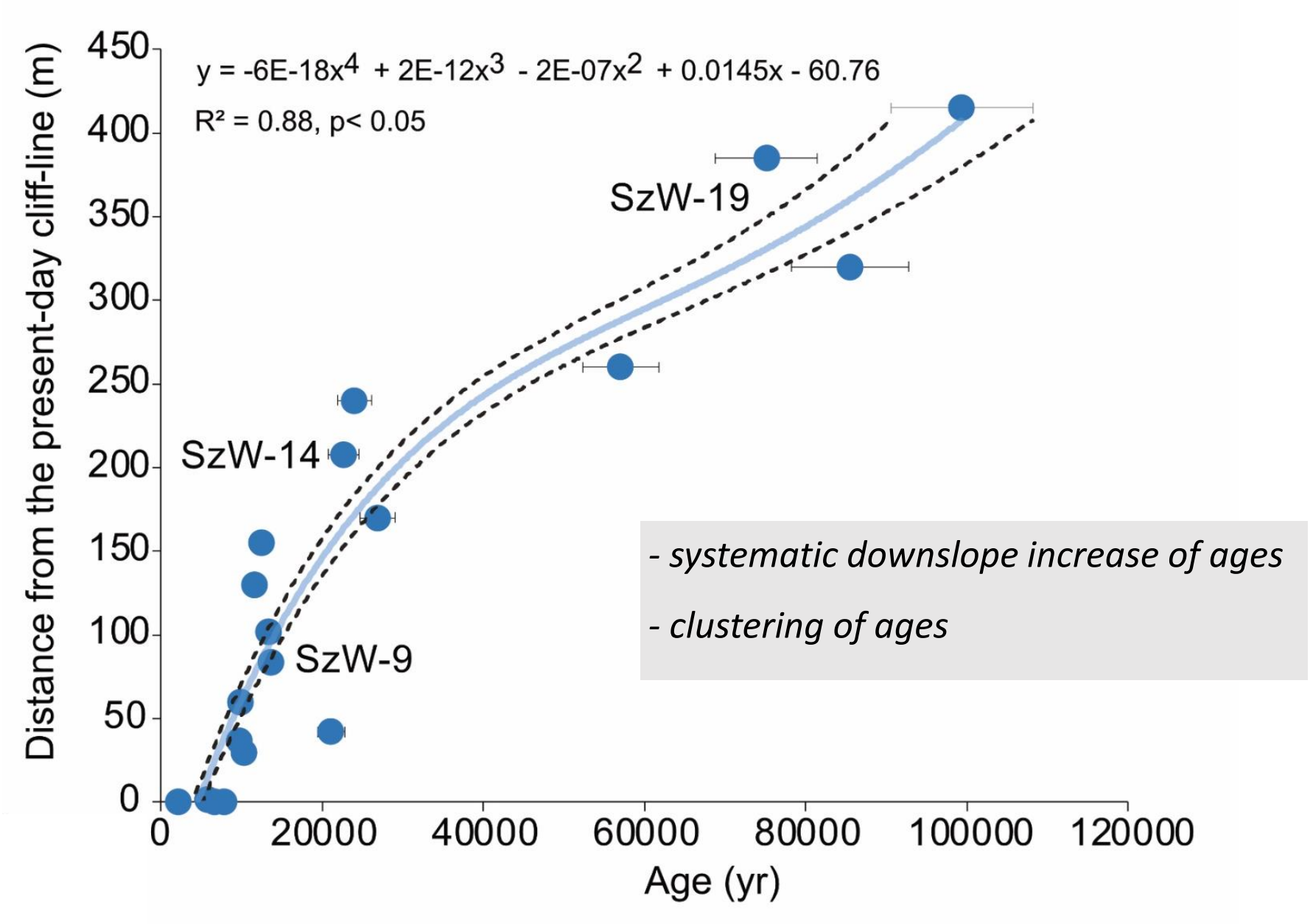


Sandstone-capped escarpments – what are rates of their retreat?





Sandstone-capped escarpments – what are rates of their retreat?



- *systematic downslope increase of ages*
- *clustering of ages*

Sandstone-capped escarpments – what are rates of their retreat?

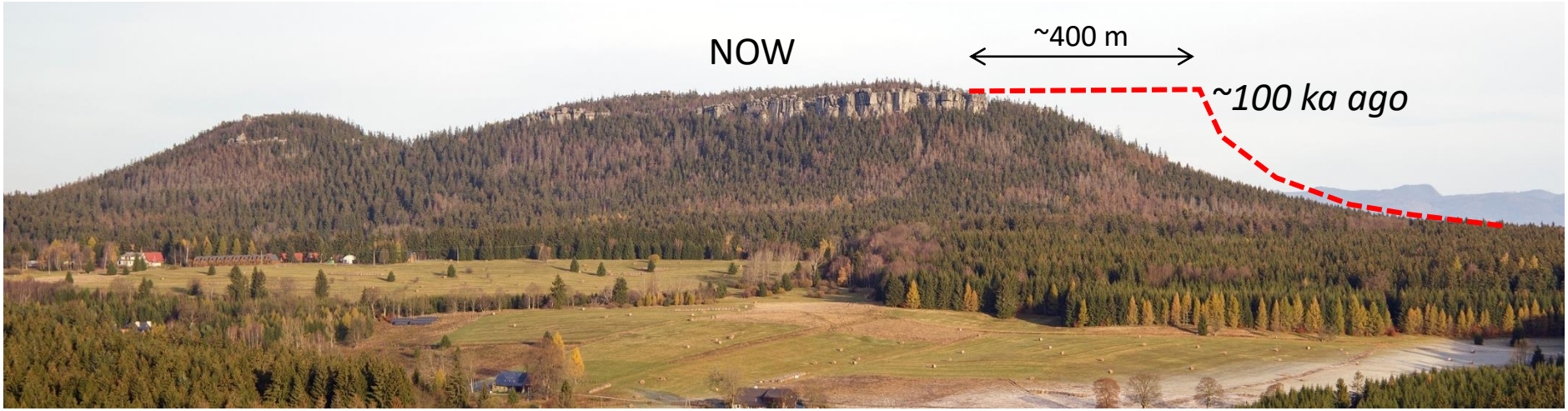
If each of the dated hillslope boulders approximates the past extent of the mesa rim, then...

415 m — The distance of boulder SzW-20 from the present-day cliff lines

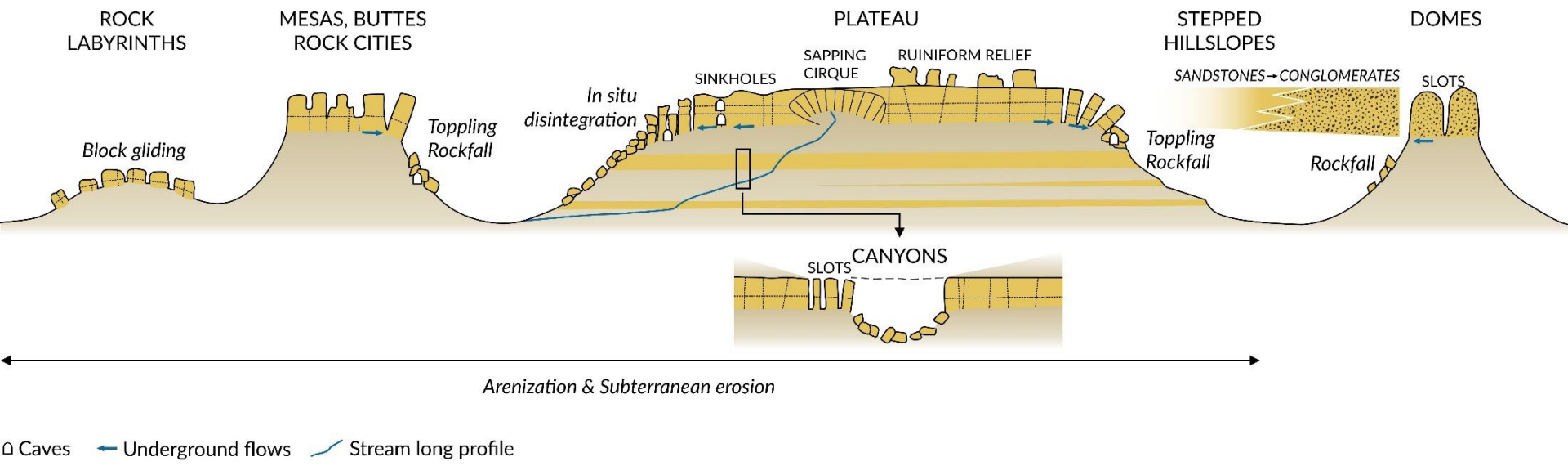
99.3 kyr — The age of boulder SzW-20 determined on the basis of cosmogenic ^{10}Be dating

4.18 m/10^3 yr — Average rate of scarp retreat of the mesa of Szczeliniec Wielki

The rate an order of magnitude higher than most data reported so far (mostly from arid and semi-arid environments)



Conclusions – Take home messages



1. Considerable geomorphological diversity of sedimentary tablelands – reasons as yet not entirely clear
2. Geological background as a fundamental control
3. Importance of „strong-over-weak" lithological setting
4. Multitude of processes involved and alternative evolutionary pathways → no simple solutions
5. Important role of subterranean processes, possibly karstic
6. Challenges: temporal context of landform evolution; landform parametrization using high-resolution DTM; filling regional gaps

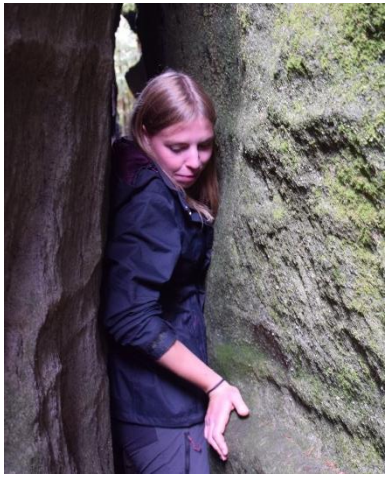
Contributors:

Filip Duszyński

Kacper Jancewicz

Milena Różycka

Wioleta Porębna



Maria Kotowska

Jarosław Waroszewski

Markus Egli

Krzysztof Parzóch

Wojciech Bartz

Marek Kasprzak

Tępek