Earth surface dynamics of arid landscapes

The experiment & model perspective on stone pavement evolution and beyond

Michael Dietze

GFZ German Research Centre for Geosciences, Section 5.1 Geomorphology

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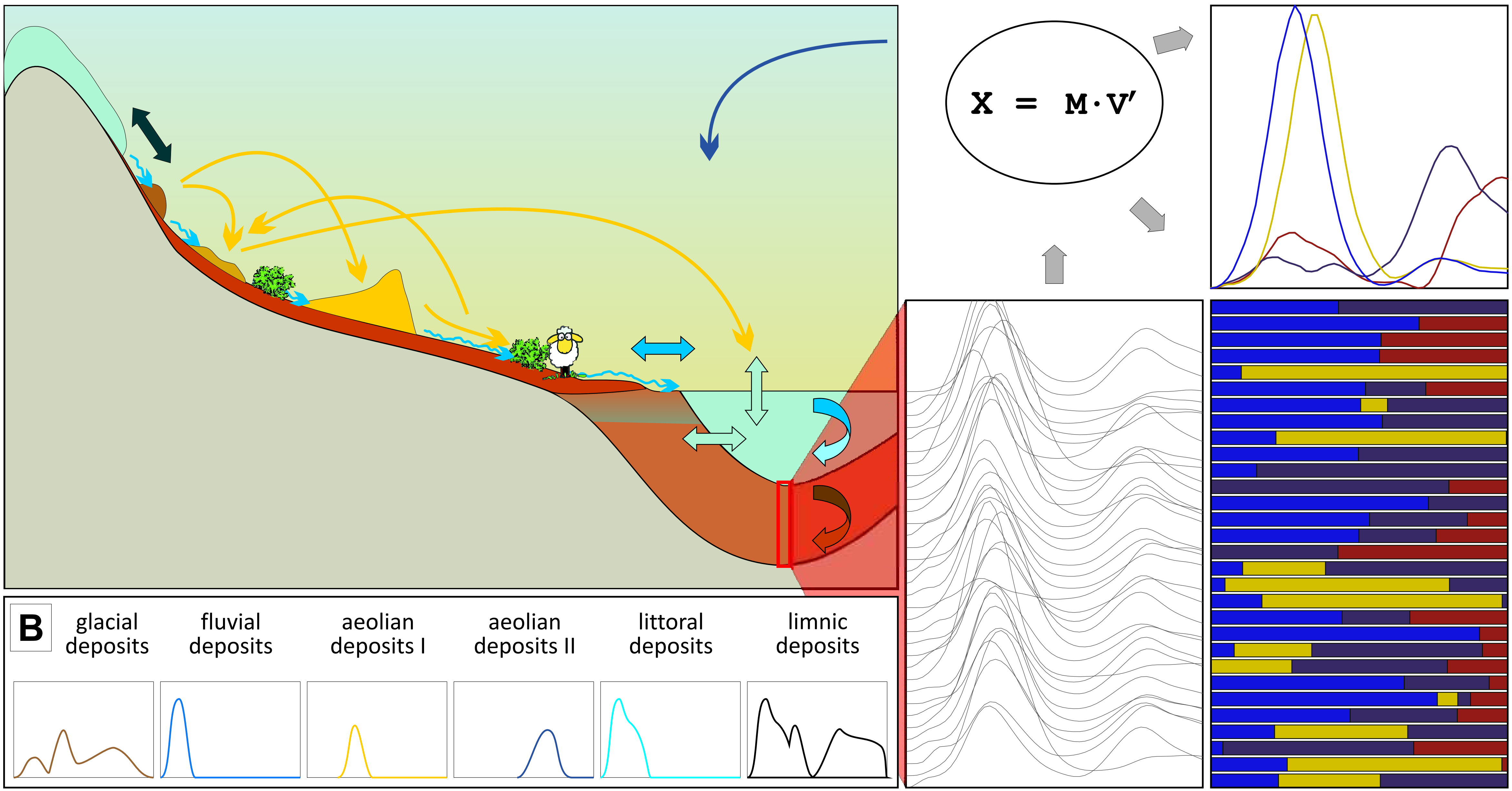
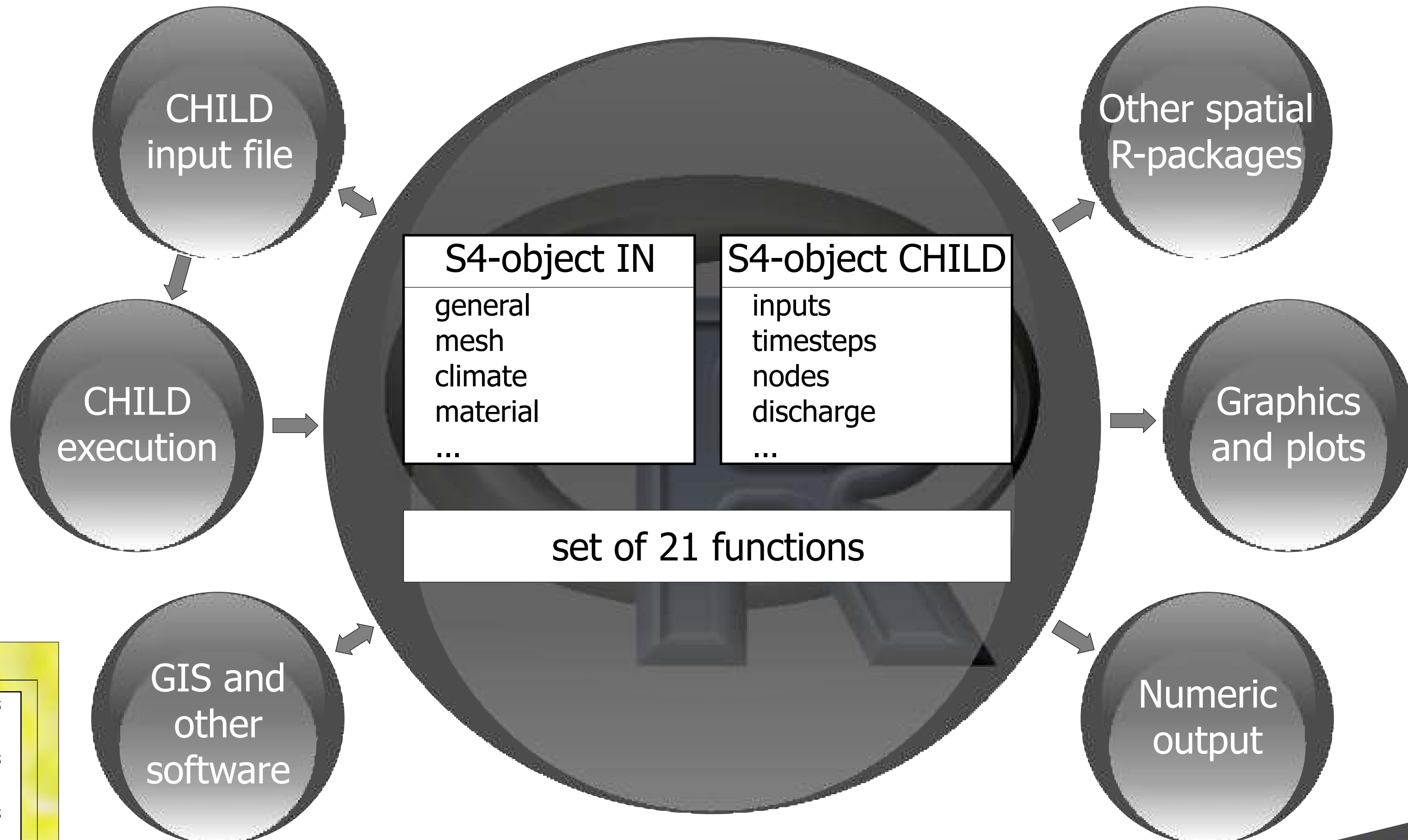
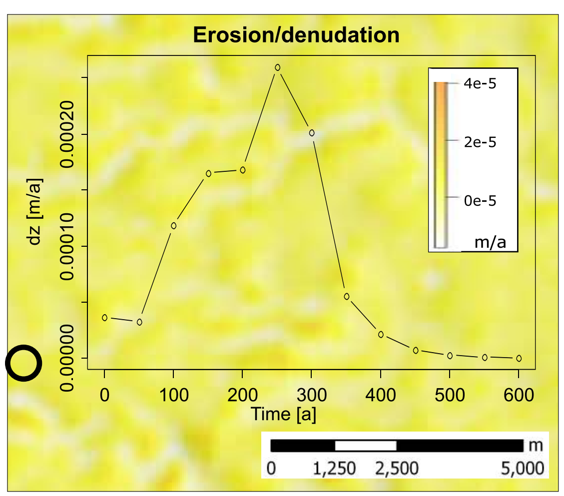
End-member modelling analysis Unmixing grain-size distributions

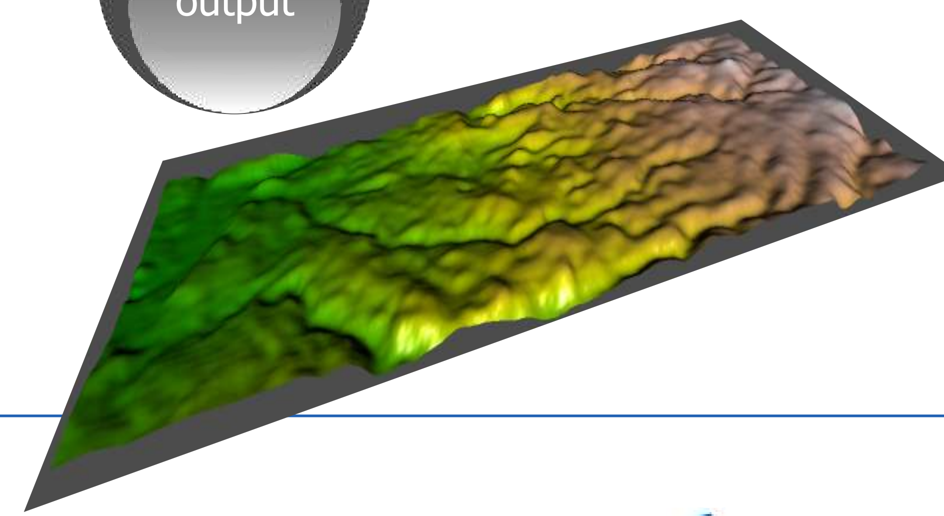


Dietze & Dietze (2013)

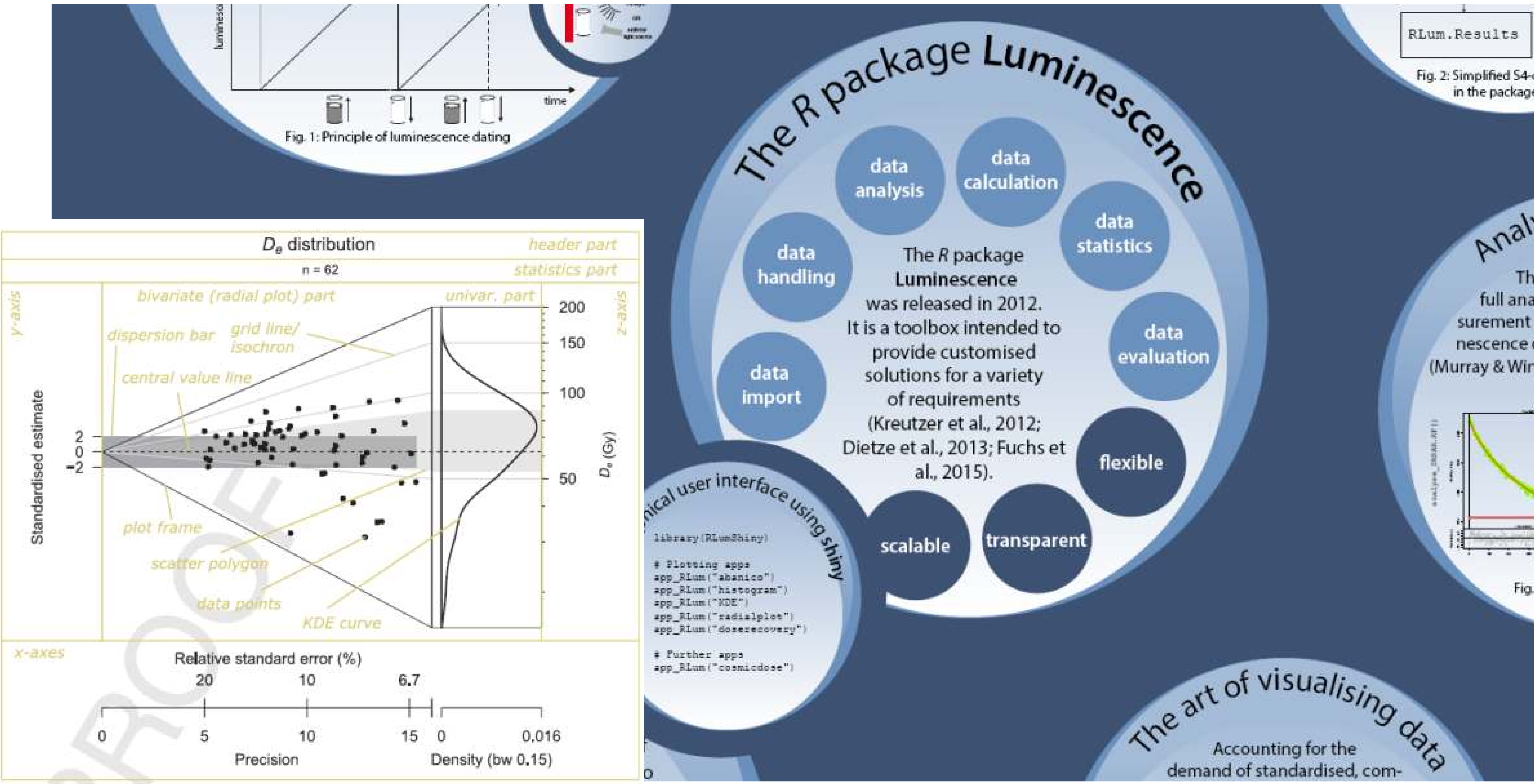
RCHILD A package to integrate CHILD to R



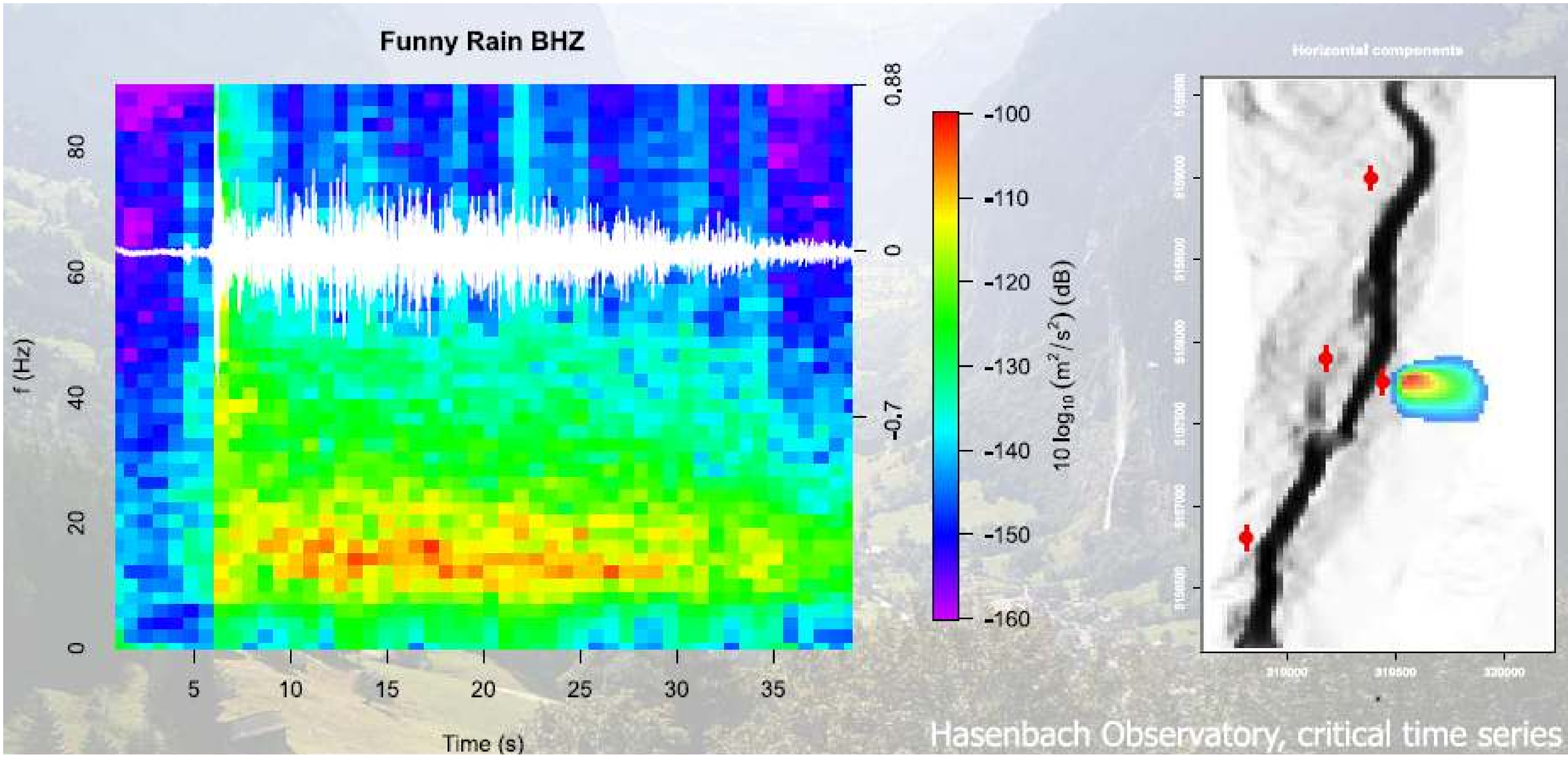




Luminescence An R-package for comprehensive data analysis



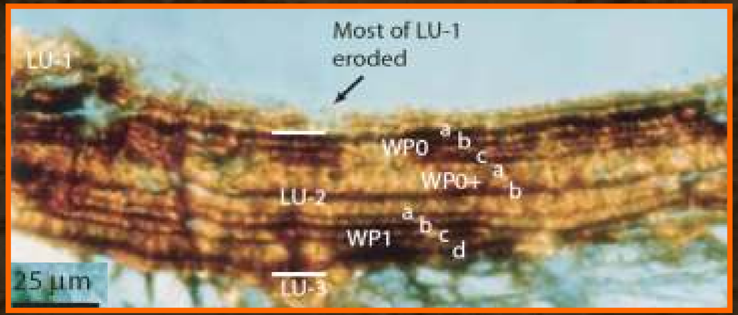
Environmental seismology Investigating signals emitted by Earth surface processes



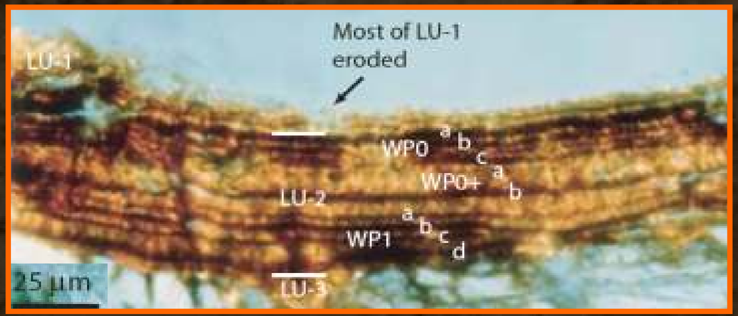
Valle de barrancas blancas, Nevado Tres Cruces, Atacama Desert

Somewhere above the arid Southwestern US

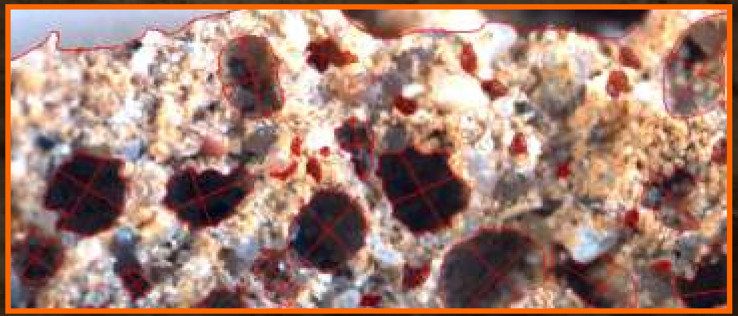
Cima volcanic field, eastern Mojave Desert



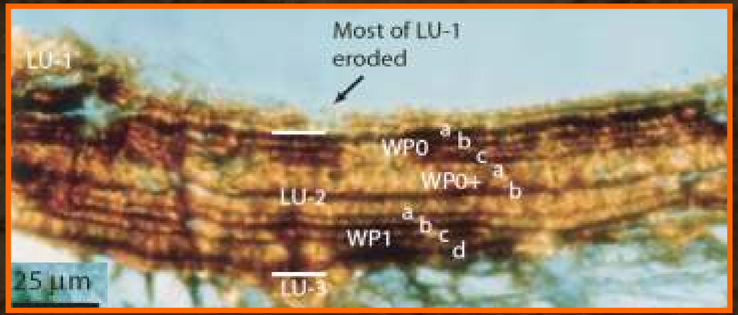
Liu & Broecker (2008)



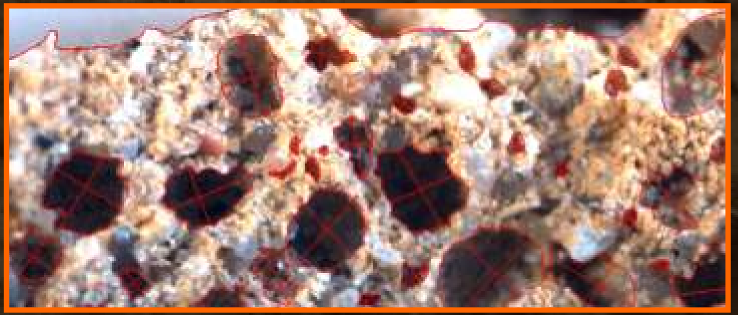
Liu & Broecker (2008)



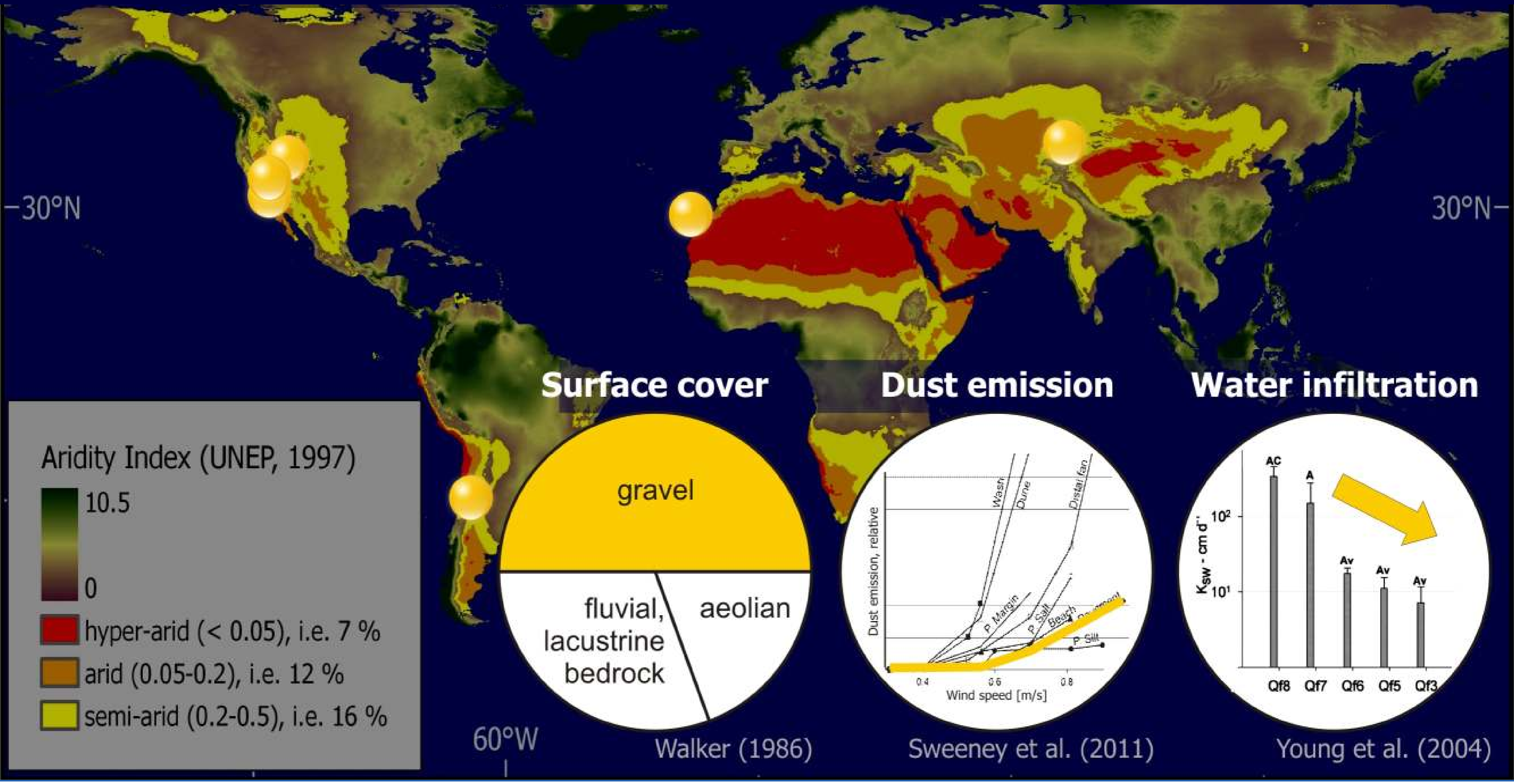
Dietze et al. (2012)



Liu & Broecker (2008)

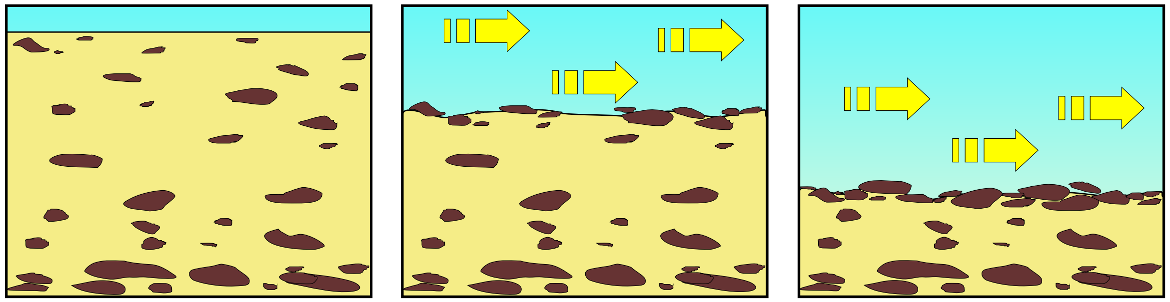


Dietze et al. (2012)

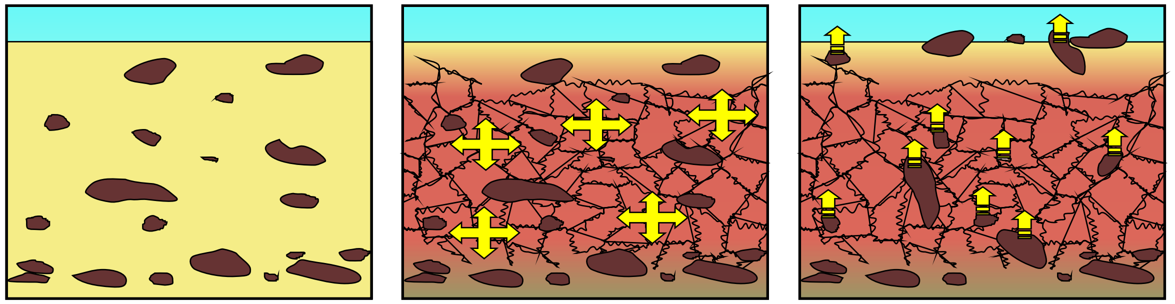

30°N
30°N
Aridity Index (UNEP, 1997)
10.5
0
hyper-arid (< 0.05), i.e. 7 %
arid (0.05-0.2), i.e. 12 %
semi-arid (0.2-0.5), i.e. 16 %
60°W
Surface cover
gravel
fluvial, lacustrine bedrock
aeolian
Walker (1986)
Dust emission
Dust emission, relative
Wind speed [m/s]
Wash
Dune
Distal fan
P Margin
P Salt
Beach
P Silt
Sweeney et al. (2011)
Water infiltration
AC
A
Av
Av
Av
Qf8
Qf7
Qf6
Qf5
Qf3
Young et al. (2004)

Formation models

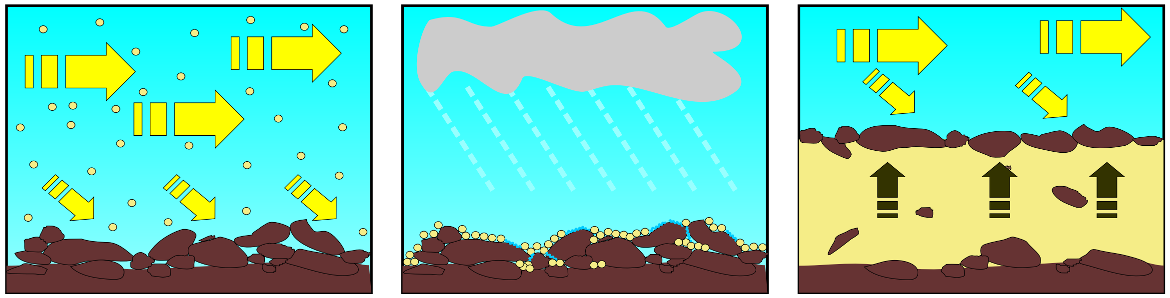
Deflation



Exhumation

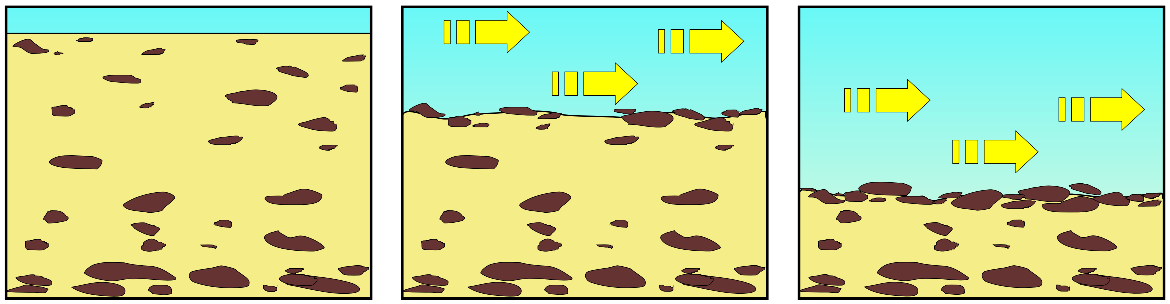


Accretion

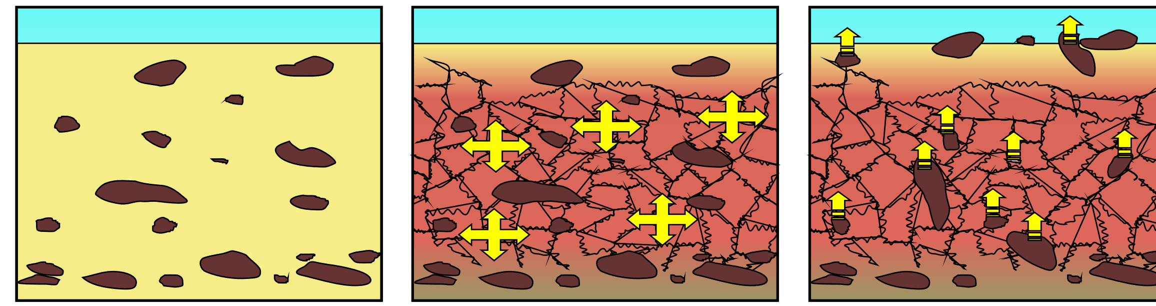


Formation models

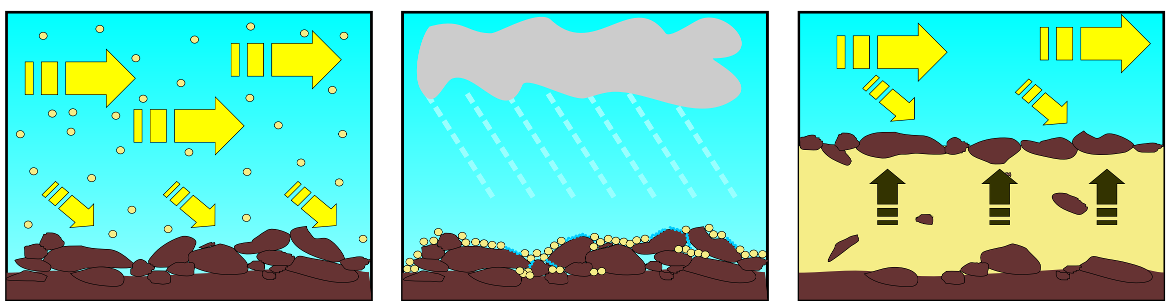
Deflation



Exhumation



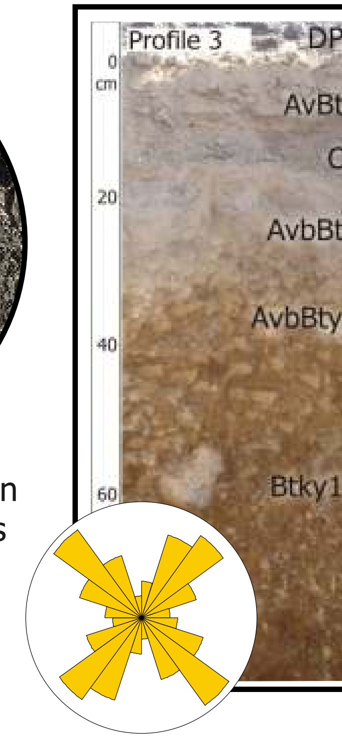
Accretion



Mojave Desert

eastern Jordan

Missing deposition behind obstacles

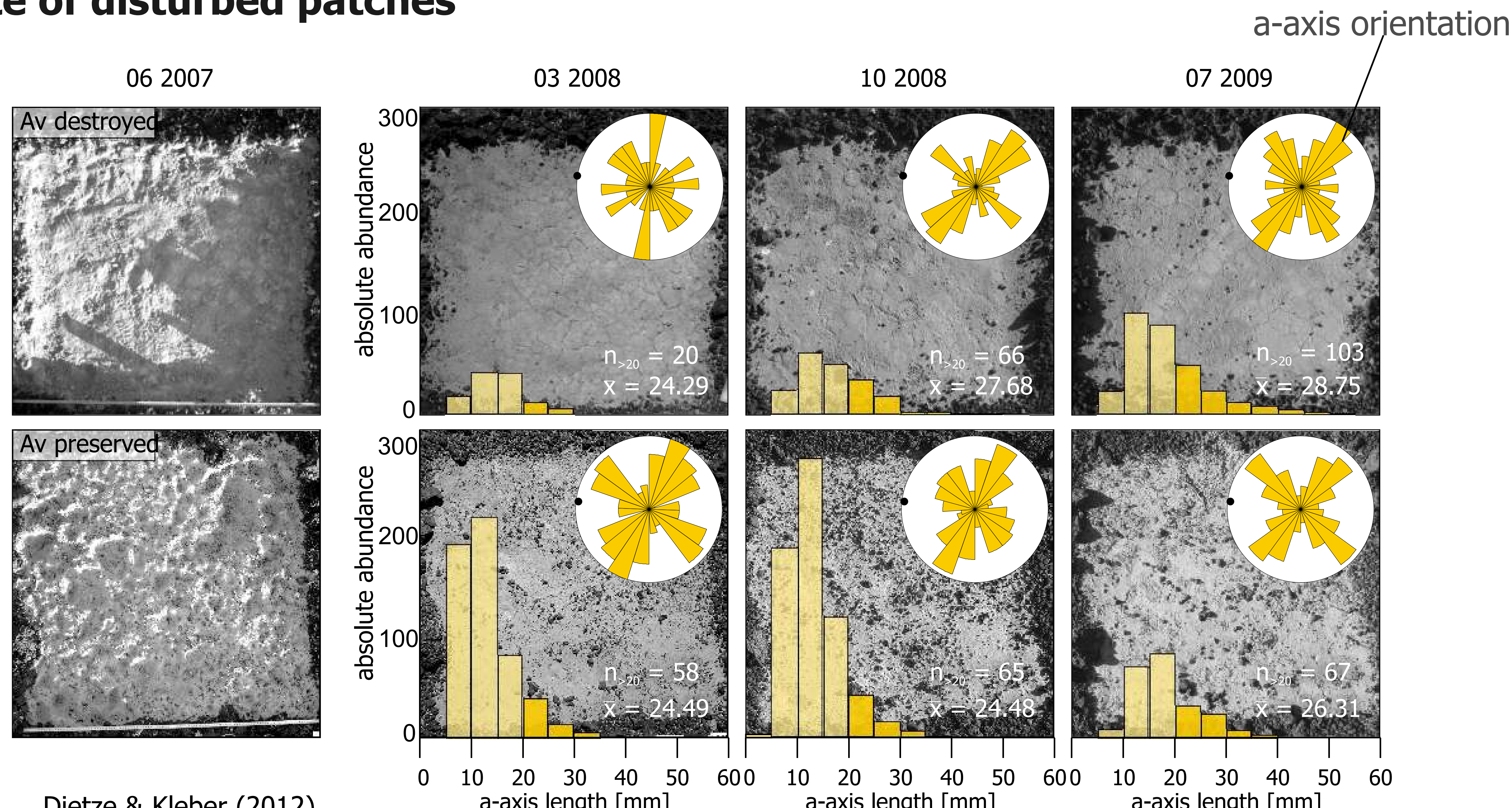


Modern and buried vesicular horizons

Modern and buried stone pavements

with preferred clast orientation patterns

Fate of disturbed patches



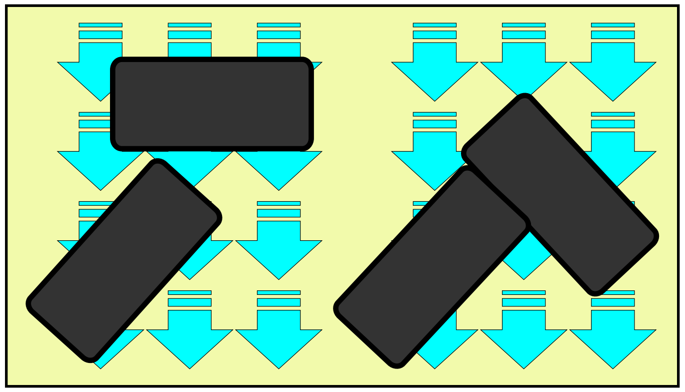
Dietze & Kleber (2012)

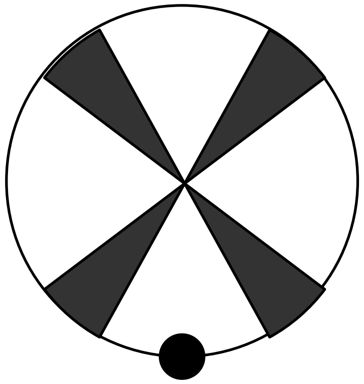
What to explain and how to solve it

Multiple pavement generations, scar recovery, missing cover behind obstacles, orientation patterns, ...

What to explain and how to solve it

Multiple pavement generations, scar recovery, missing cover behind obstactles, orientation patterns, ...





Boundary conditions

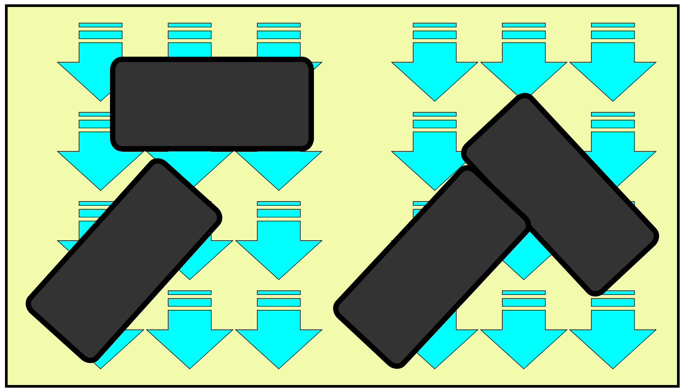
Flat, finegrained, resistive surface

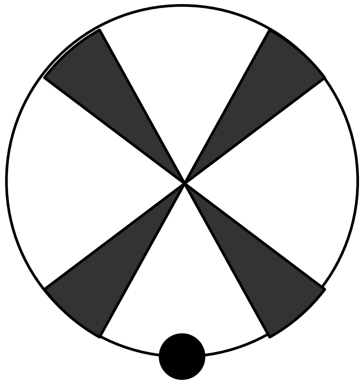
Transport by drag

Rotation upon collision

What to explain and how to solve it

Multiple pavement generations, scar recovery, missing cover behind obstacles, orientation patterns, ...





Boundary conditions

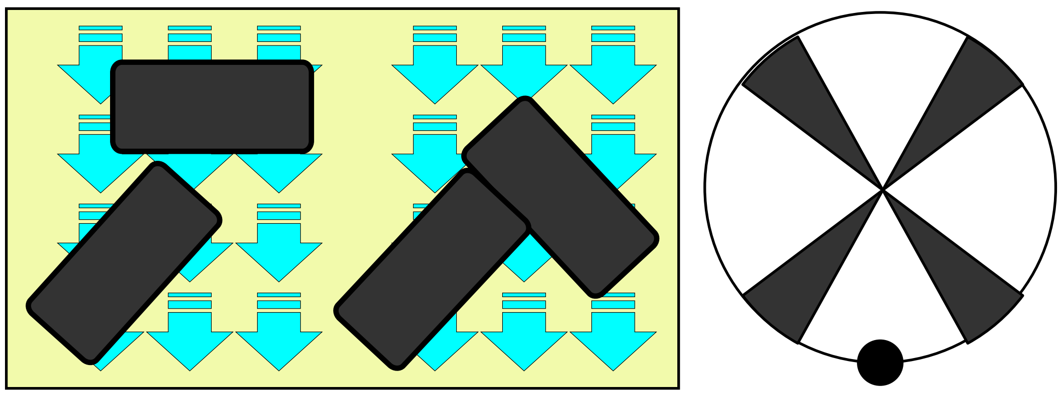
- Flat, finegrained, resistive surface
- Transport by drag
- Rotation upon collision

water drag force $F_A = F_R$ underground-clast friction force

$$\frac{1}{2} \cdot \rho_W \cdot C_f \cdot \bar{v}_O^2 \cdot A_O = F_A \qquad F_R = V_O \cdot g \cdot (\rho_O - \rho_W) \cdot \cos(\gamma) \cdot \mu$$

What to explain and how to solve it

Multiple pavement generations, scar recovery, missing cover behind obstacles, orientation patterns, ...



Boundary conditions

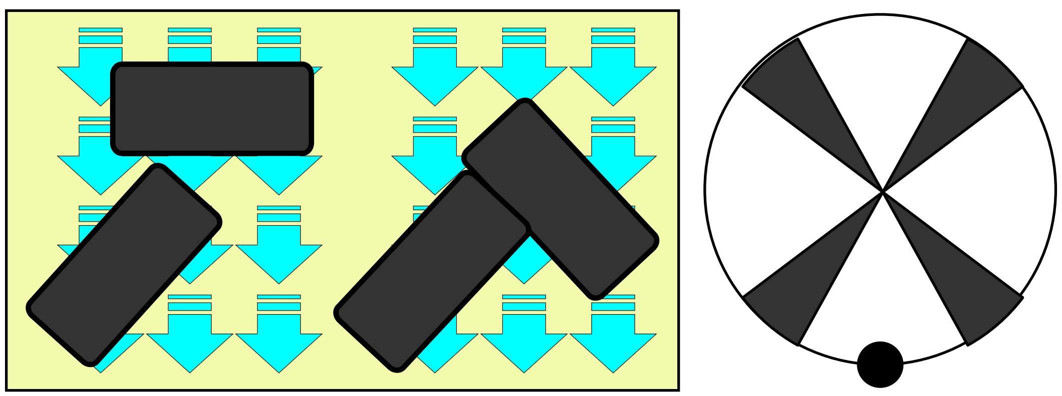
- Flat, finegrained, resistive surface
- Transport by drag
- Rotation upon collision

water drag force $$F_A = F_R$$ underground-clast friction force

$$\phi = \arccos\left(\frac{2 \cdot V_o \cdot g \cdot (\rho_o - \rho_w) \cdot \cos(\gamma) \cdot \mu}{\rho_w \cdot \bar{v}^2 \cdot C_w \cdot c \cdot \sqrt{a^2 + b^2}}\right) - \arctan\left(\frac{b}{a}\right)$$

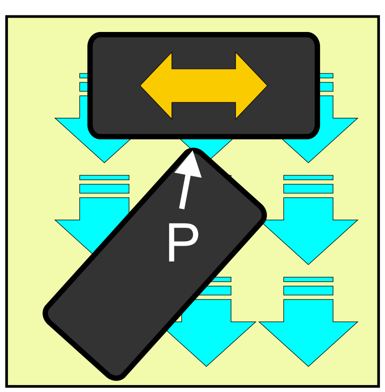
What to explain and how to solve it

Multiple pavement generations, scar recovery, missing cover behind obstactles, orientation patterns, ...

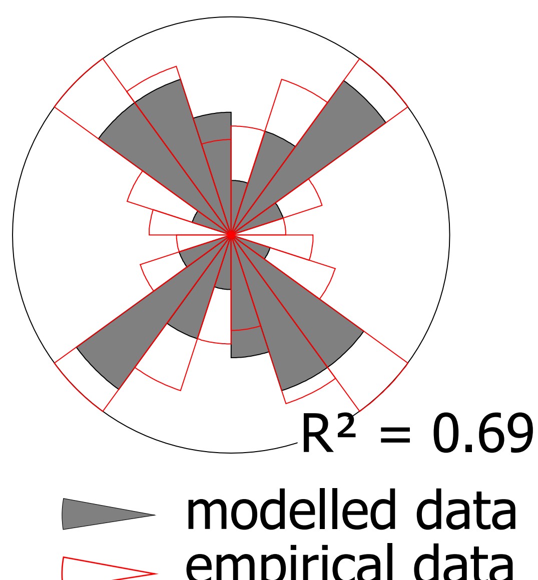


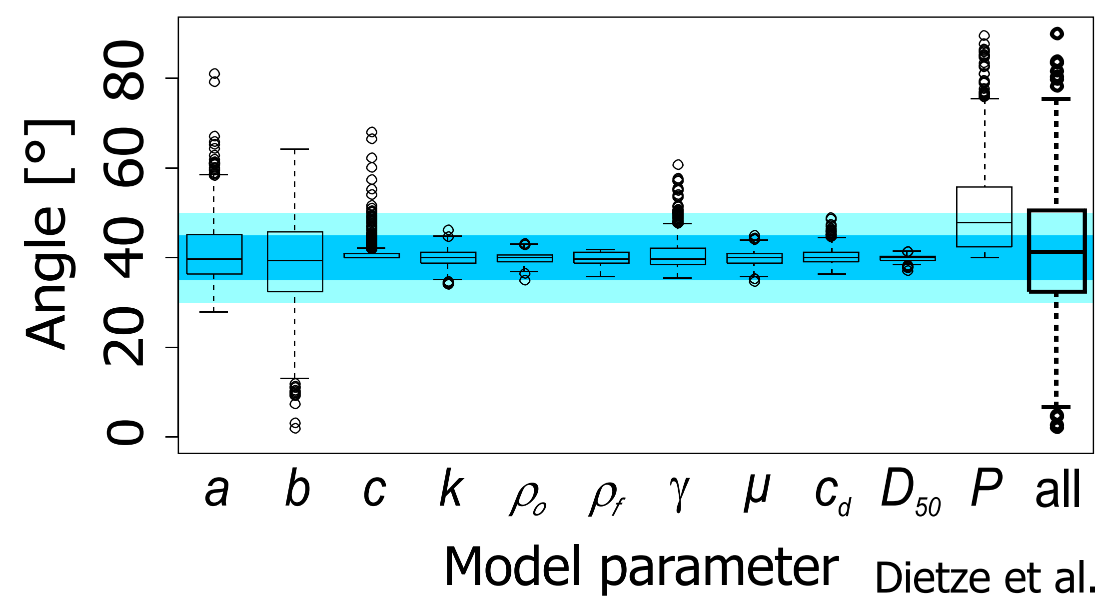
Boundary conditions

- Flat, finegrained, resistive surface
- Transport by drag
- Rotation upon collision



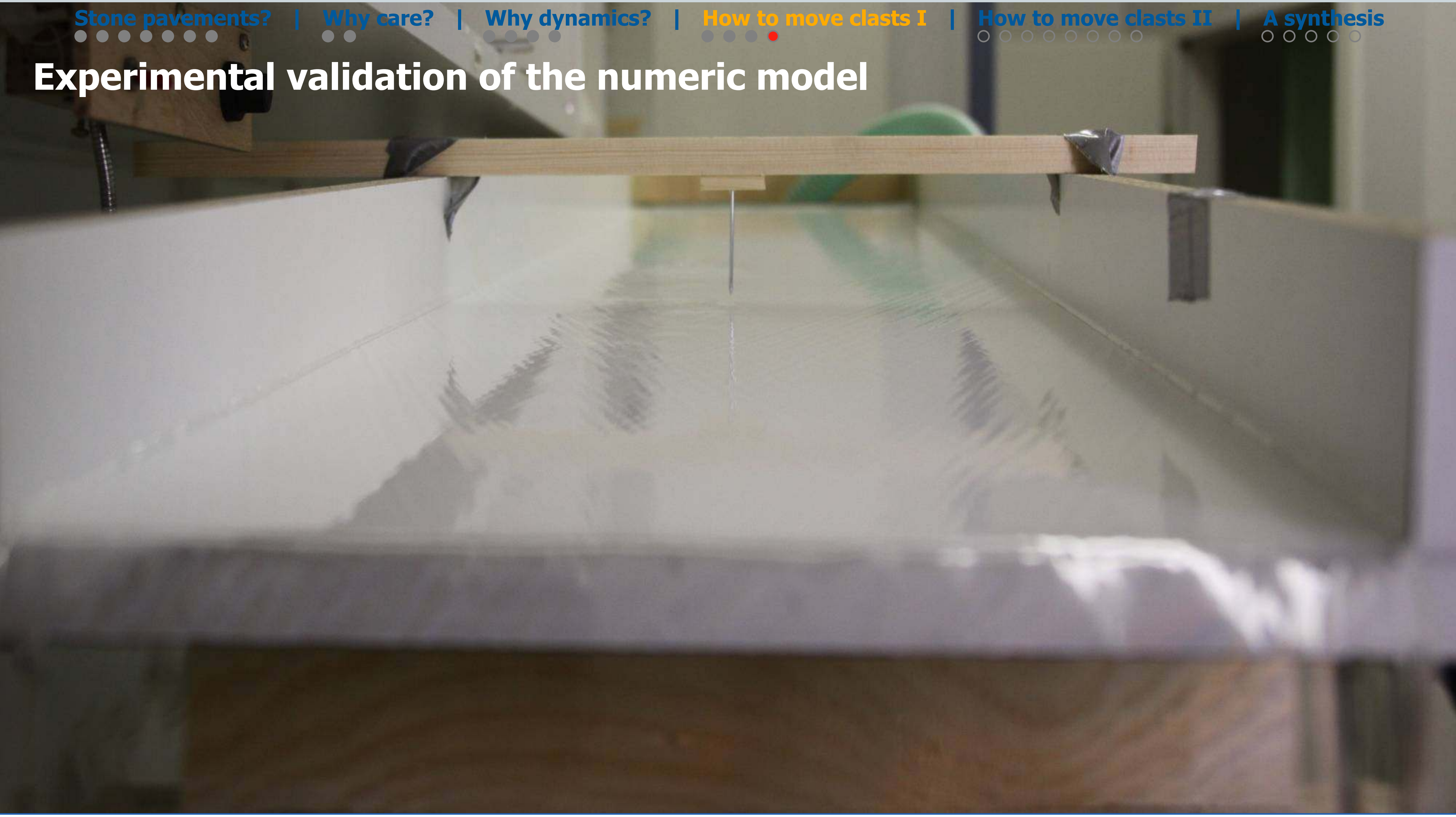
$$\varphi = \varphi \cdot \left(\frac{\frac{a}{2} - P}{\frac{a}{2}} \right)$$



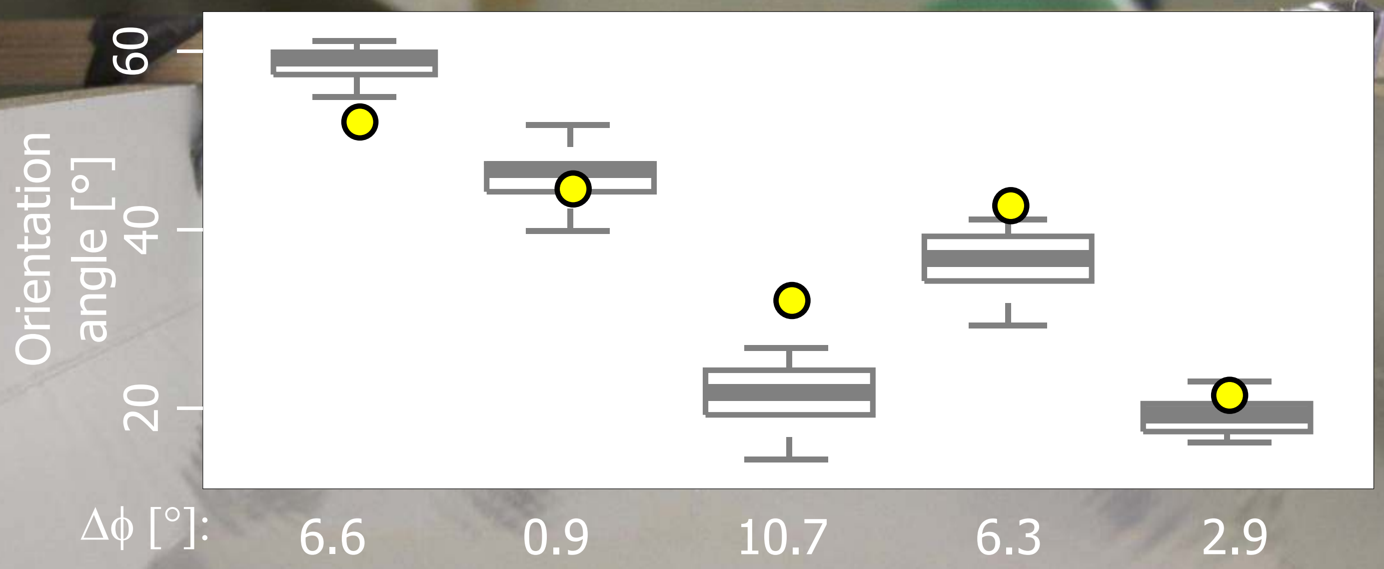


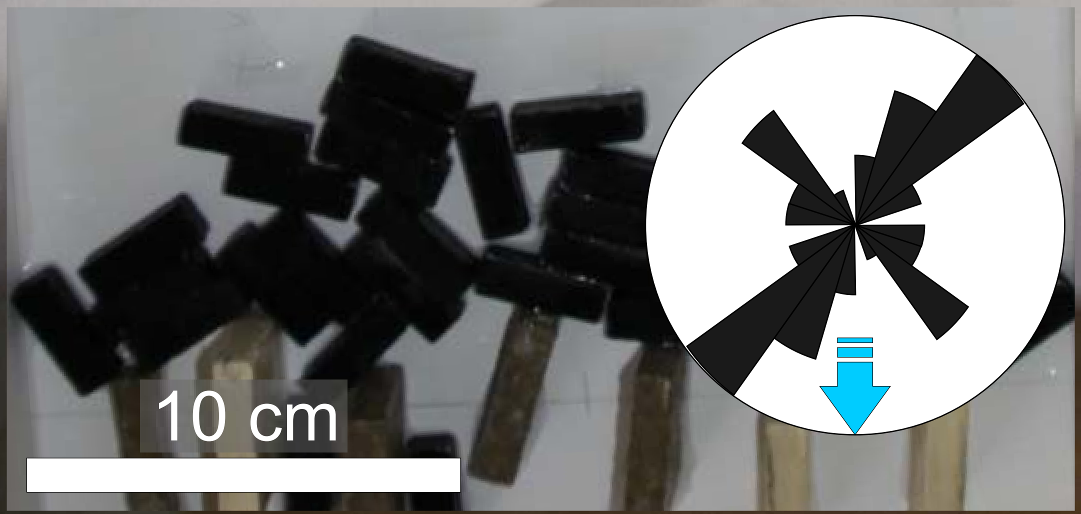
Dietze et al. (2013)

Experimental validation of the numeric model



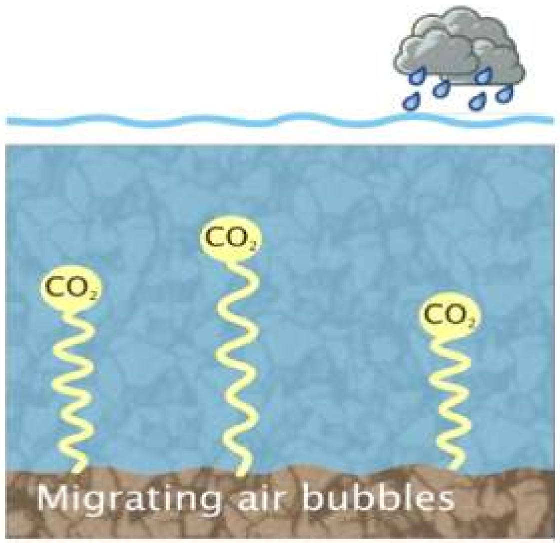
Experimental validation of the numeric model



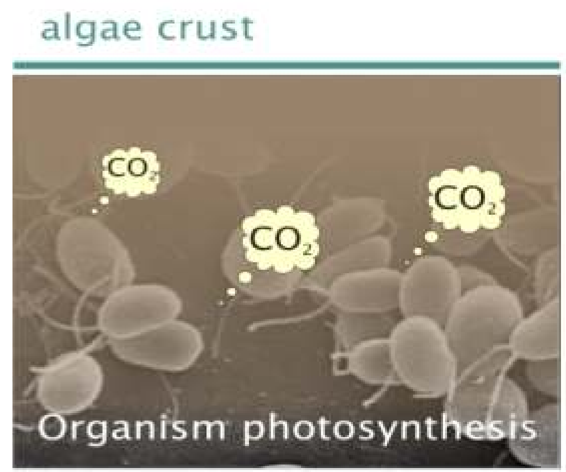


Dietze et al. (2013)

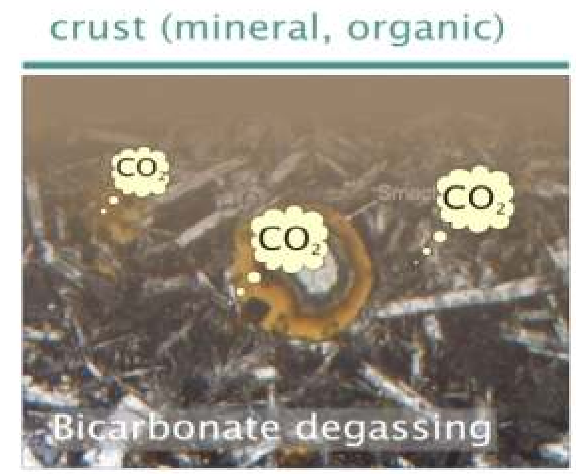
A further, complementary mechanism - just as secondary product...



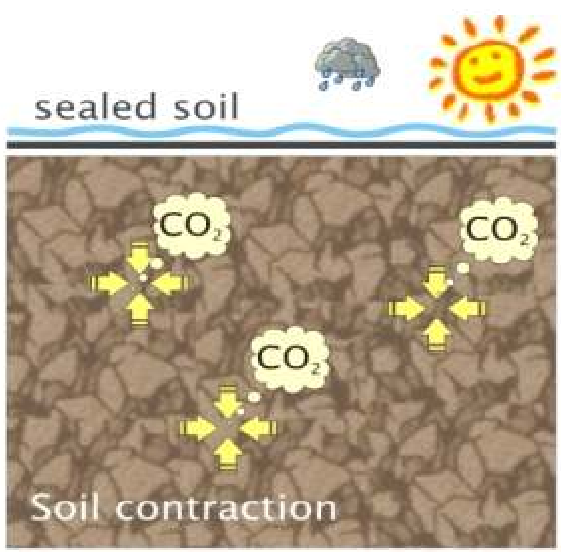
Hugie & Passey (1964)



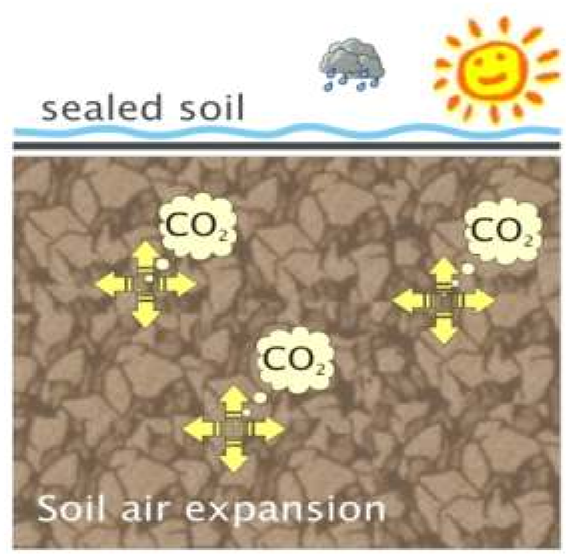
Bazilevich et al. (1956)



Paletskaya et al. (1958)



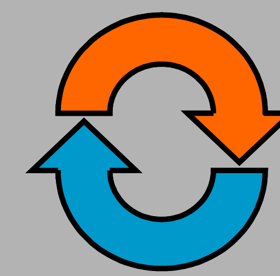
Rozanov (1951)



Evenari et al. (1974)

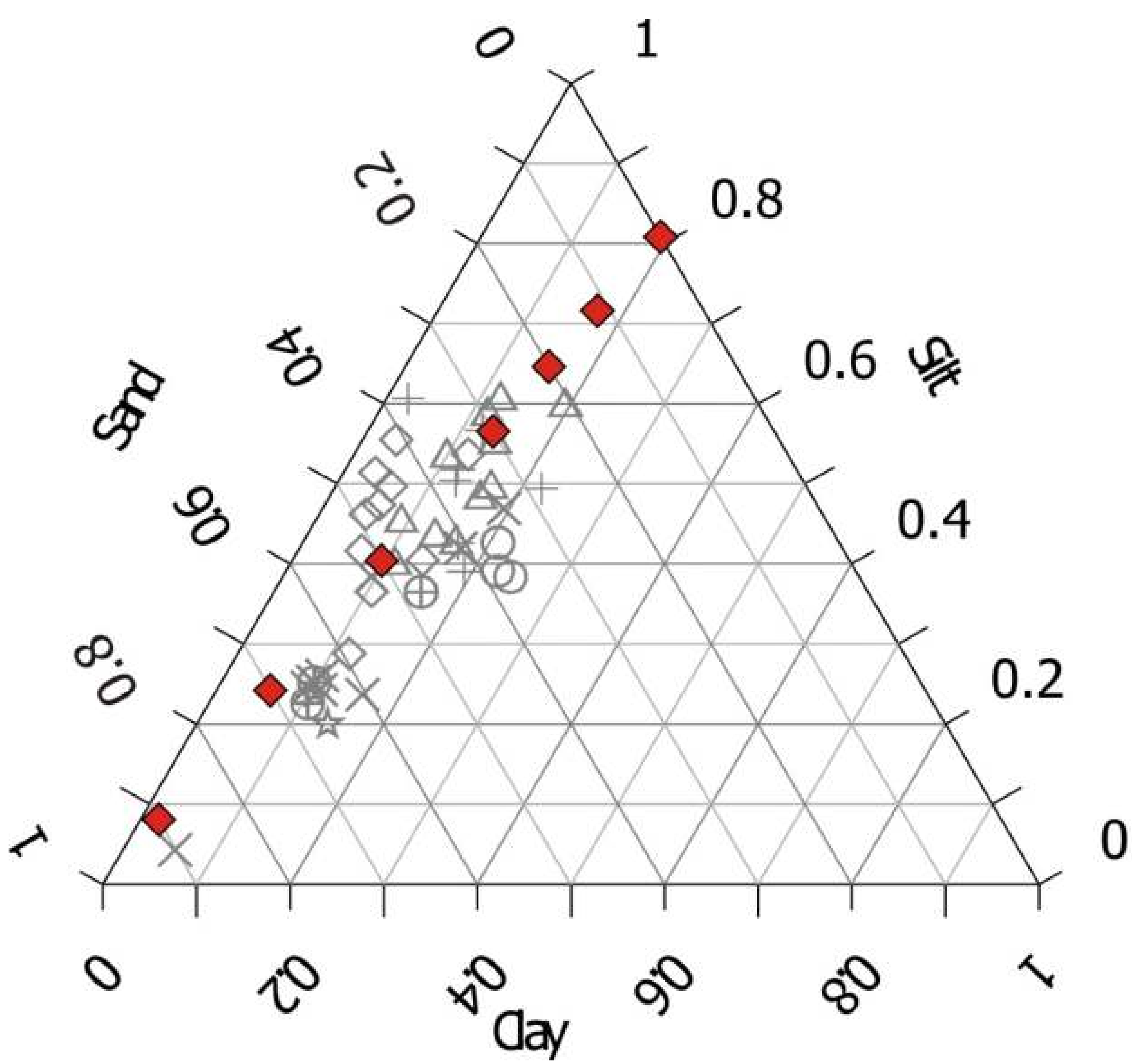
Springer (1958)

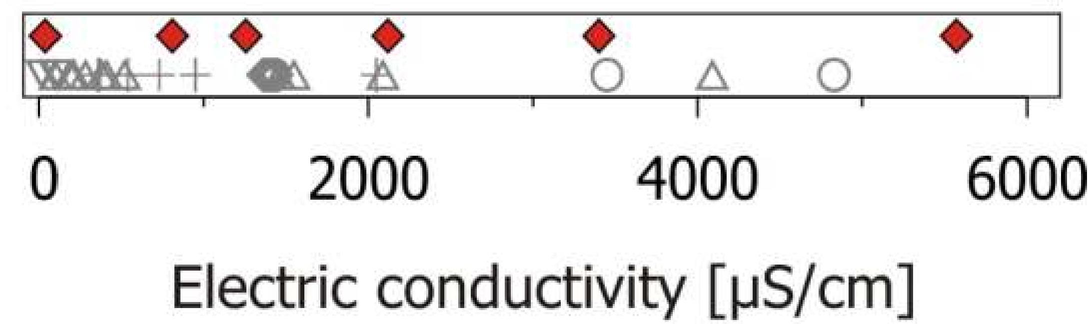
A further, complementary mechanism - just as secondary product...

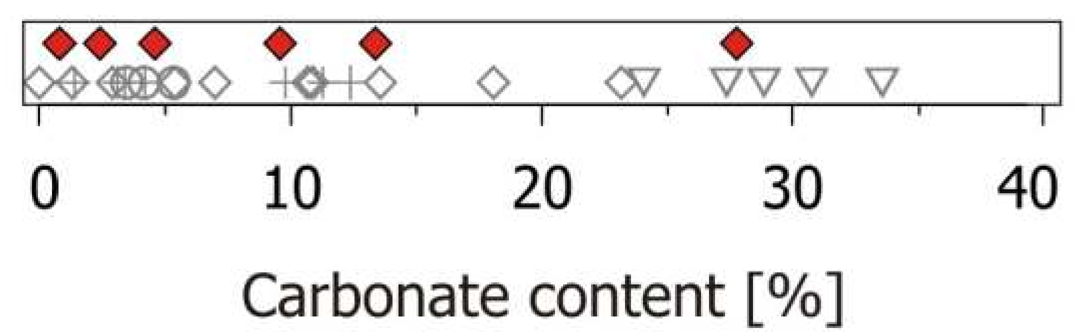


Sand [%]	$CaCO_3$ [%]	NaCl [%]	EC [µS/cm]	Wetting
0	1	0.25	810	40 ml
10	2.4	0.5	1260	60 ml
20	4.6	1	2120	80 ml
30	9.6	2	3400	100 ml
50	13.4	5	5570	spray
70	27.8			from bottom
(90)				flooding

A further, complementary mechanism - just as secondary product...



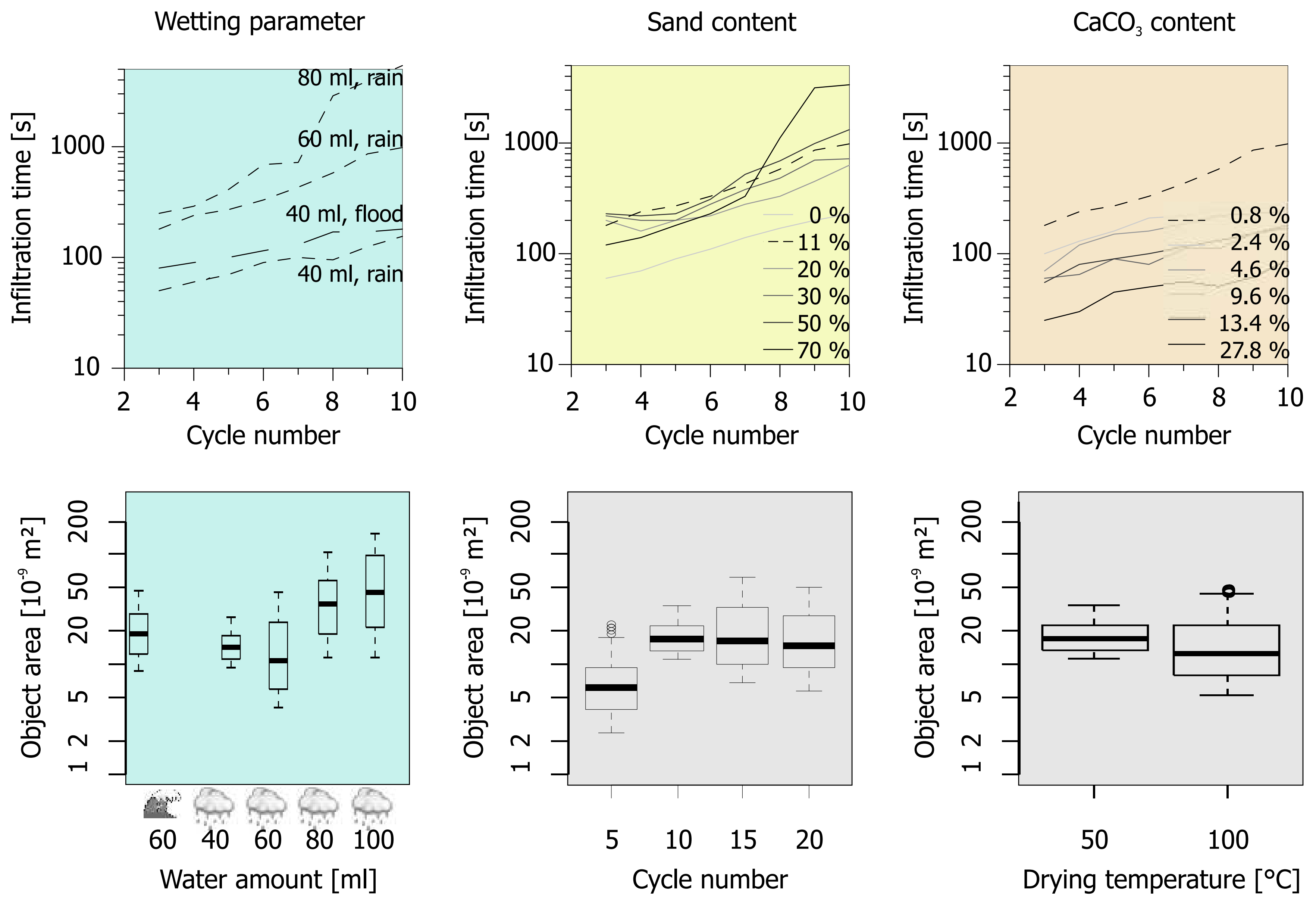




A further, complementary mechanism - just as secondary product...

Infiltration time evolution

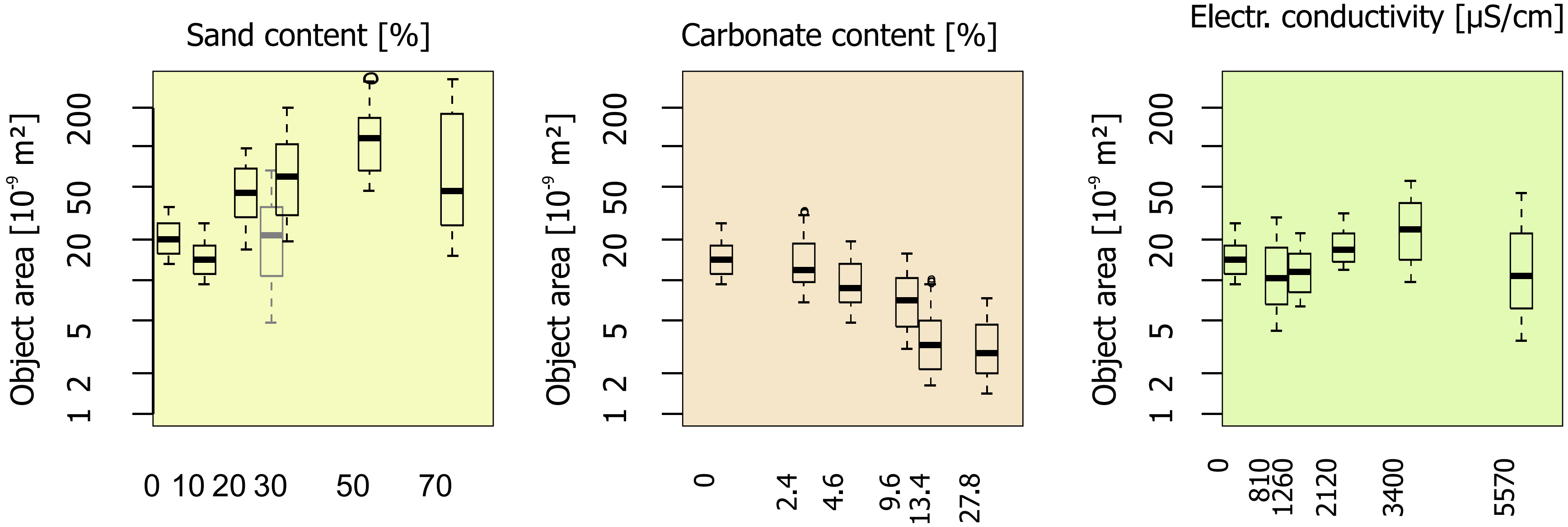
Resulting vesicle parameter "size"



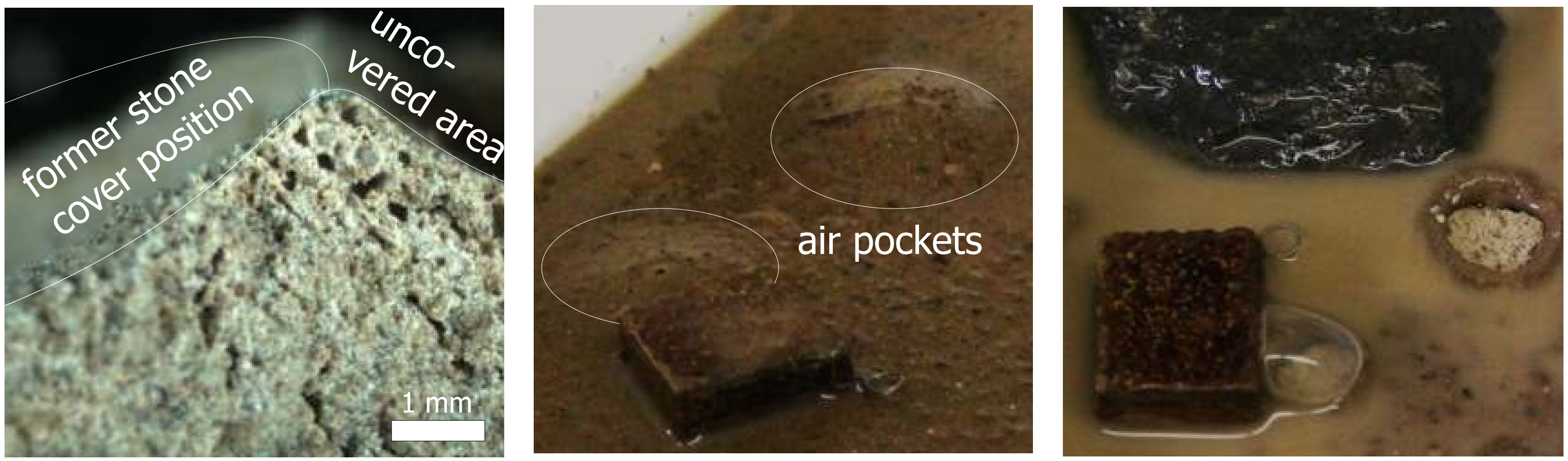
Dietze et al. (2012)

A further, complementary mechanism - just as secondary product...

Resulting vesicle parameter "size"

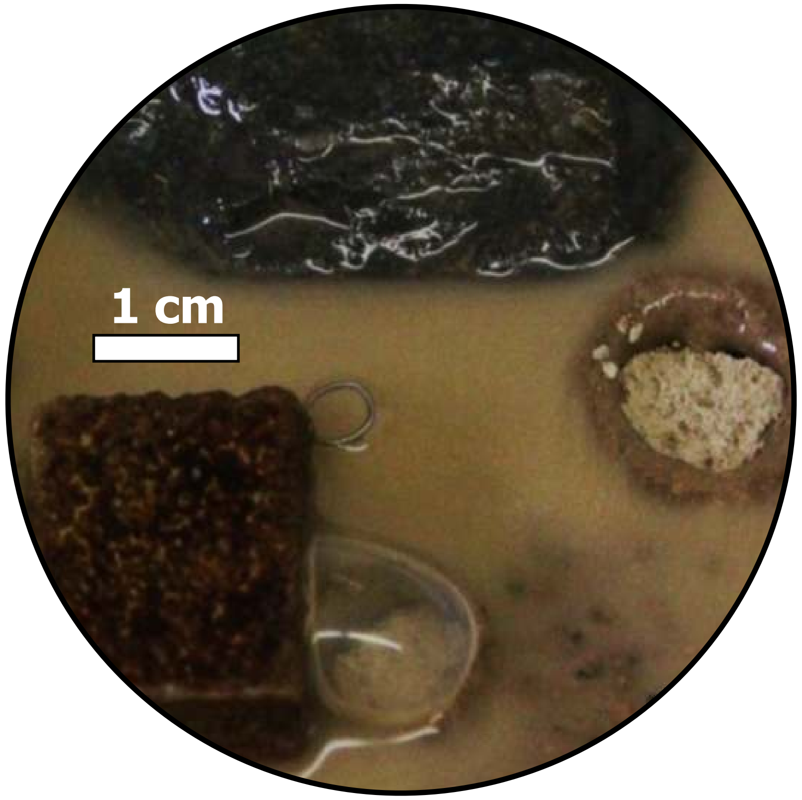


Some further observations

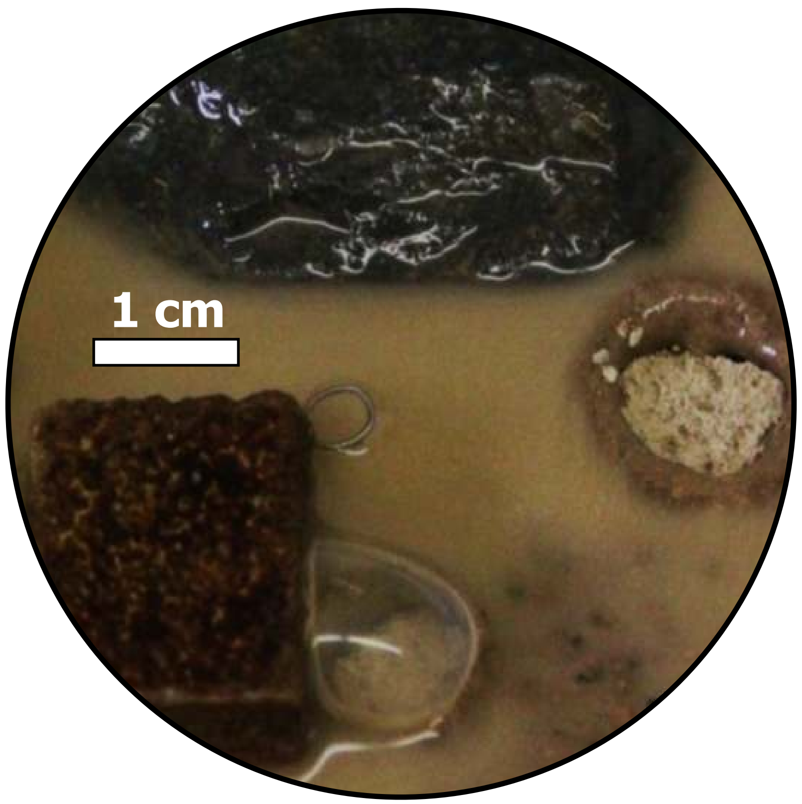


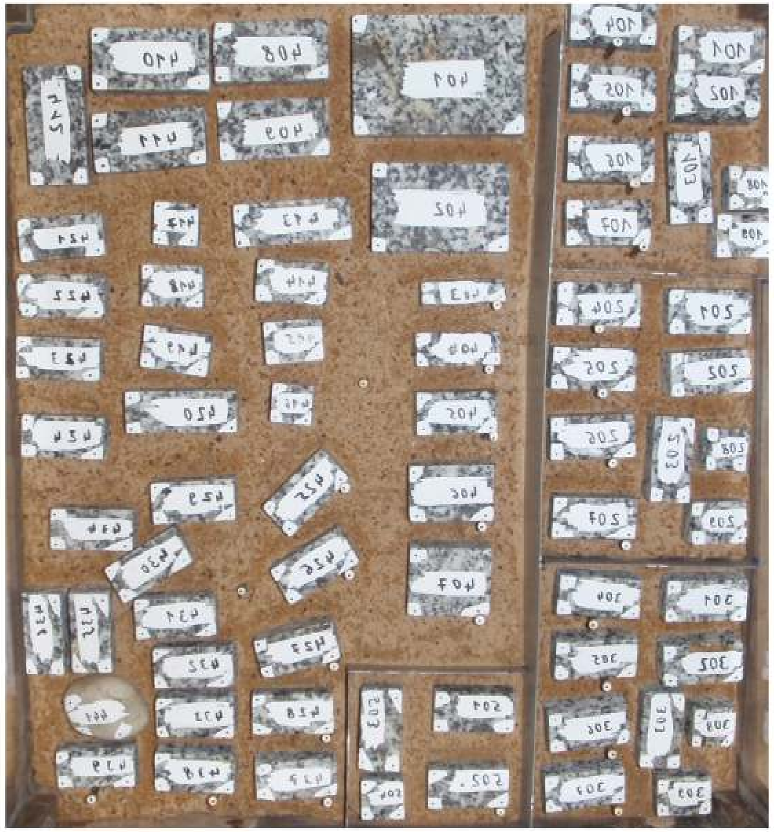
Dietze et al. (2012)

A further, complementary mechanism



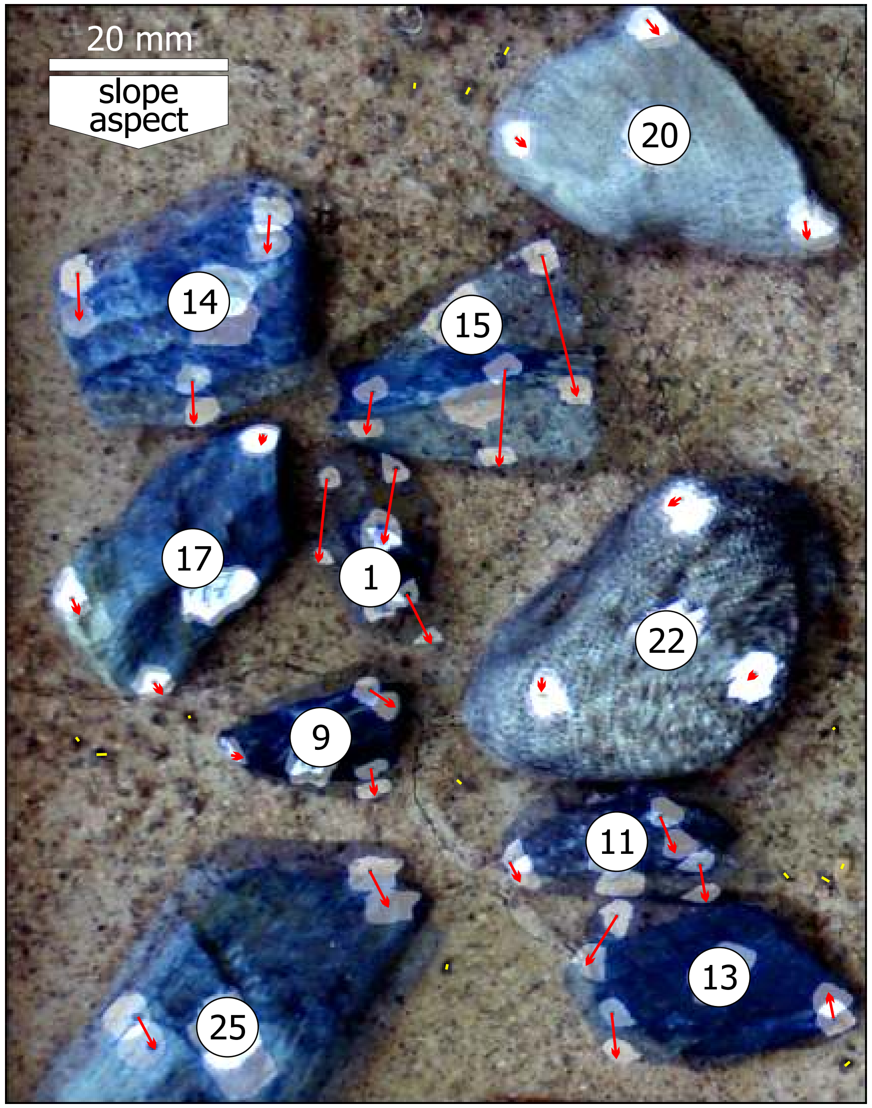
A further, complementary mechanism



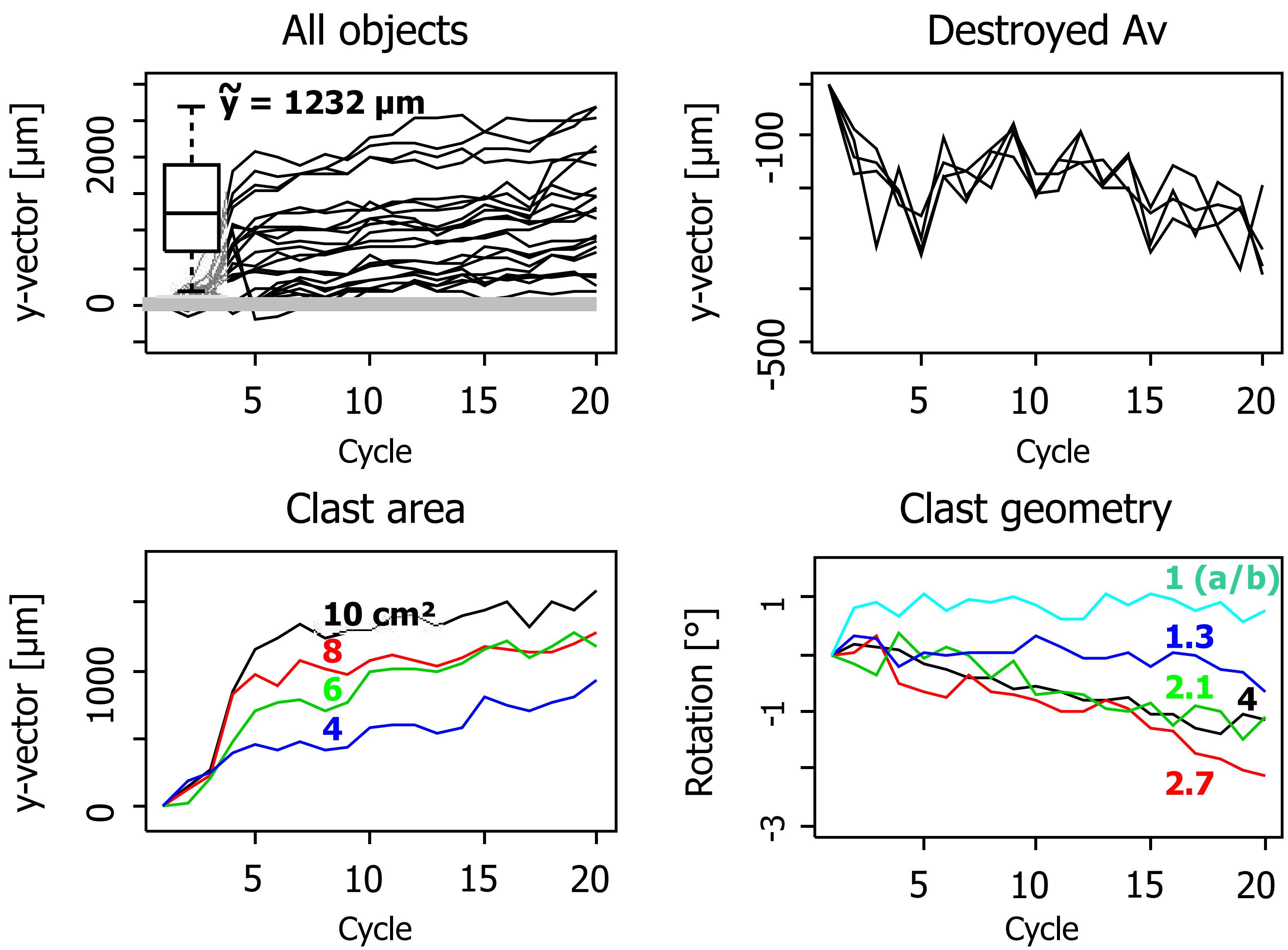


A further, complementary mechanism

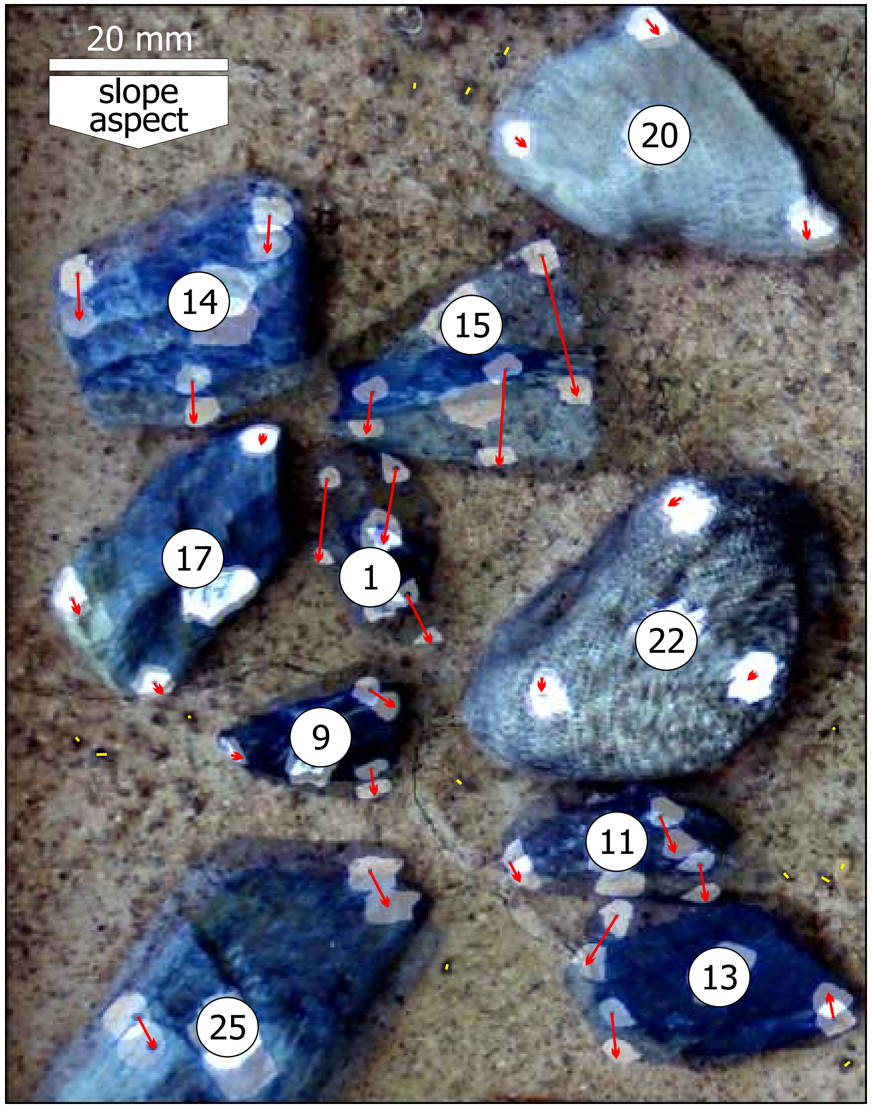
Natural clasts

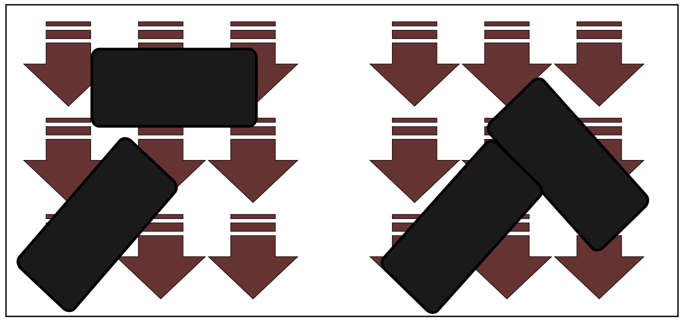


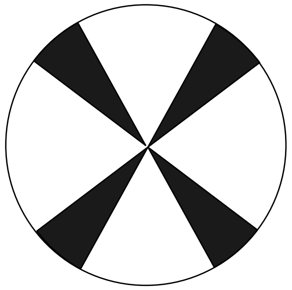
Artificial cuboids



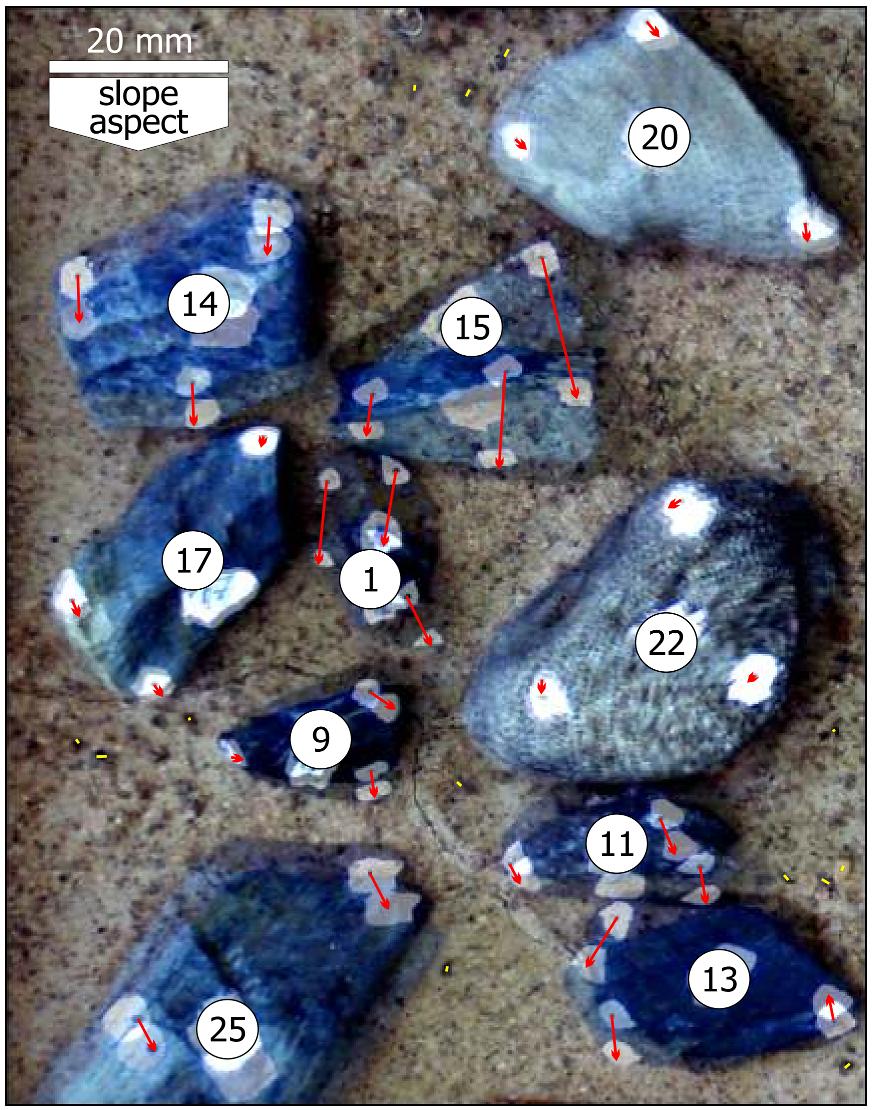
A further, complementary mechanism

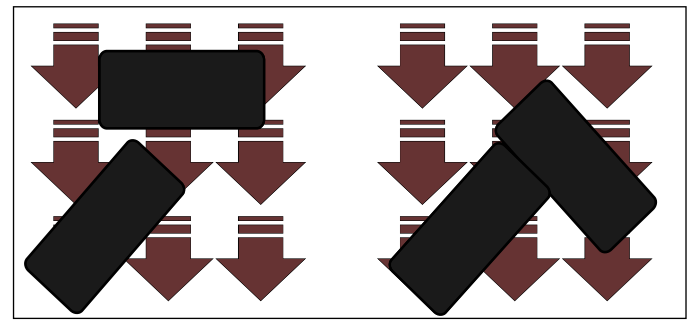


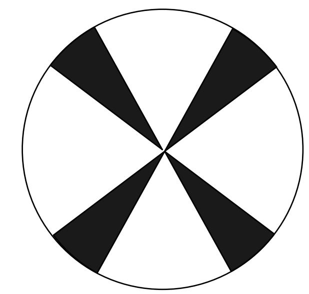




A further, complementary mechanism



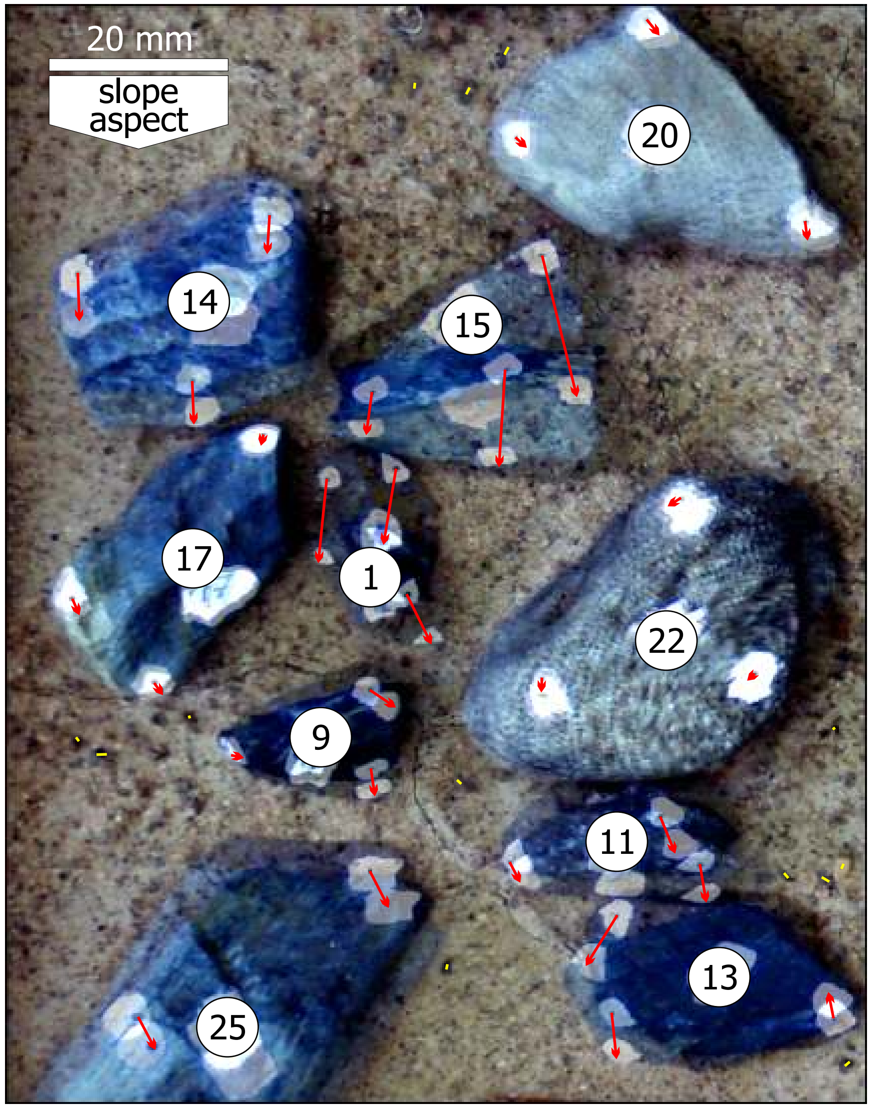


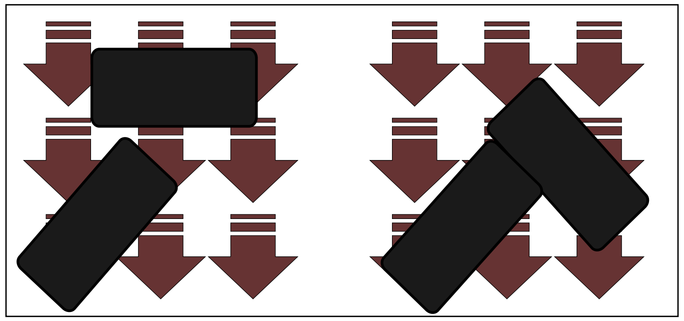


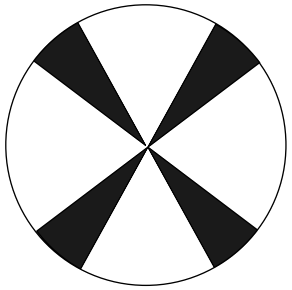
$$\varphi = arctan\left(\frac{b}{a}\right)$$

Allen (1982)

A further, complementary mechanism

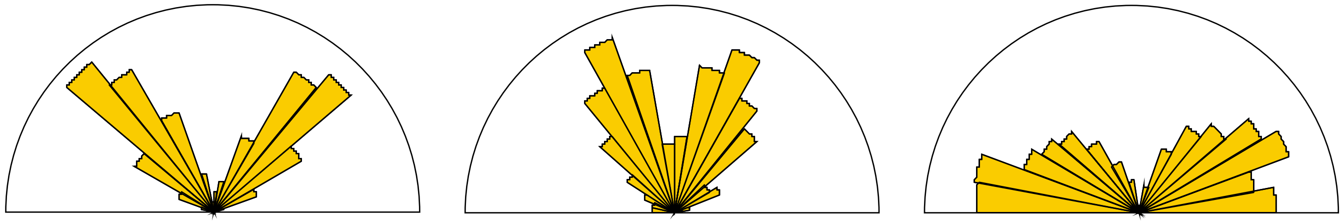






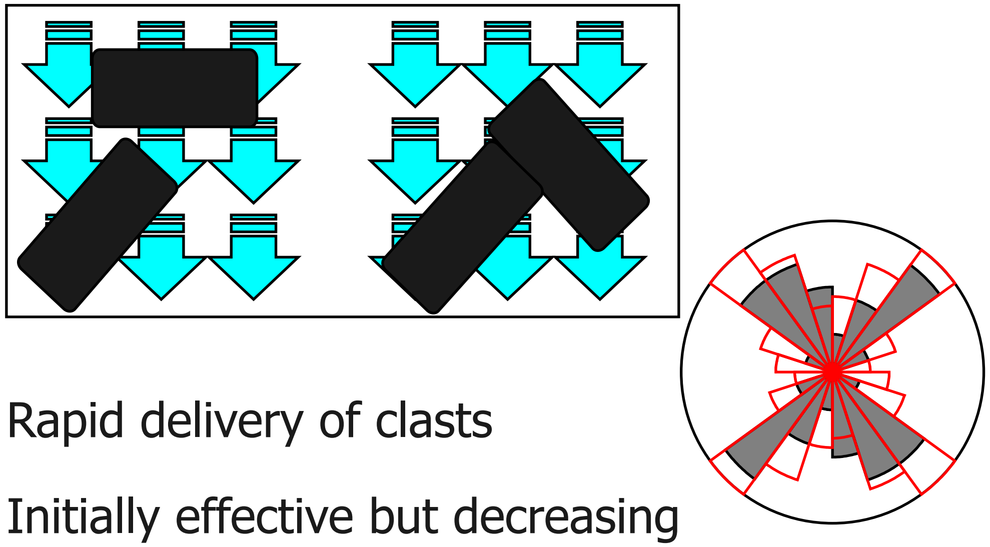
$$\varphi = \mathit{arctan}\left(\frac{b}{a}\right) \cdot \left(\frac{\frac{a}{2} - P}{\frac{a}{2}}\right)$$

?



One short overview of the two lateral processes

Clast drag by surface runoff

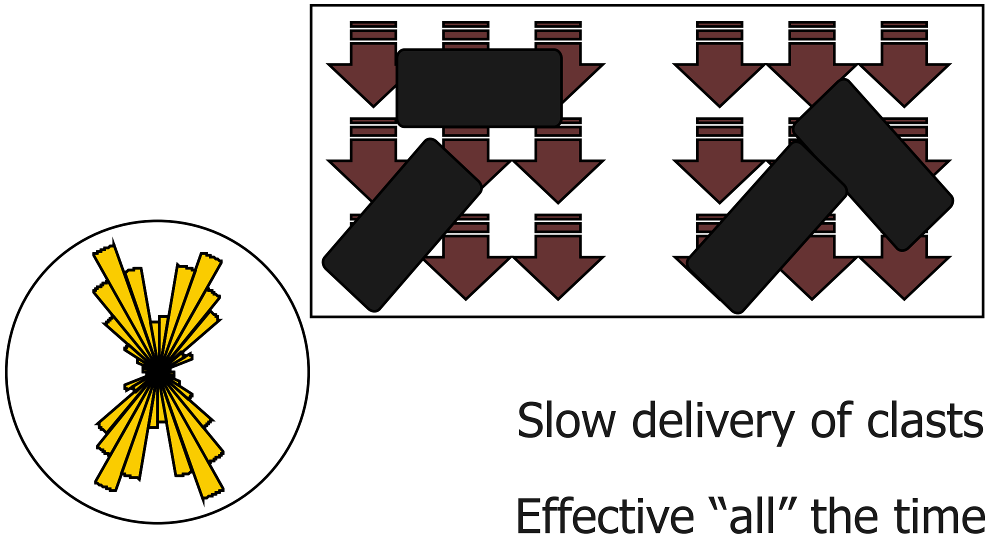


Rapid delivery of clasts

Initially effective but decreasing

topography-related limitations

Clast creep by air escape

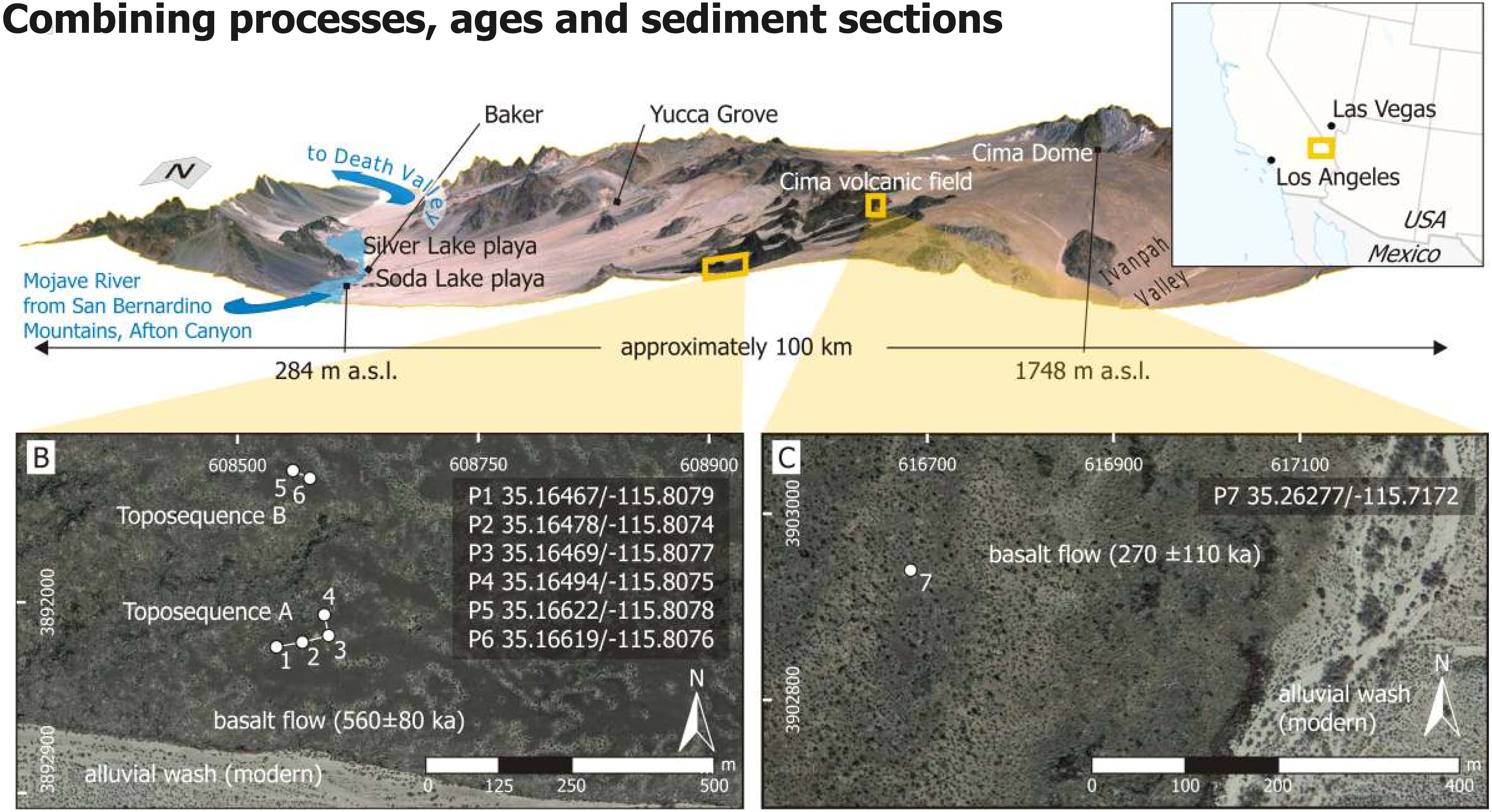


Slow delivery of clasts

Effective "all" the time

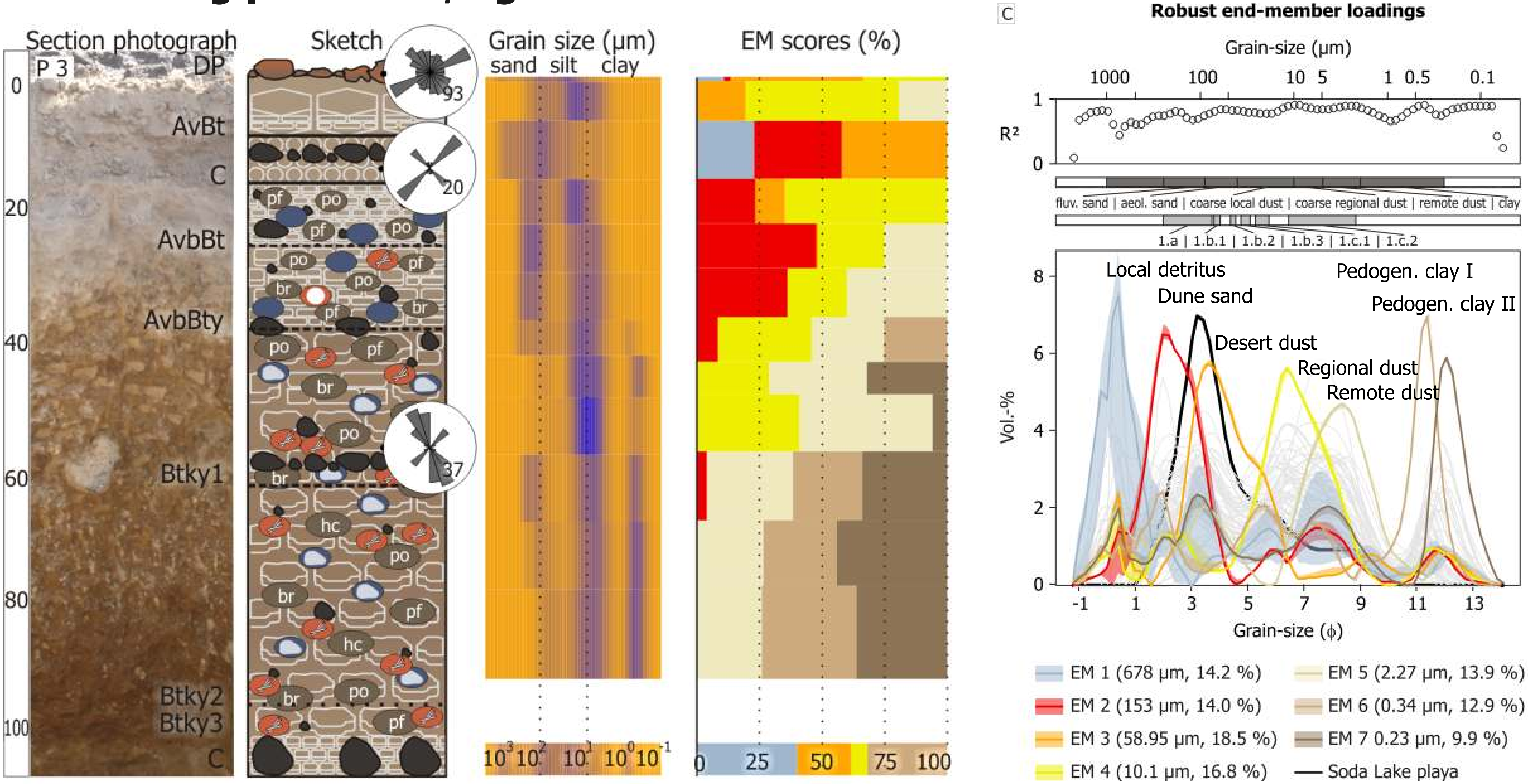
Almost independent of topography

Combining processes, ages and sediment sections



Dietze et al. (in press)

Combining processes, ages and sediment sections



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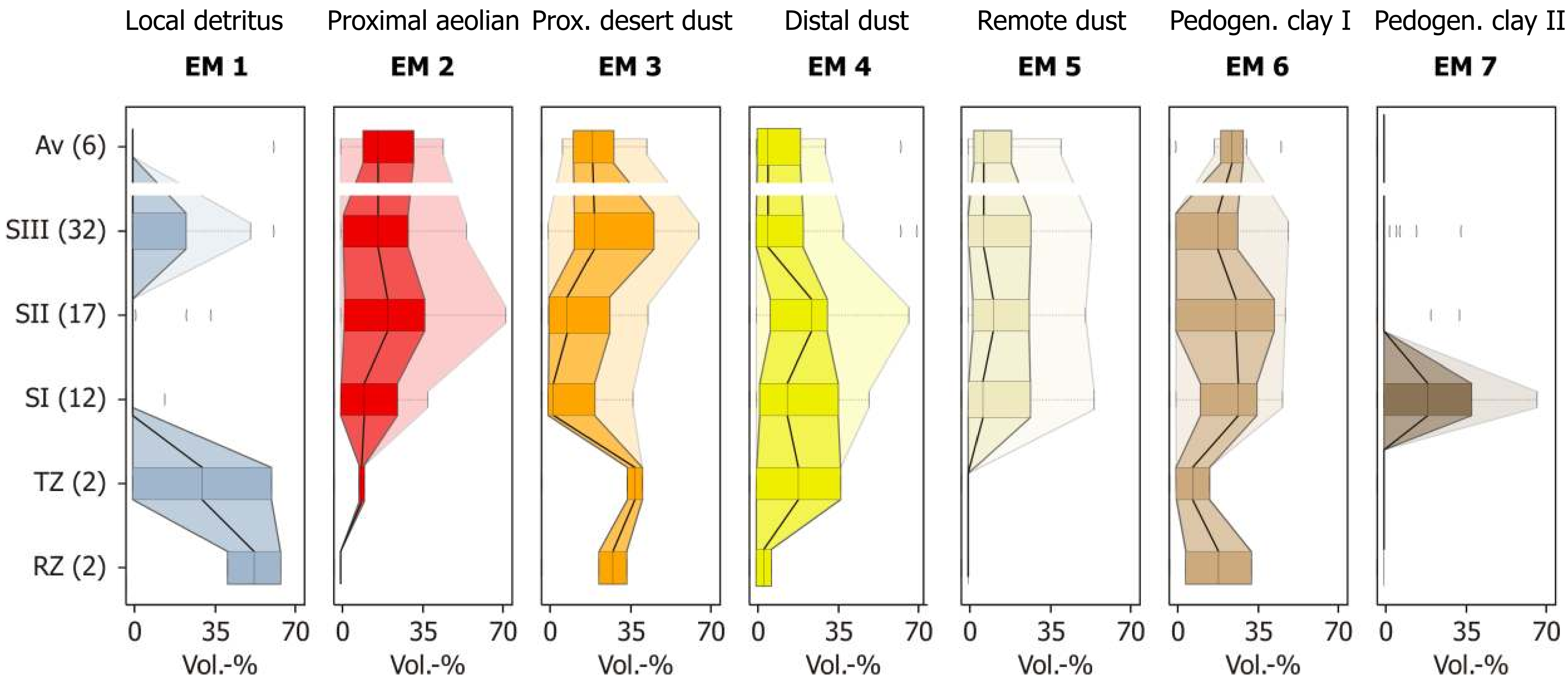

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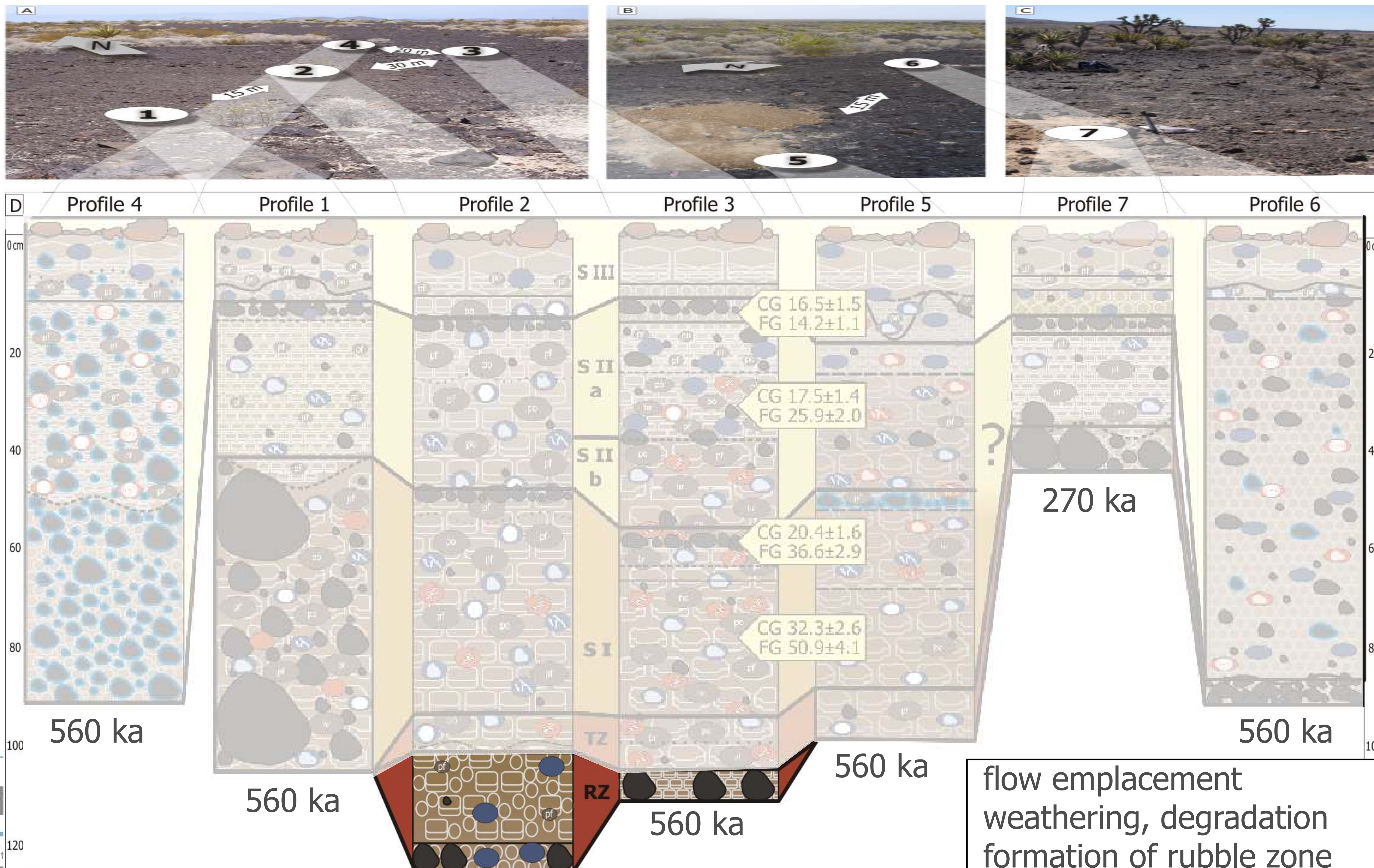
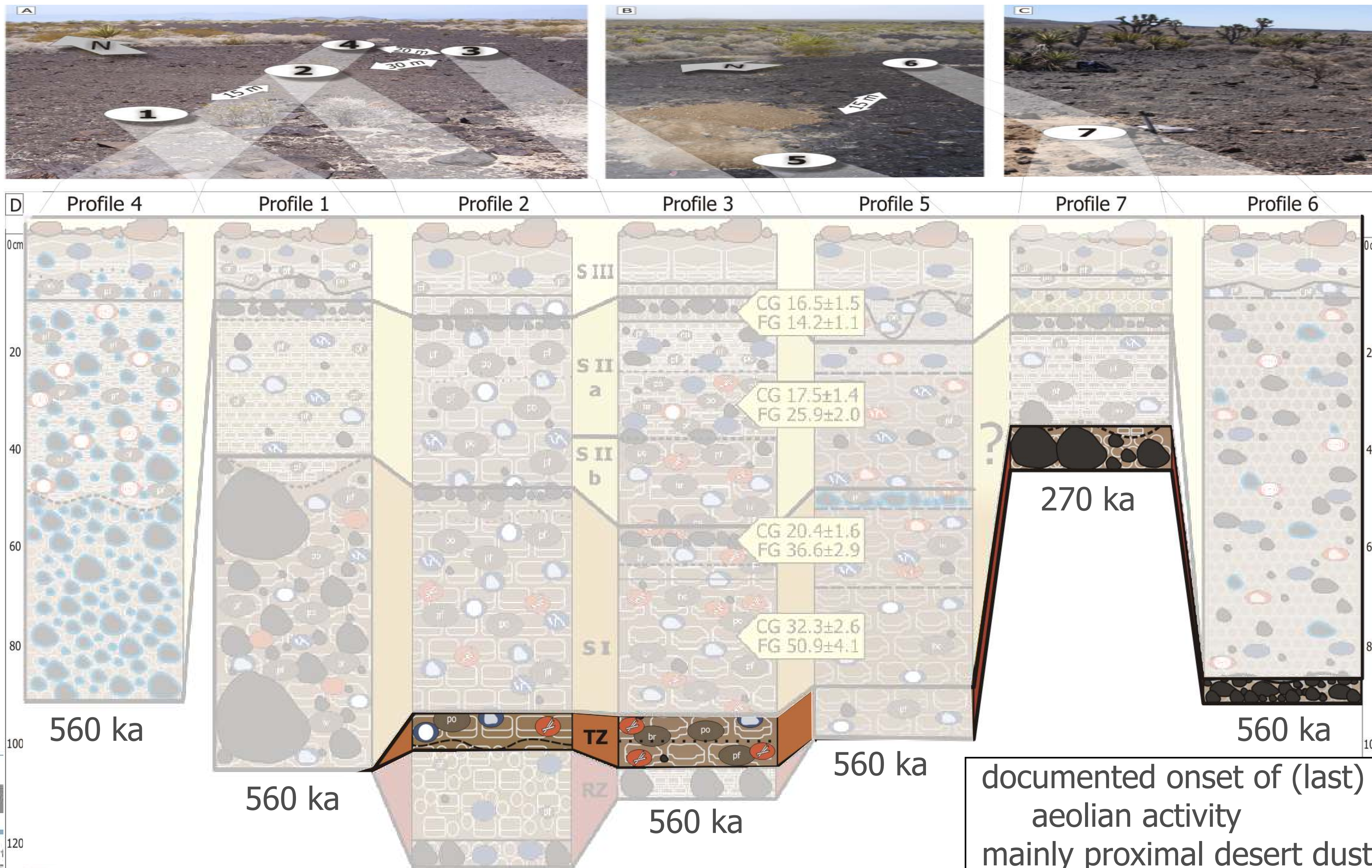


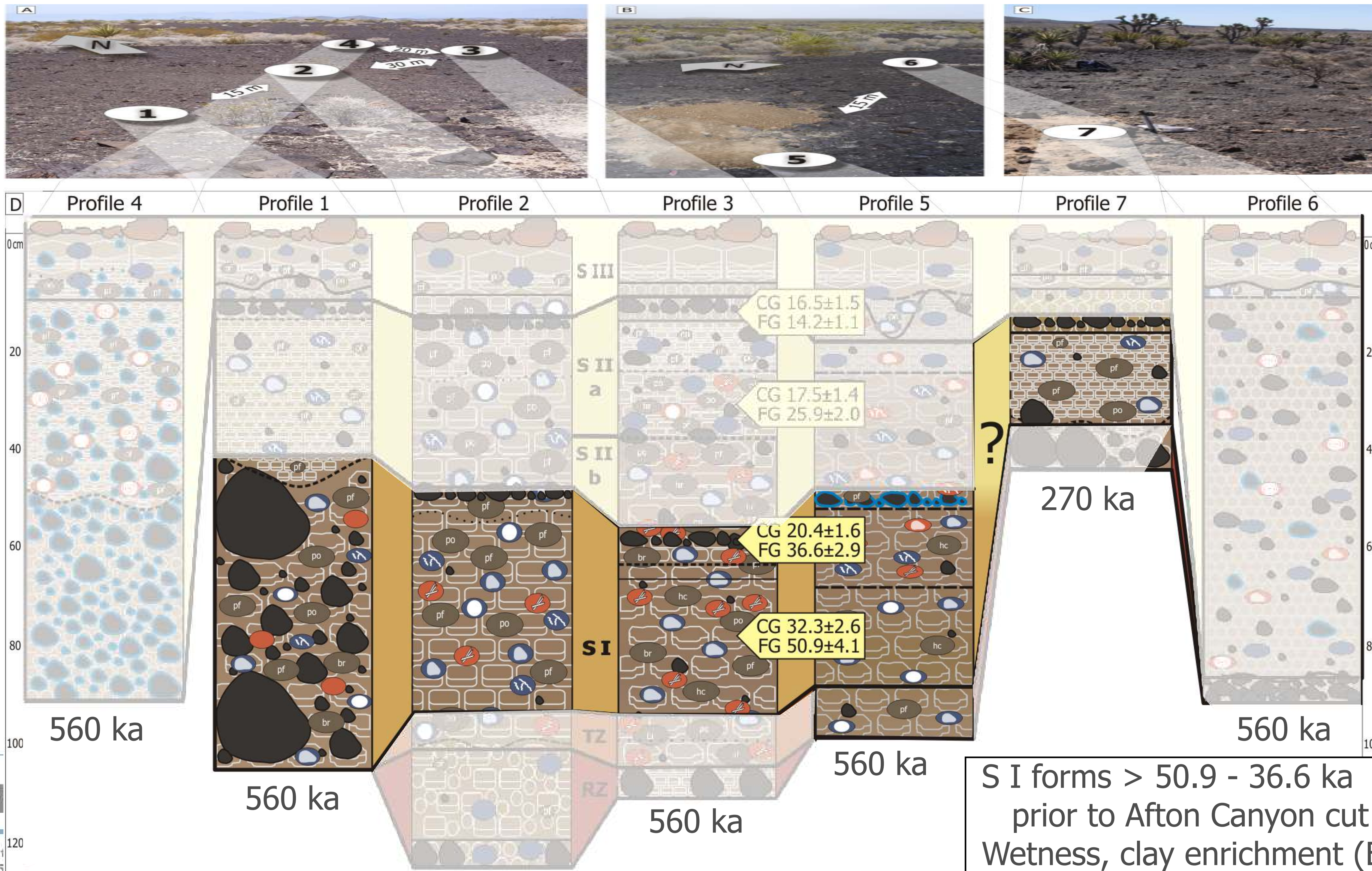
flow emplacement
weathering, degradation
formation of rubble zone

Combining processes, ages and sediment sections



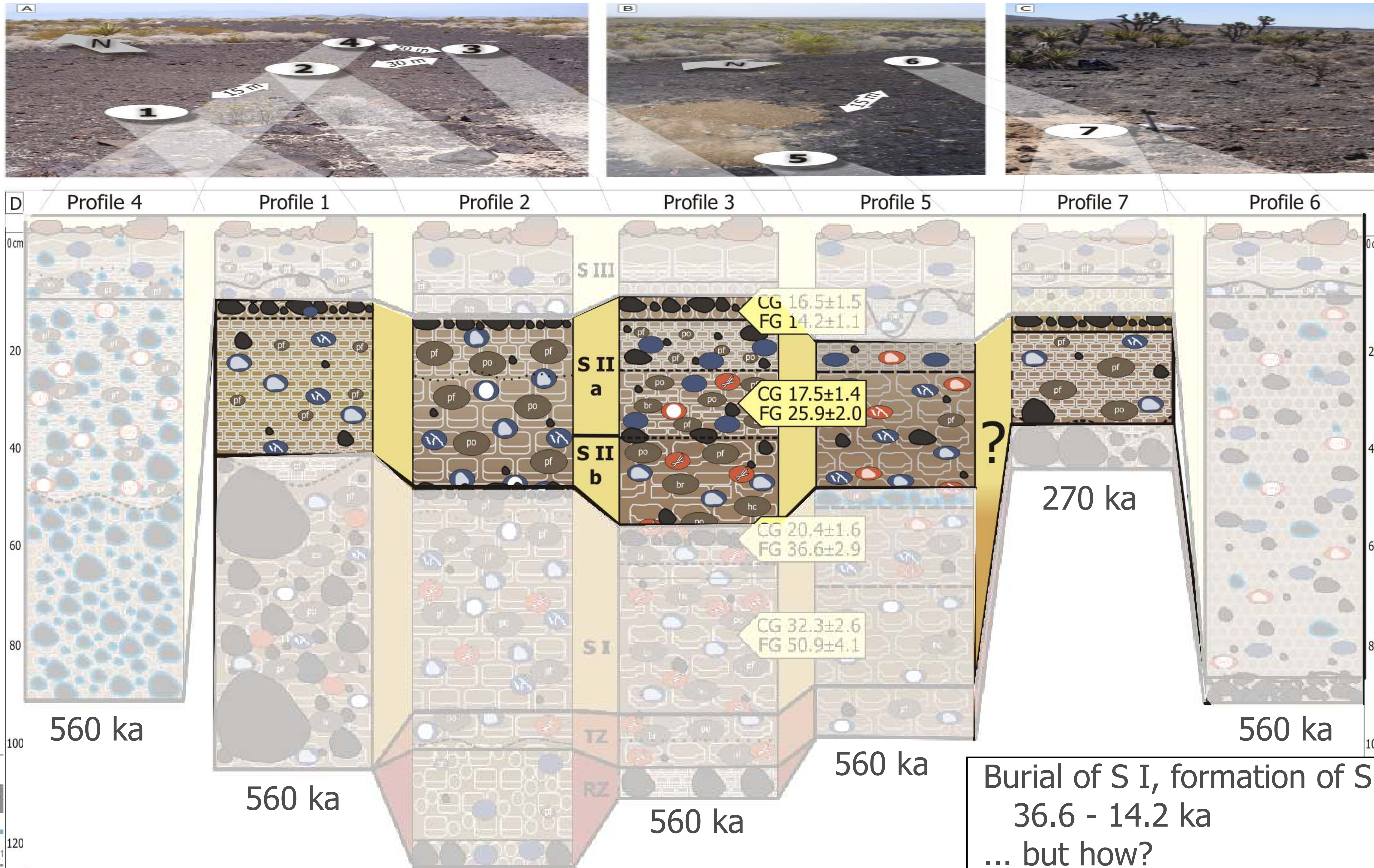
documented onset of (last) aeolian activity
mainly proximal desert dust

Combining processes, ages and sediment sections



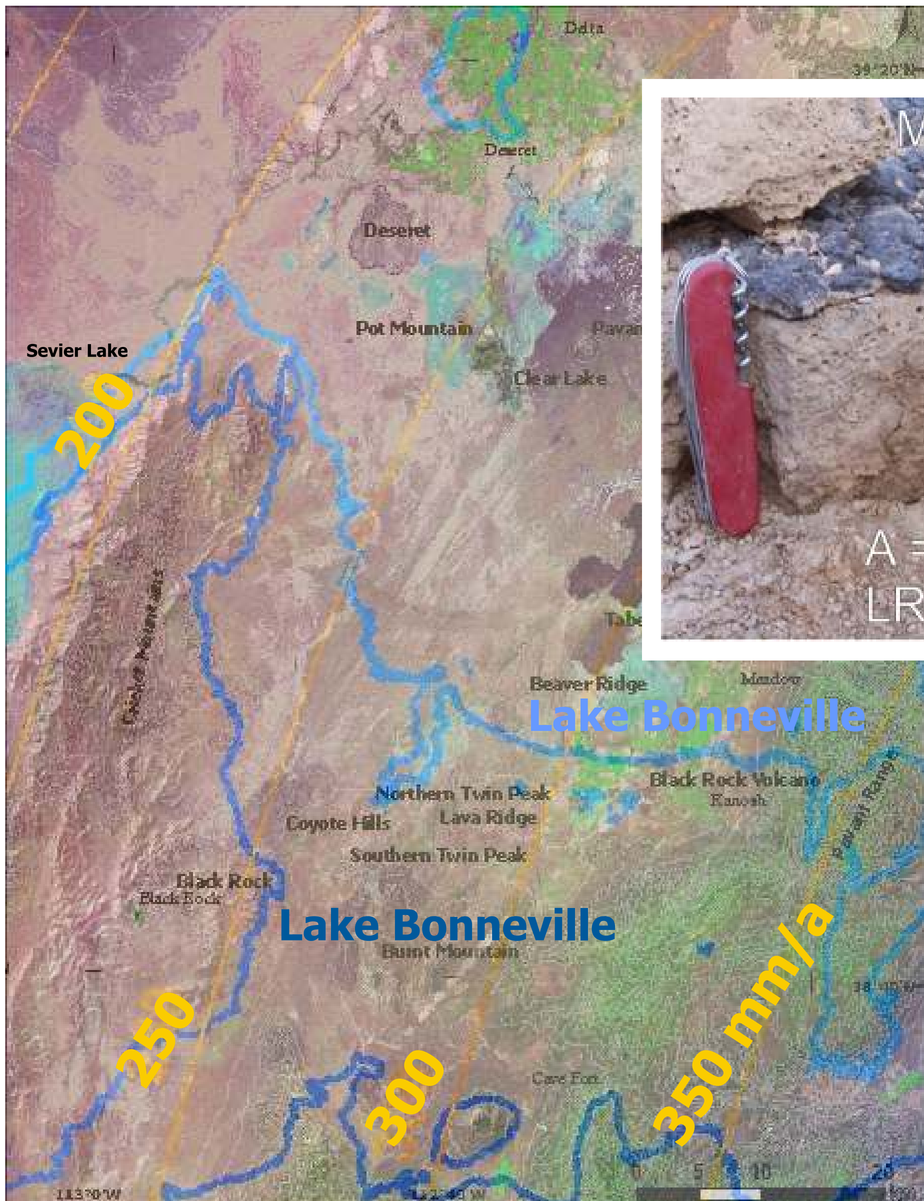
S I forms > 50.9 - 36.6 ka
prior to Afton Canyon cut
Wetness, clay enrichment (EM7)

Combining processes, ages and sediment sections

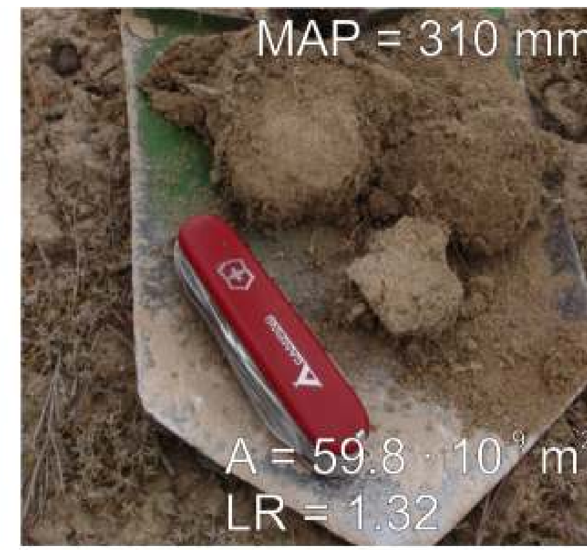


Burial of S I, formation of S II,
36.6 - 14.2 ka
... but how?

Combining processes... From dry to moist

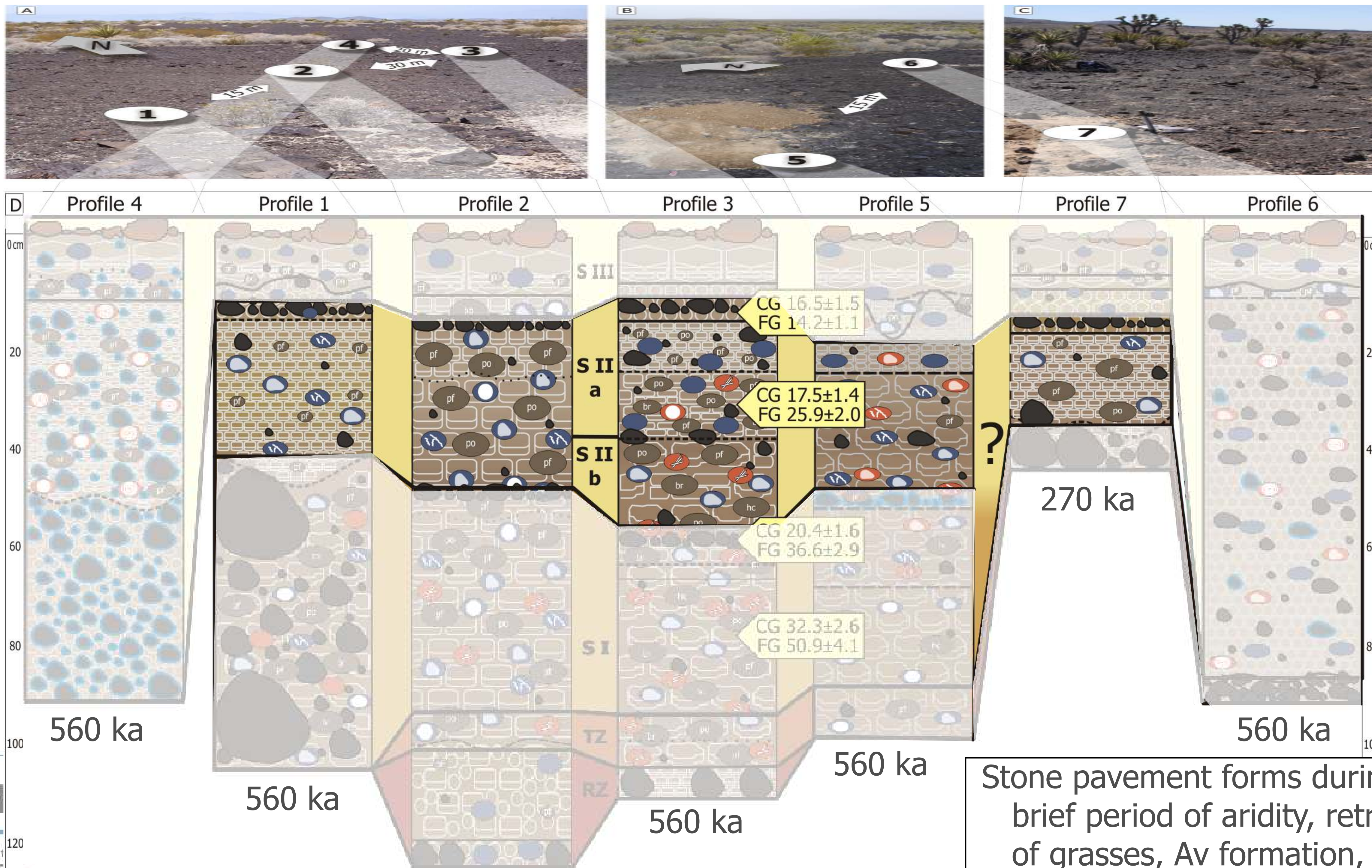


The Black Rock Desert, Utah



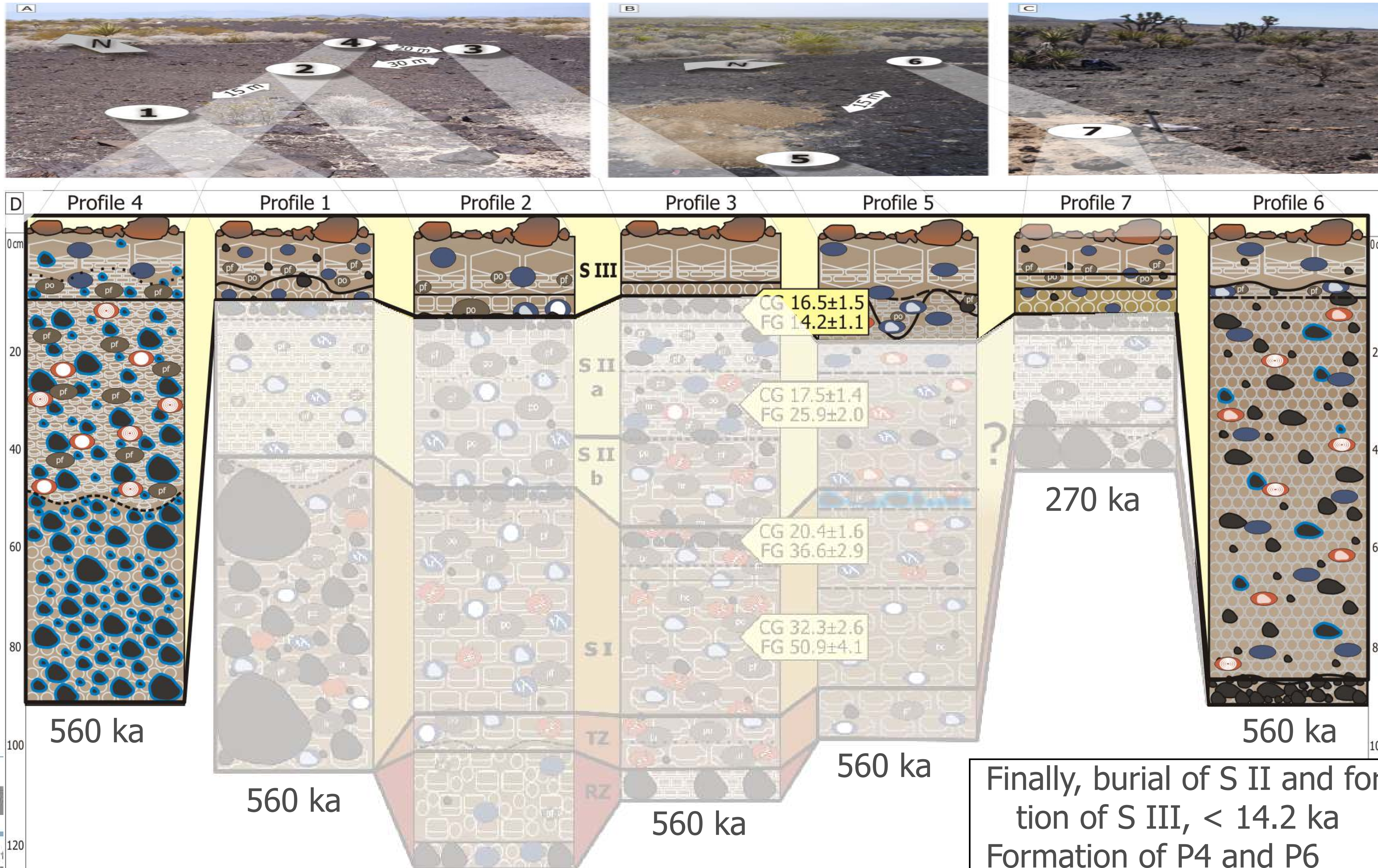
Grasses can migrate and spread rapidly, destroy the Av and lead to pavement burial.

Combining processes... From dry to moist... ...and back to dry again



Stone pavement forms during brief period of aridity, retreat of grasses, Av formation, ...

Combining processes, ages and sediment sections



Finally, burial of S II and formation of S III, < 14.2 ka
Formation of P4 and P6

Stone pavements result from dust accretion AND lateral processes (drag and creep).

Stone pavements form dynamic surfaces, being both stable and unstable.

Stone pavements support emergence of intrinsic patterns (e.g. clast orientation)

Vesicular horizons form by advancing wetting fronts

They can form quickly (< 10 cycles) and in a wide variety of sediment properties

They are destroyed/prevented from formation by grassy vegetation

Accretionary systems can be regarded as complementary environmental archives

They record slope processes, aeolian history, soil formation and pavement formation