Sediment transport dynamics & grain size trends recorded by Oligo-Miocene megafans in the Swiss Molasse basin

Philippos Garefalakis[1]

Alexander C. Whittaker[2], Ariel do Prado[1], David Mair[1] and Fritz Schlunegger[1]

[1] University of Bern, Institute of Geological Sciences, Bern, Switzerland;

[2] Imperial College, Department of Earth Science and Engineering, London, United Kingdom

Abstract:

UNIVERSITÄT BERN

Imperial College London

EGU General Assembly

This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

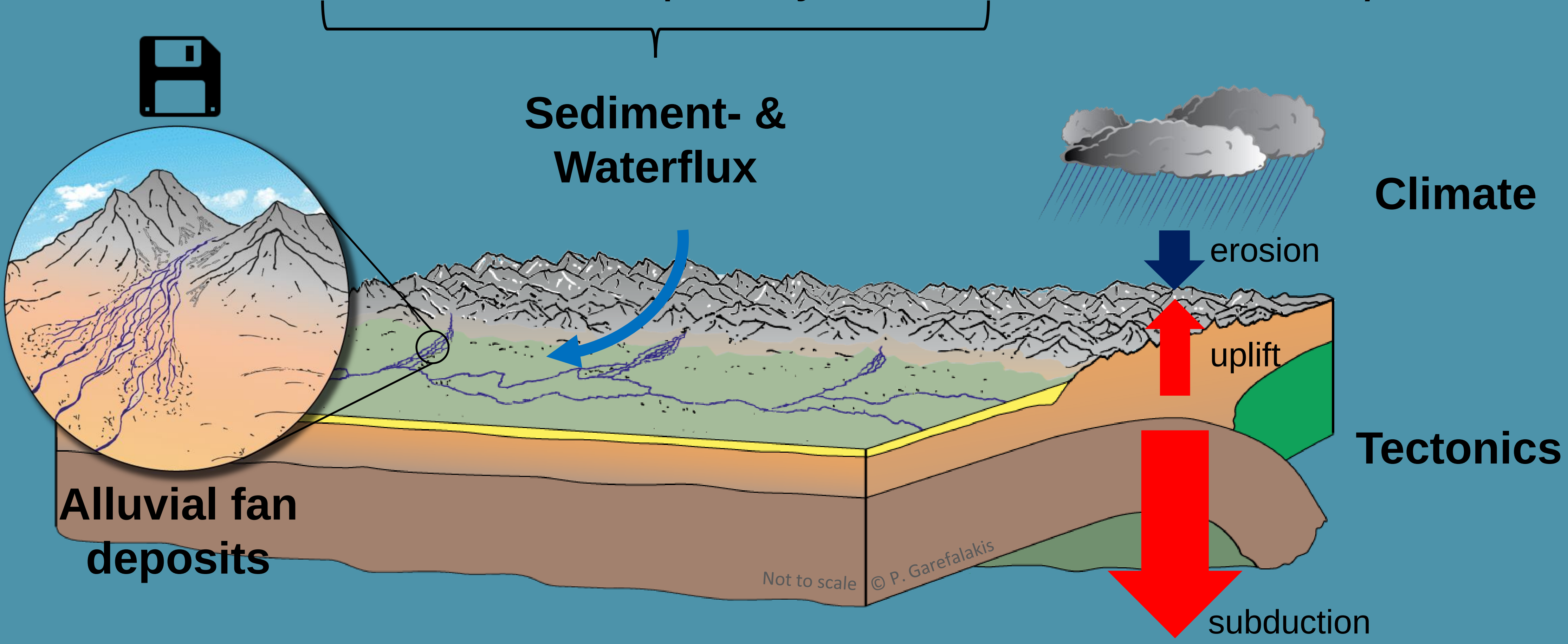
philippos.garefalakis@geo.unibe.ch

27th May 2022 - GM10.1/SSP3.15

Motivation: Foreland basin → *key to the adjacent mountain belt*

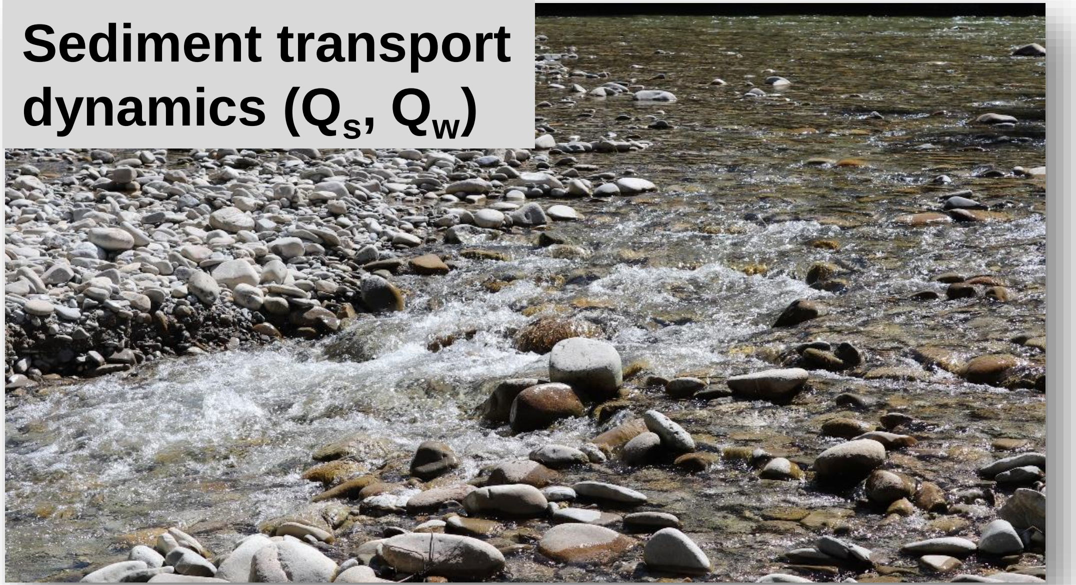
Forleand basin deposits controlled by *climate* and *tectonics*.

Information on sediment transport dynamics *stored in fan deposits*.



Focus: Extraction of sediment fluxes from conglomerates

i. Estimates of actual fan sediment fluxes Q_s by applying a self-similar model
(e.g. Fedele & Paola, 2007; D'Arcy et al., 2017)



We can extract sediment fluxes (Qs) from the stratigraphic record by applying a self-similar grain size fining model (e.g. Fedele & Paola, 2007; D'Arcy et al., 2017).

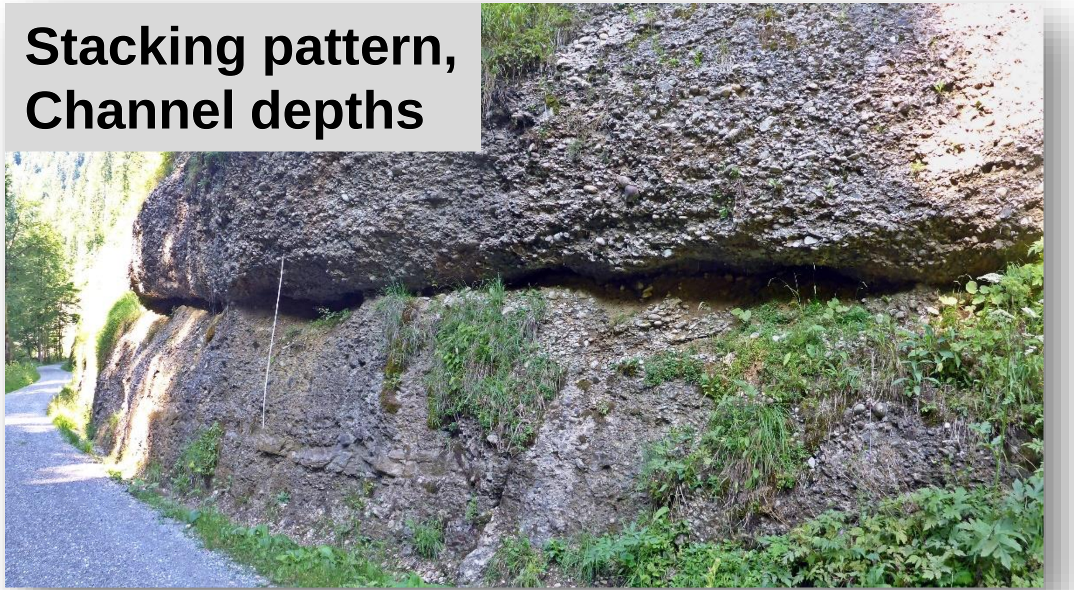
The model is based on:

- sediment accumulation rates / subsidence
- grain size (input grain size, fining rate)
- grain size distribution follows self-similarity

philippos.garefalakis@geo.unibe.ch

Focus: Extraction of sediment fluxes from conglomerates

i. Estimates of actual fan sediment fluxes Q_s by applying a self-similar model
(e.g. Fedele & Paola, 2007; D'Arcy et al., 2017)



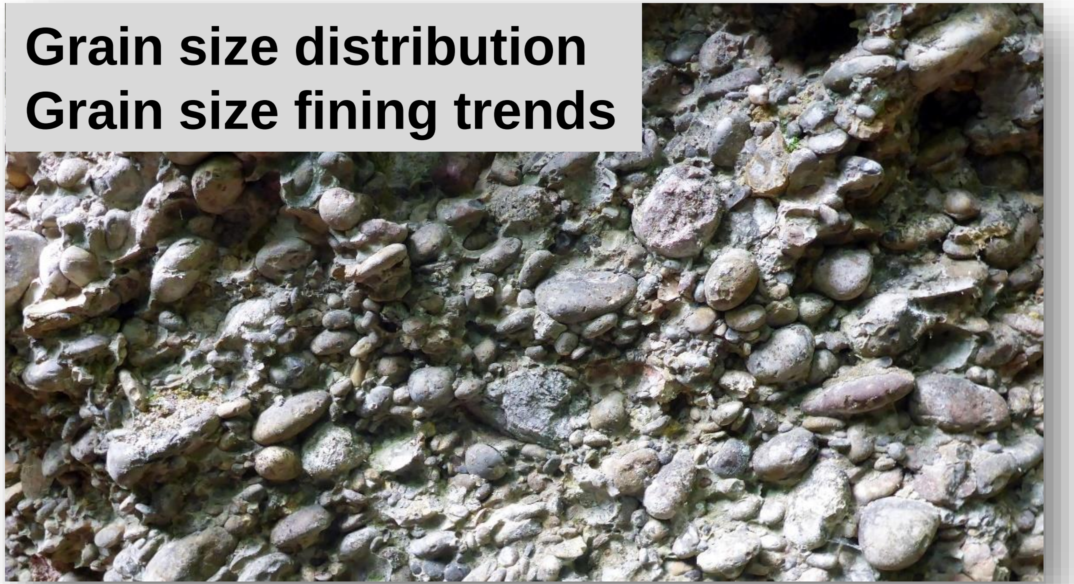
First we need to have information on the fan (or channel) morphometry by analysing the stacking pattern (architecture of the fan) and measuring channel depths preserved during bankfull flow-depth conditions.

This helps to estimate fan surface slopes, in combination with measurements on grain size…

philippos.garefalakis@geo.unibe.ch

Focus: Extraction of sediment fluxes from conglomerates

i. Estimates of actual fan sediment fluxes Q_s by applying a self-similar model
(e.g. Fedele & Paola, 2007; D'Arcy et al., 2017)



…which we measured on digital photographs using the Wolman (1954) approach.

For each outcrop we measure 100 grains and calculate the percentiles of interest (e.g. D_{50} for the 50th percentile, or D_{84} for the 84th percentile).

In combination with the channel depth and hydrological formulas based on initial sediment transport, we can estimate the fan surface slopes.

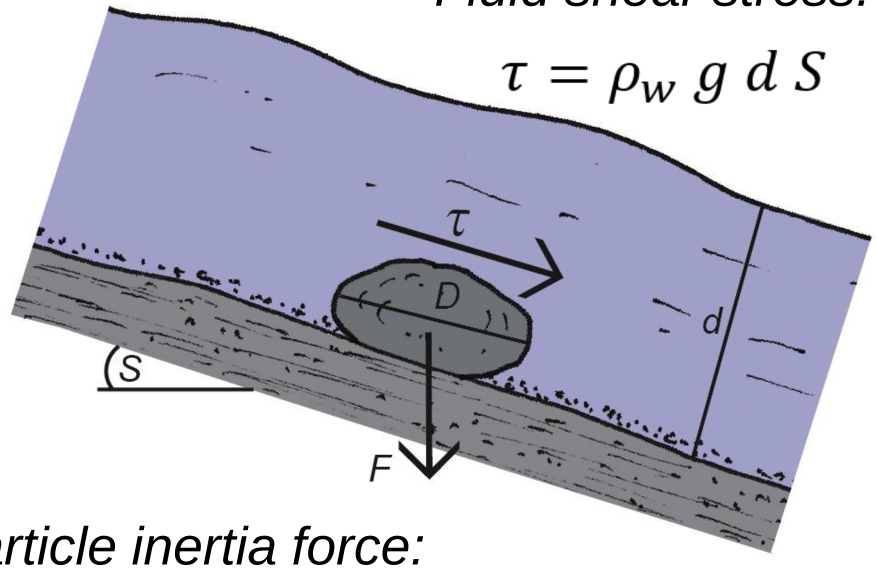
Furthermore, each section of interest discloses proximal-distal geometries from the Apex towards distal positions, which is needed to calculate the grain size fining trends (decrease of grain size along distance).

Focus: Extraction of sediment fluxes from conglomerates

ii. Estimates of fan capacities (or bedload gravel-fluxes Q_b) by paleo-hydrological calculations to get fan intermittencies (e.g. Meyer-Peter & Müller, 1948; Wong & Parker, 2006)

Fluid shear stress:

$$\tau = \rho_w \, g \, d \, S$$



Particle inertia force:

$$F = (\rho_s - \rho_w) \, g \, D$$

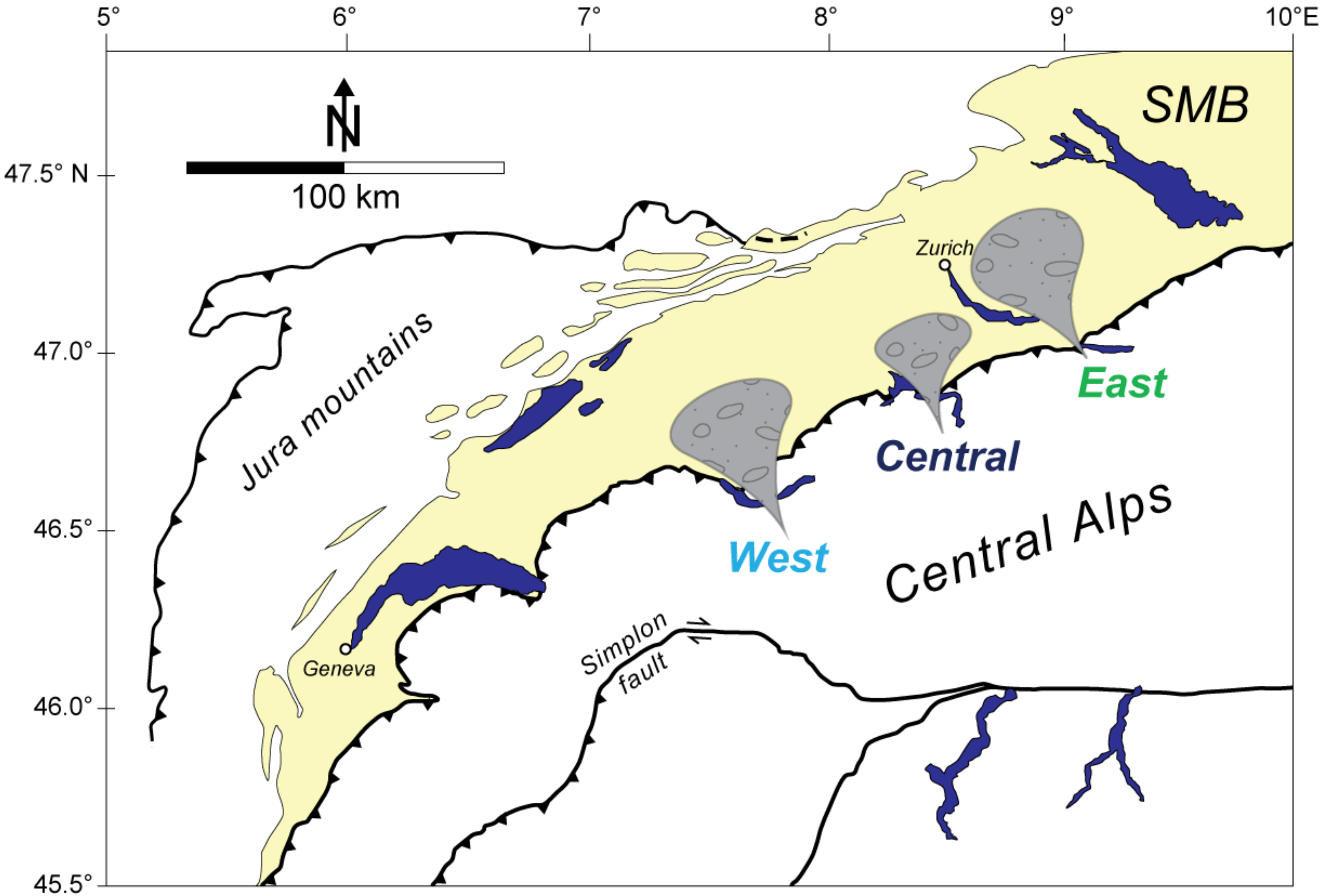
Mod. after Garefalakis & Schlunegger, 2018

We can calculate the bedload transport rate in dry weight per unit channel width q_b (or alternatively the bedload gravel-flux or the sediment flux capacities) of the fans by combining:

- The dimensionless bedload transport capacity after Meyer-Peter & Müller (1948) and
- The dimensionless bedload transport rate after Einstein, H.A. (1950)
- We used the recalibrated formula based on the reanalysis of the original Meyer-Peter & Müller (1948) work by Wong & Parker (2006)

philippos.garefalakis@geo.unibe.ch

Study area: Swiss Molasse Basin (SMB)



Depositional centres (megafans) active during last c. 35 – 10 Ma

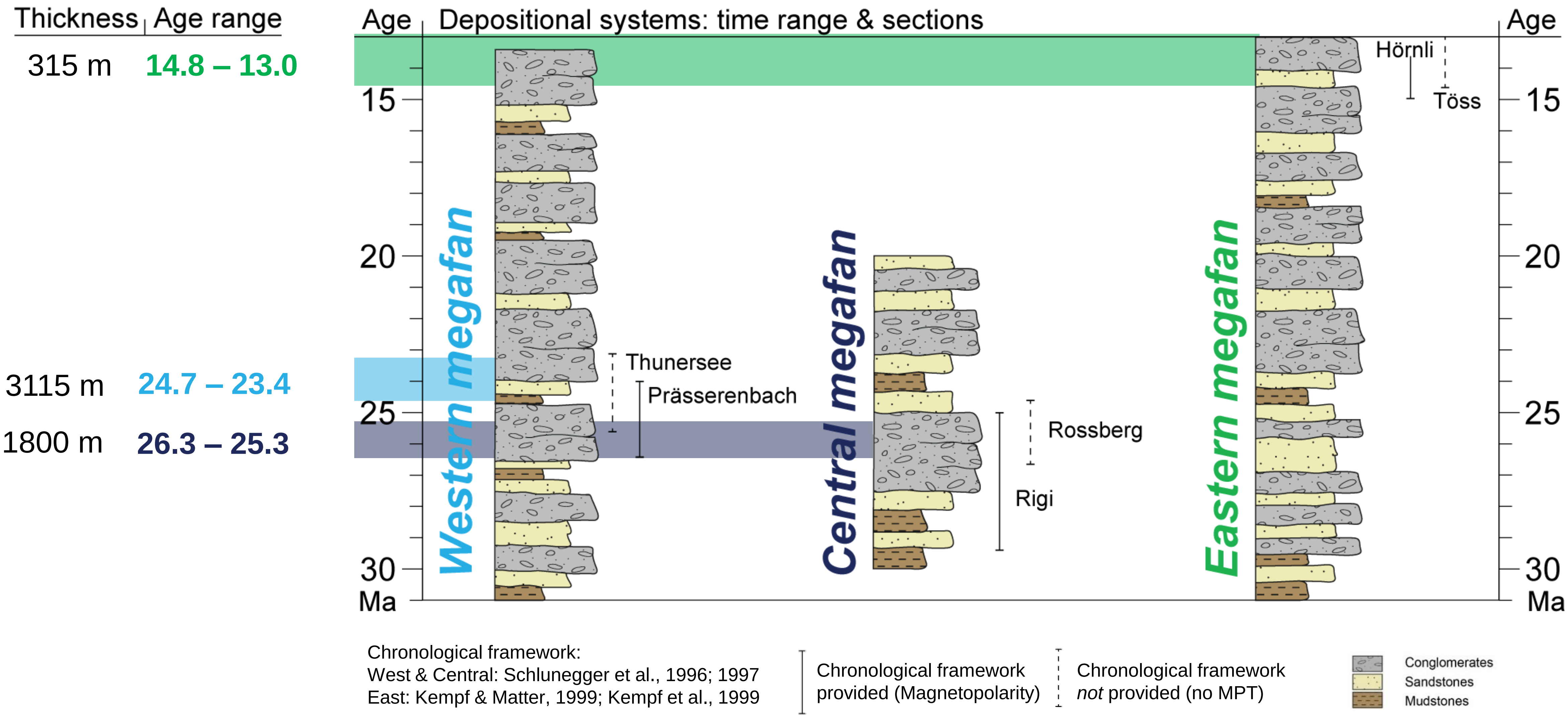
Recorders of the erosional history of the Alps and analysed for:

- temporal & spatial relationships to Alpine formation
- paleogeography, source areas and clast composition

Here, we focus on three individual sections with proximal-distal geometries and extract grain size fining trends and sediment fluxes at the section scale.

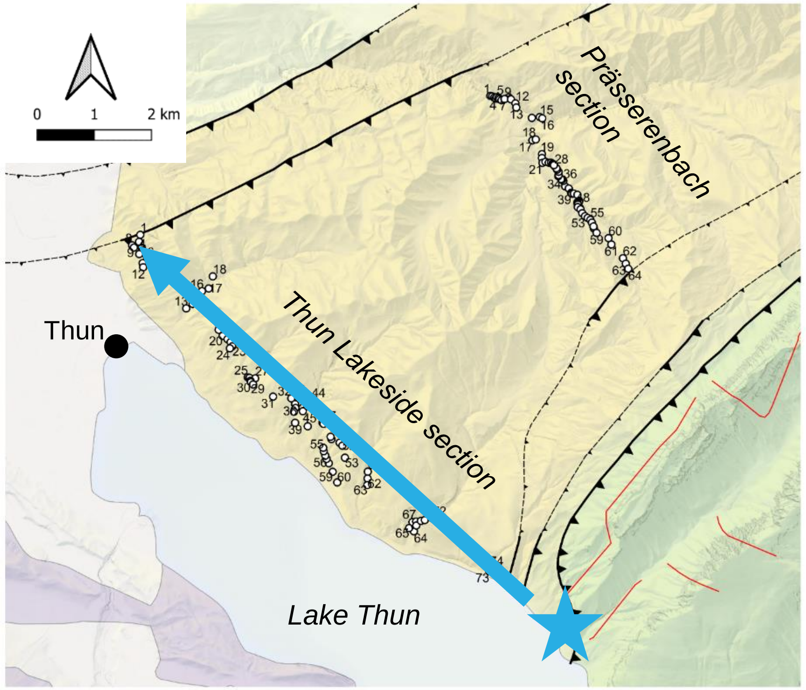
philippos.garefalakis@geo.unibe.ch

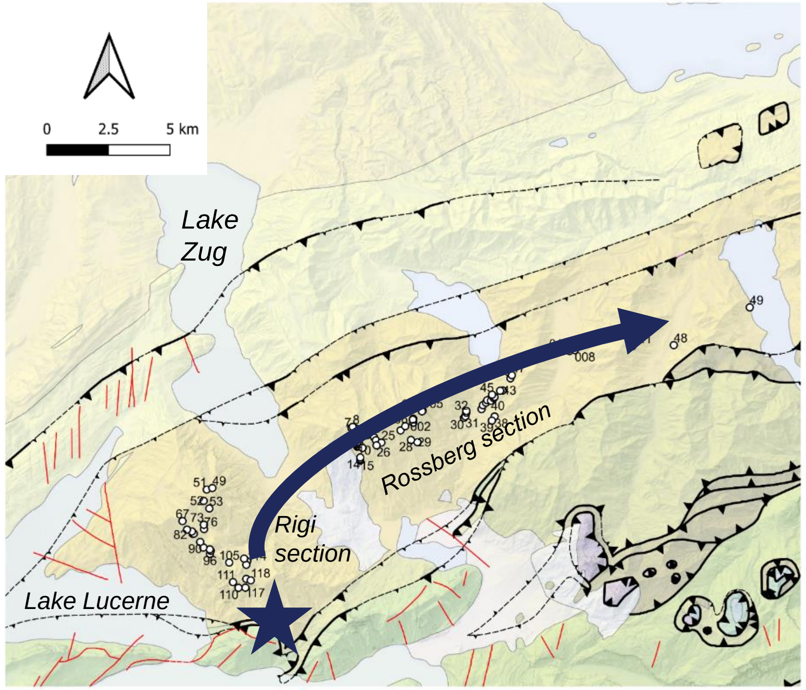
Study area: Proximal-distal sections and temporal framework

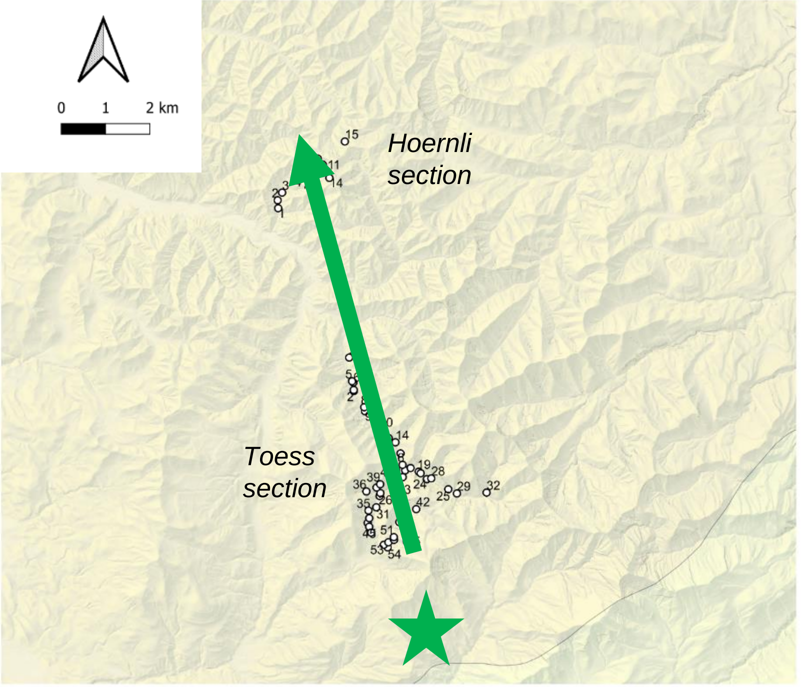


philippos.garefalakis@geo.unibe.ch

Study area: Proximal-distal sections in the Swiss Molasse Basin







West – c. 12 km

Central – c. 30 km

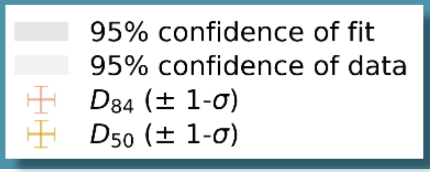
East – c. 12 km

Discharge direction based on paleo-flow measurements

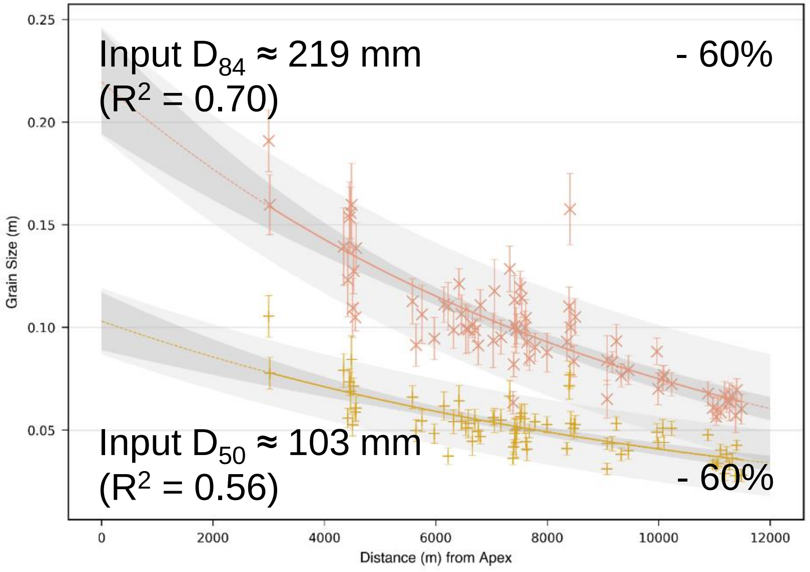
- preserved channel geometries
- sets of imbricated clasts, gutter casts or cross-beds
- identification of paleo-apex from stacking pattern and clast morphometry

Flat lying Molasse
Subalpine Molasse
Penninic nappes
Helvetic nappes
Allochthonous nappes
Quaternary deposits

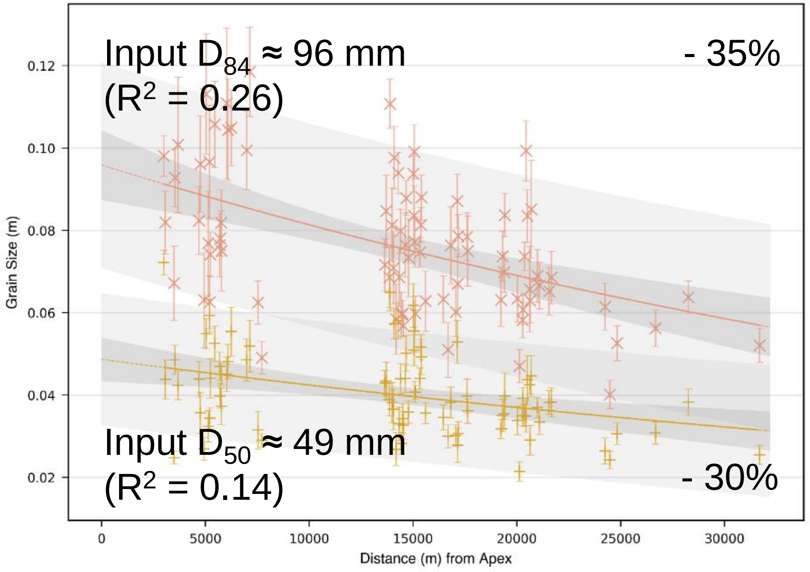
Results: Grain size trends along distance & characteristics



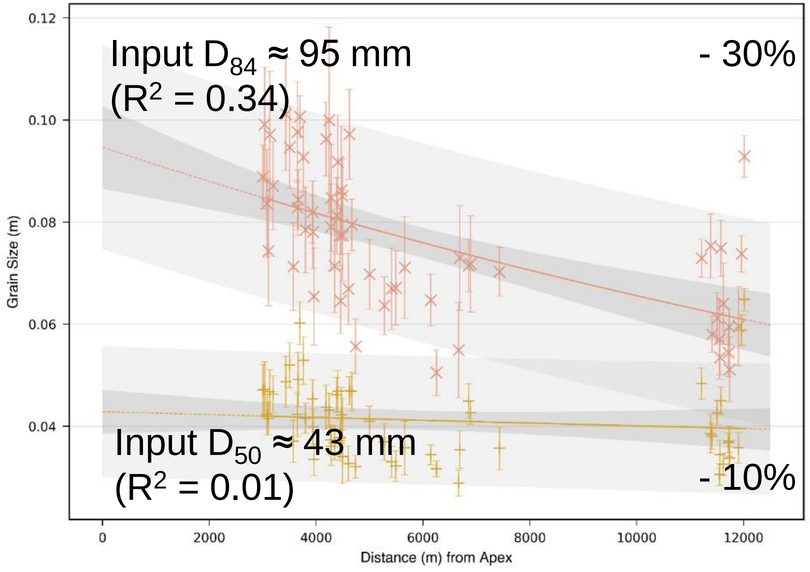
West (c. 12 km)



Central (c. 30 km)



East (c. 12 km)



$D_{84\ avg.}$	98 mm	76 mm	76 mm
$D_{50\ avg.}$	51 mm	40 mm	41 mm
$d_{bf\ avg.}$	1.40 m	1.45 m	1.50 m
$S_{(D84)\ avg.}$	0.60% or 0.36°	0.50% or 0.30°	0.45% or 0.26°
$S_{(D50)\ avg.}$	0.30% or 0.18°	0.25% or 0.15°	0.24% or 0.14°

Results: Sediment fluxes & activities of target sections

→ **Actual sediment fluxes per unit width:**

- sediment accumulation rates / subsidence
- grain size (input grain size, fining rate)
- self-similarity
- e.g., Fedele & Paola, 2007; D'Arcy et al., 2017

*Average **actual** sediment fluxes (D_{84} & D_{50})*

West = 18.8 ± 1.45 km² · Myr⁻¹

Central = 39.8 ± 3.74 km² · Myr⁻¹

East = 6.6 ± 1.6 km² · Myr⁻¹

→ **Gravel bedload capacity per unit width:**

- based on sediment transport equations
- grain size, channel depth and slope
- critical shear stress (Shields stress)
- e.g., Wong & Parker, 2006

*Average **gravel bedload** capacities (D_{84} & D_{50})*

West = 1200 km² · Myr⁻¹

Central = 1300 km² · Myr⁻¹

East = 1200 km² · Myr⁻¹

→ **Fan activity (intermittency):**

- ratio between actual sediment flux and gravel-bedload capacity

West = 1 – 4 % *(or 3 – 14 days / yr)*
Central = 2 – 6 % *(or 8 – 21 days / yr)*
East = 0.2 – 2 % *(or 1 – 7 days / yr)*

Discussion: Sediment fluxes & activities of target sections

→ Actual sediment fluxes per unit width:

- Presumably controlled by differences in mountain building processes (tectonics / erosion)
- Paleo-climate: climate was probably similar (e.g., Zachos, 2001; Mosbrugger et al., 2005)

*Average **actual** sediment fluxes (D_{84} & D_{50})*

West = 18.8 ± 1.45 km² · Myr⁻¹

Central = 39.8 ± 3.74 km² · Myr⁻¹

East = 6.6 ± 1.6 km² · Myr⁻¹

→ Gravel bedload capacity per unit width:

- Similar fan characteristics (average grain size, channel depths, slopes, stacking pattern / architecture and appearance of conglomerates are prone for a similar fan (or channel) morphometry

*Average **gravel bedload** capacities (D_{84} & D_{50})*

West = 1200 km² · Myr⁻¹

Central = 1300 km² · Myr⁻¹

East = 1200 km² · Myr⁻¹

→ Fan activity (intermittency):

- Highest sediment concentration in Central fan, probably driven by tectonic processes (Garefalakis & Schlunegger, 2018)

West = 1 – 4 % *(or 3 – 14 days / yr)*
Central = 2 – 6 % *(or 8 – 21 days / yr)*
East = 0.2 – 2 % *(or 1 – 7 days / yr)*

Questions and comments? Happy to help!

philippos.garefalakis@geo.unibe.ch

UNIVERSITÄT BERN

Imperial College London

EGU General Assembly

References

D'Arcy, M., Whittaker, A. C., & Roda-Boluda, D. C. (2017). Measuring alluvial fan sensitivity to past climate changes using a self-similarity approach to grain-size fining, Death Valley, California. *Sedimentology*, *64*(2), 388–424.

Einstein, H. A. (1950). The Bed-Load Function for Sediment Transportation in Open Channel Flows. *Soil Conservation Service*, (1026), 1–31.

Fedele, J. J., & Paola, C. (2007). Similarity solutions for fluvial sediment fining by selective deposition. *Journal of Geophysical Research: Earth Surface*, *112*(2), 1–13.

Garefalakis, P., & Schlunegger, F. (2018). Link between concentrations of sediment flux and deep crustal processes beneath the European Alps. *Scientific Reports*, *8*(1).

Kempf, O., & Matter, A. (1999). Magnetostratigraphy and depositional history of the Upper Freshwater Molasse (OSM) of eastern Switzerland. *Eclogae Geologicae Helvetiae*, *92*(1), 97–103.

Kempf, O., Matter, A., Burbank, D. W., & Mange, M. (1999). Depositional and structural evolution of a foreland basin margin in a magnetostratigraphic framework: The eastern Swiss Molasse Basin. *International Journal of Earth Sciences*, *88*(2), 253–275.

Meyer-Peter, E., & Müller, R. (1948). Formulas for Bed-Load Transport. *Proceedings of the 2nd Meeting of the International Association of Hydraulic Research*, 39–64.
Wolman, M. G. (1954). A method of sampling coarse river-bed material. *Transactions, American Geophysical Union*, *35*(6), 951–956.

Mosbrugger, V., Utescher, T., Dilcher, D.L., 2005. Cenozoic continental climatic evolution of Central Europe. Proc. Nat. Acad. Sci. USA 102, 14964–14969.

Schlunegger, F., Burbank, D. W., Matter, A., Engesser, B., & Mödden, C. (1996). Magnetostratigraphic calibration of the Oligocence to Middle Miocene (30-15 Ma) mammal biozones and depositional sequences of the Swiss Molasse Basin. *Eclogae Geologicae Helvetiae*, *89*, 753–788.

Schlunegger, F., Matter, A., Burbank, D. W., & Klaper, E. M. (1997). Magnetostratigraphic constraints on relationships between evolution of the central Swiss Molasse basin and Alpine orogenic events. *Bulletin of the Geological Society of America*, *109*(2), 225–241.

Wong, M., & Parker, G. (2006). Reanalysis and Correction of Bed-Load Relation of Meyer-Peter and Müller Using Their Own Database. *Journal of Hydraulic Engineering*, *132*(11), 1159–1168.

Zachos, J., Pagani, H., Sloan, L., Thomas, E., & Billups, K. (2001). Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science*, *292*(5517), 686–693.

This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

philippos.garefalakis@geo.unibe.ch