Wildfire induced geohydrological risk in the Alps

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Introduction

Why are tectonic & geology settings important for wildfire and post wildfire risk?

The tectonic evolution of the Alps creates spatially-varying geologic, topographic and geomorphological conditions.

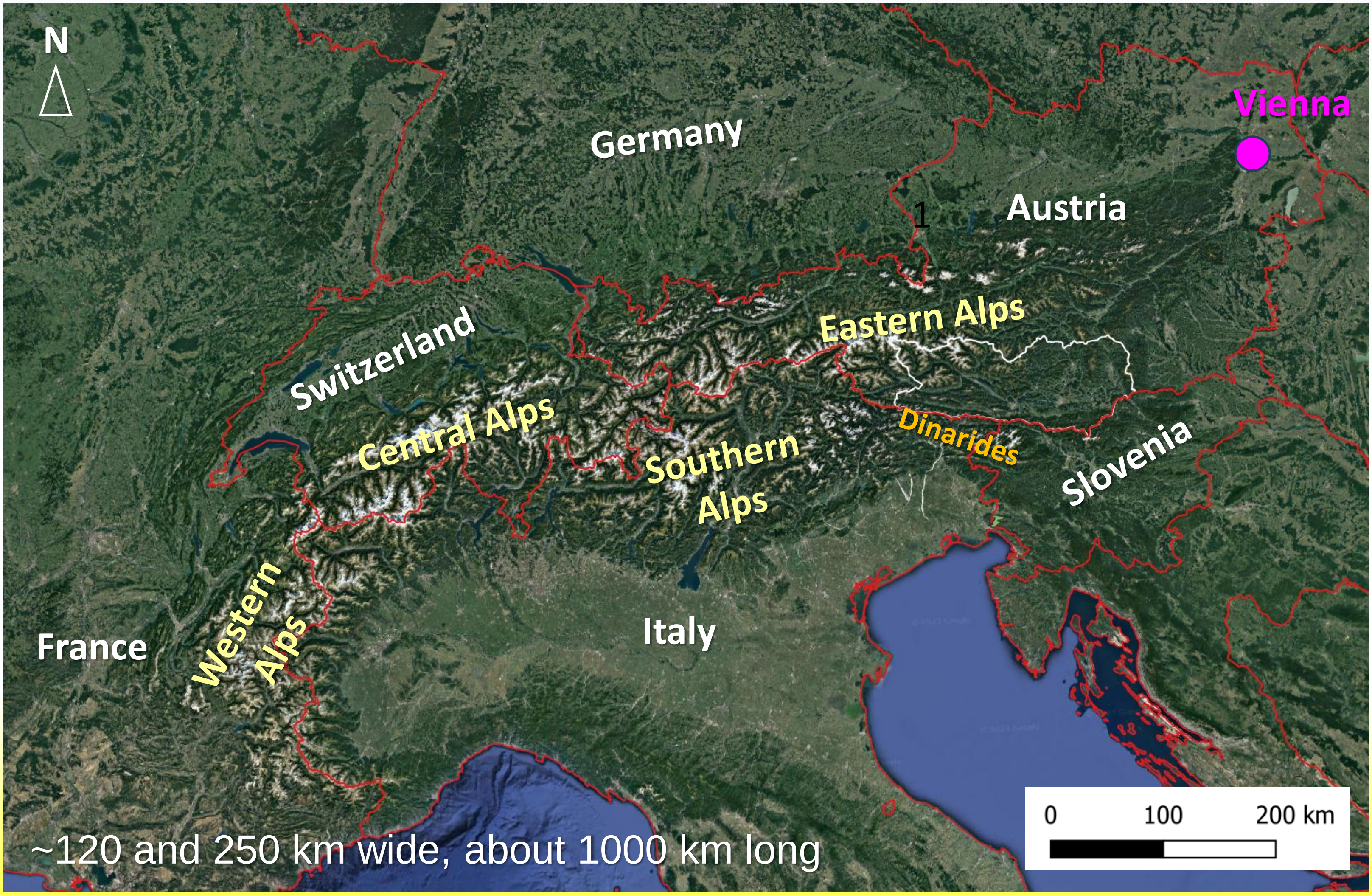
These variable conditions highly influence the occurrence of:

- Ecosystems at different elevations,
- Large- scale weather patterns & local weather patterns,
  - Wind systems (some examples)
    - Foehn wind (*Warm, dry, downslope winds),*
    - Bora (*Very strong, cold, downslope wind),*
    - Valley and Mountain Wind *(Daily thermally driven circulations)*
- Spatial and temporal occurrence of fire types (crown fire, running fire , ground fire),
- Spatial and temporal occurrence of geohydrological processes,
- Historical settlement development (geographic location of settlements & infrastructure, impacts landscape and vegetation structure).

Melzner et al. (2025)

1. Alps

Geographical regions

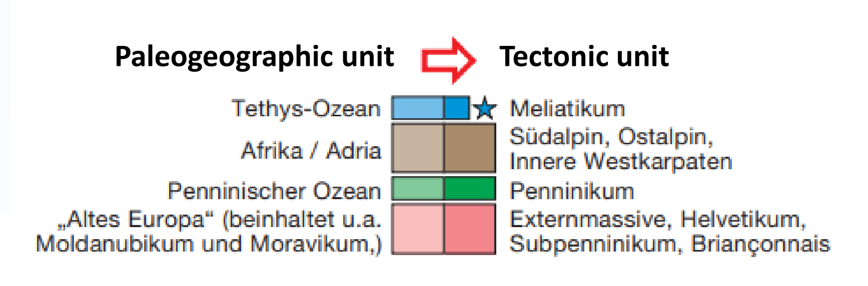


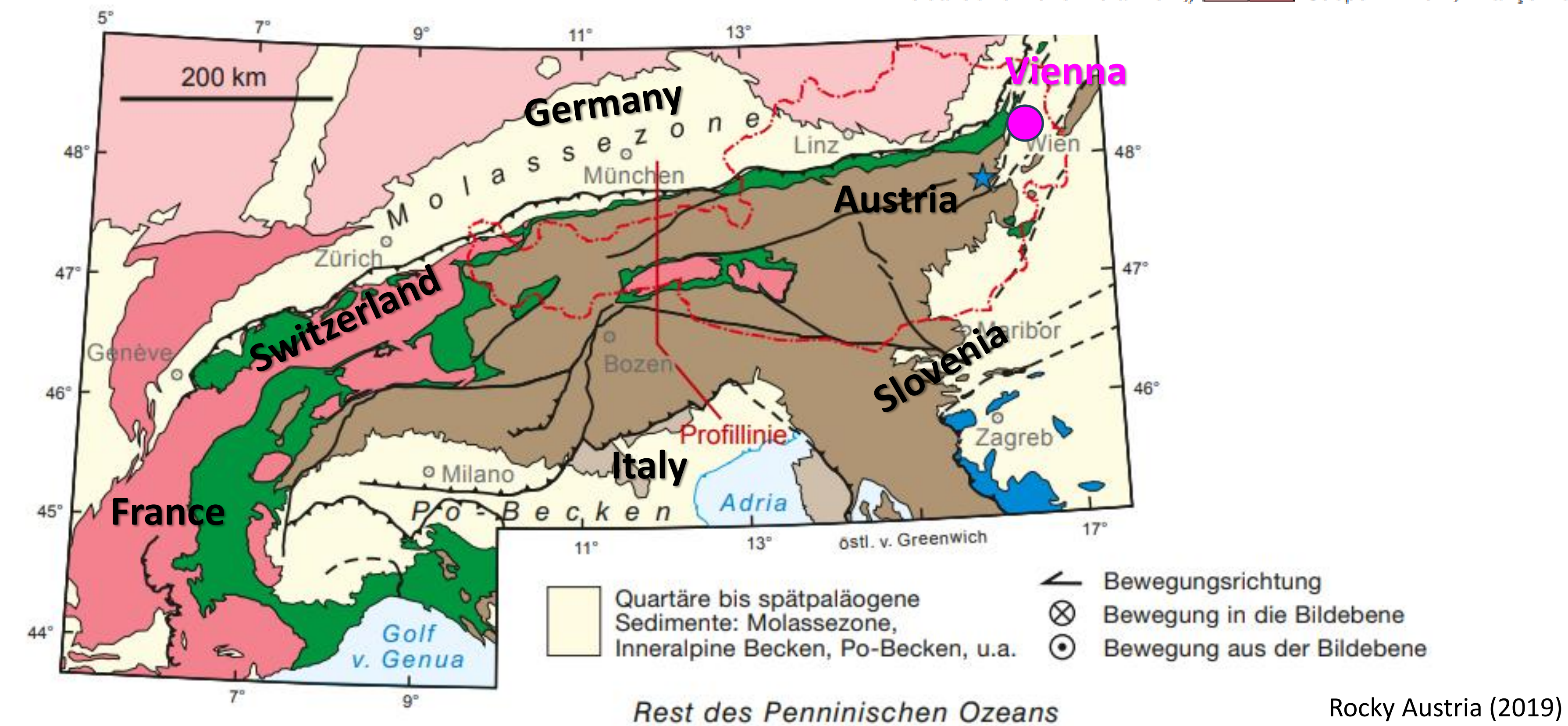
Melzner et al. (2025)

1. Alps

Paleographic units → tectonic units

Alps's rocks come from two continents (Old Europe and Africa) and two oceans (Tethys and Penninic) that existed 240 to 40 million years ago.

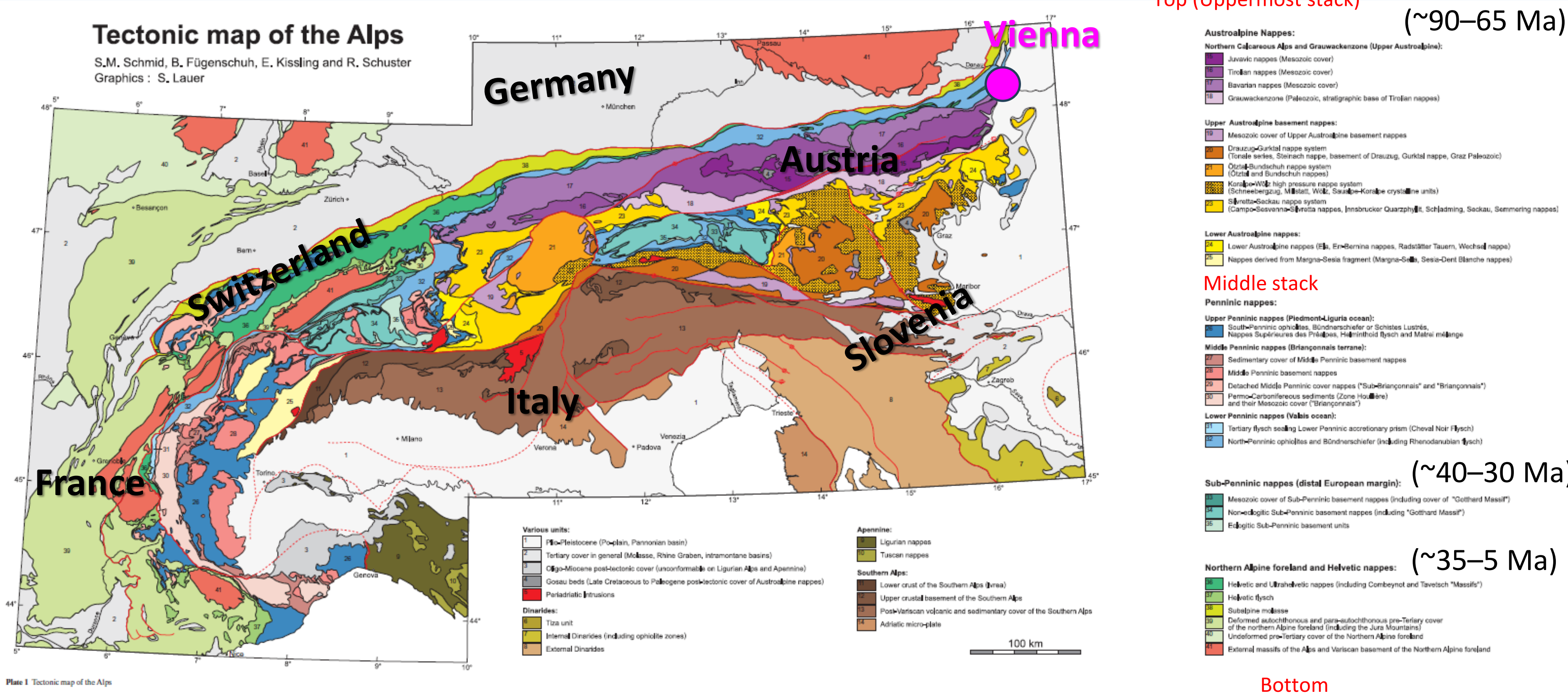




Rocky Austria (2019)

1. Alps

Tectonic units



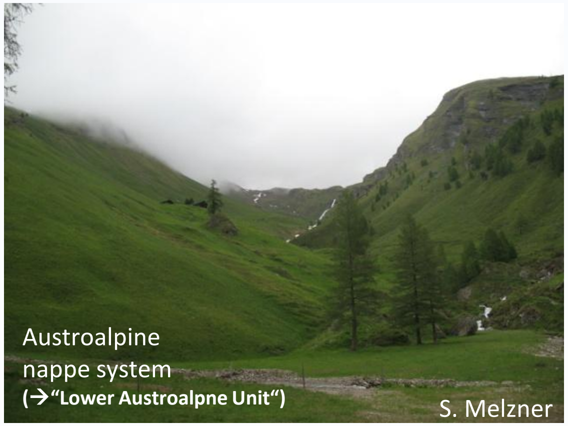
Schmid et al. (2004)

Bohemian Massif formation (Variscan Orogeny)(~350–300 Ma)→ Interaction with Alpine tectonics (compression at its margin)→ 40- 5 Ma (Teriary deformation)

1. Alps

Orientation of the tectonic units & geotechnical properties of the geological units/rocks differ significantly → impact on process susceptibility

SW dip of tectonic units
→ Dip slope situation



"Weak units" don't form such steep cliffs

NE dip of tectonic units
→ Steep cliffs
→ Competent units have higher proportions of steep terrain

calcareous mica schist

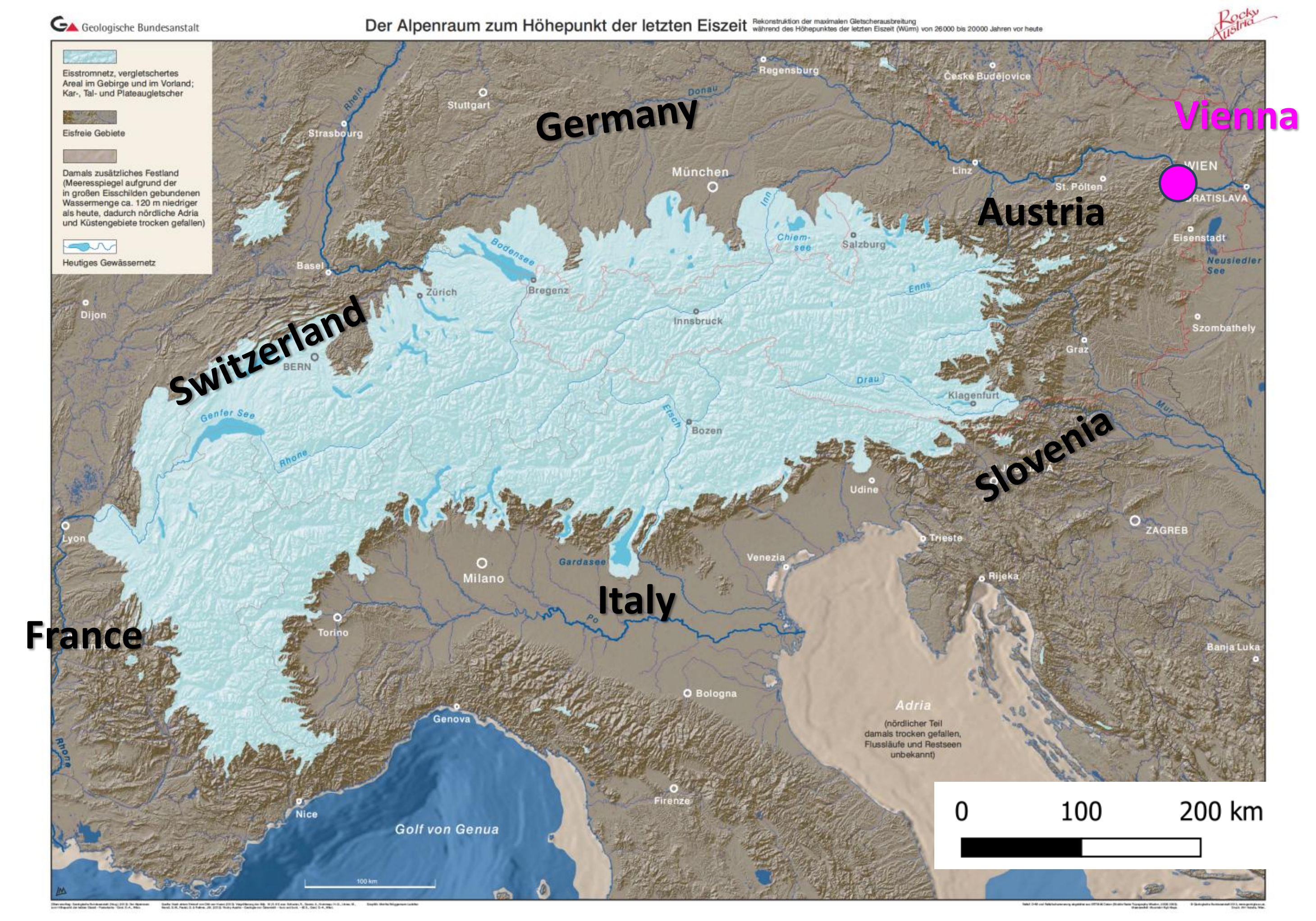
→Fast changing lithology
→Large variety of discontinuities (several ductile and brittle deformations)

Glacial or glacio-fluvial erosion processes
→ WNW-ESE- or WSW-ENE striking directions, and also most likely associated syn- und antithetic directions of the main fault systems

paragneis

1. Alps

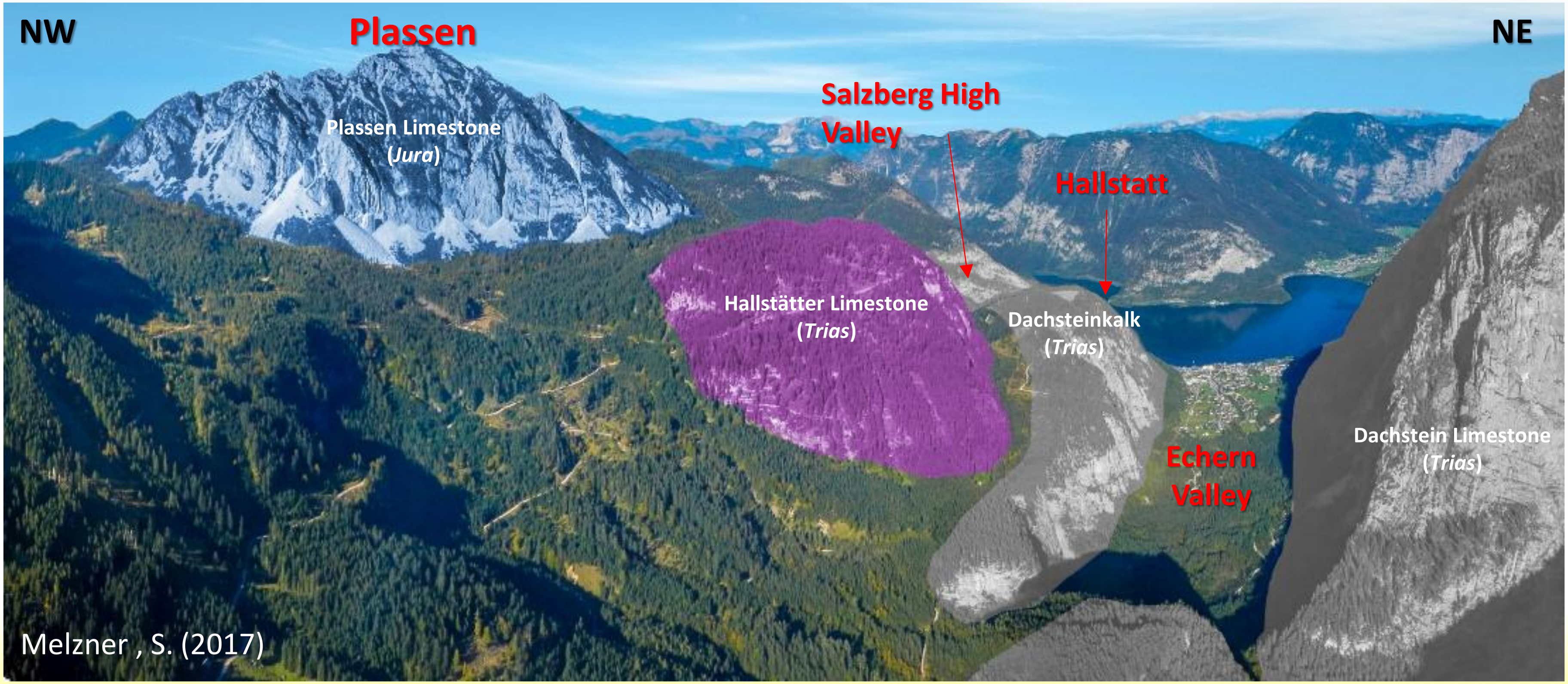
Glaciers deepened and widened pre- existing tectonics valleys by erosion → largest extent of Würm Glaciation (~115,000 to 10,000 years ago)



2. Geohydrological Processes

Glacier overdeepened relief → high susceptibility towards a variety of processes

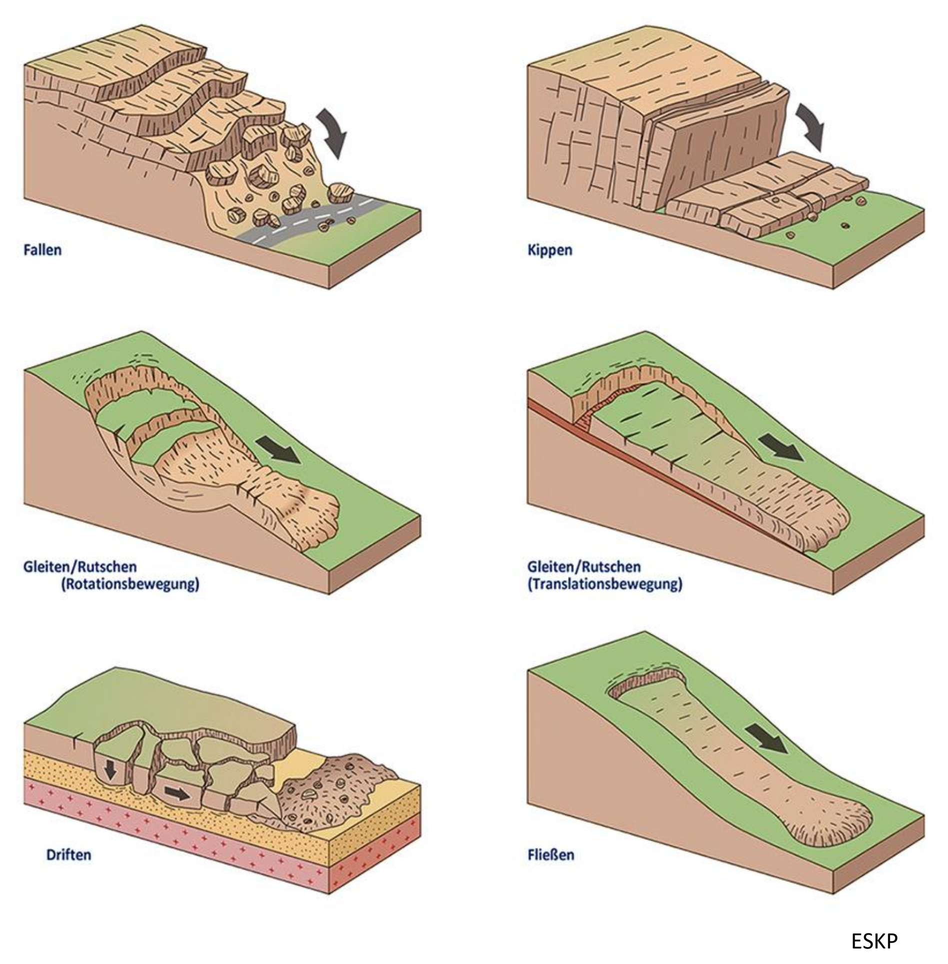
→ lateral spreading, sliding, creeping, flowing, fall processes (rockfall, large volume rockfalls)



The detachment behaviour of blocks or rock masses depends on a number of different parameters: Relief characteristics (e.g. slope inclination), material properties (e.g. friction angle) and structural characteristics (orientation of joint mass structure)

2. Geohydrological Processes

Gravitational mass movements can be classified into different types according to the type of movement (falling, toppling, etc.) and material (rock, debris & soil)



Different types often occur in combination,

e.g. a landslide develops during a heavy precipitation in a soilflow

OR

a block is detached by a landslide as a ‘secondary’ rockfall

2. Geohydrological Processes

Four process types in Alpine Torrents (Hübl 2010)

Type of relocation

Fluviatile — Debris flow like

Terminus, Process type

Flood/clean water discharge

Fluviatile sediment transport
Low sediment transport

Debris-like sediment transport
Strong sediment transport

Debris flow
Murgang

River bed inclination

<3%	3-15%	>15%


Quelle: WLV Tirol

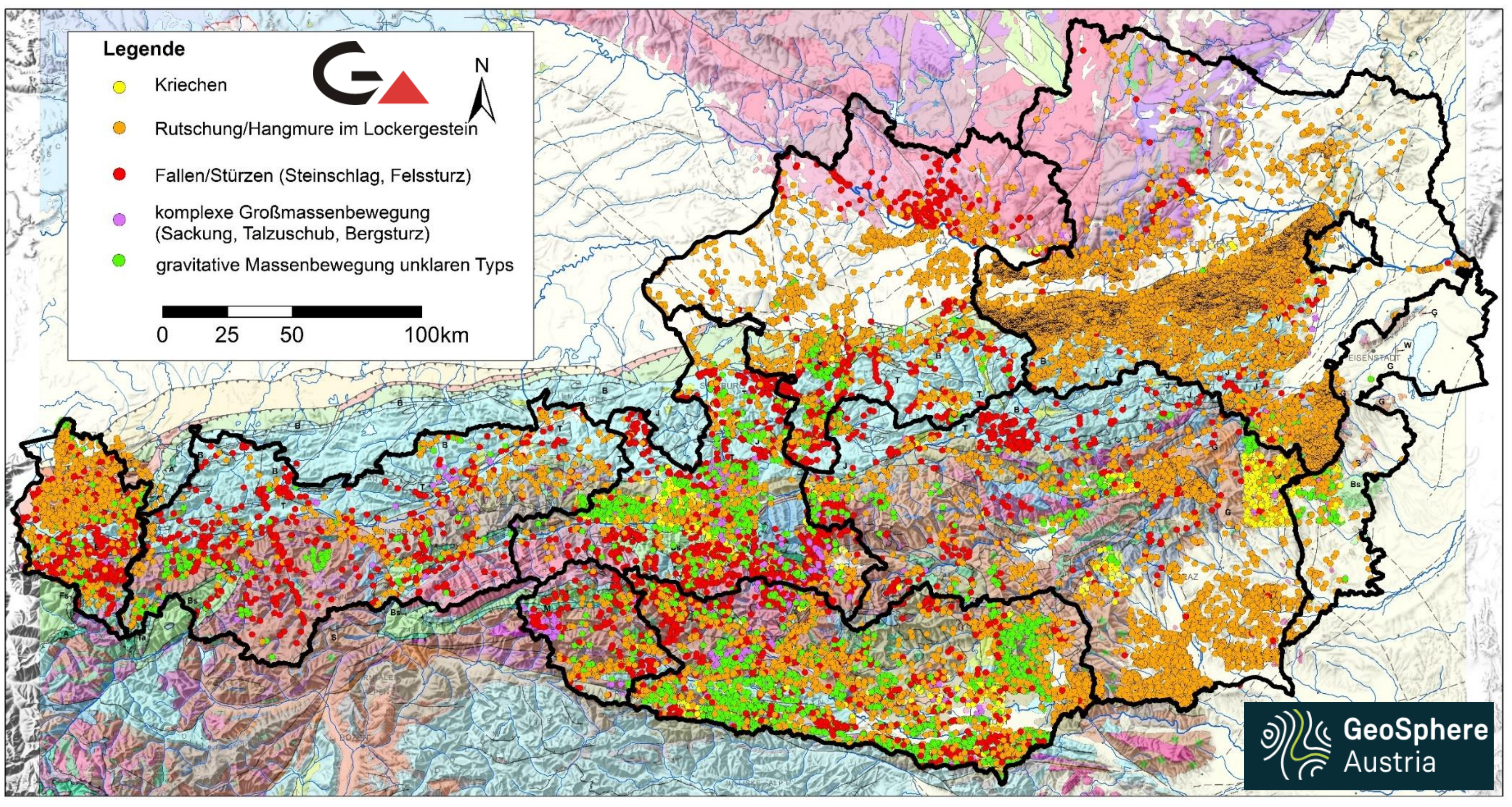

Quelle: WLV Tirol


Quelle: O'Brien, J.


Quelle: O'Brien

2. Geohydrological Processes

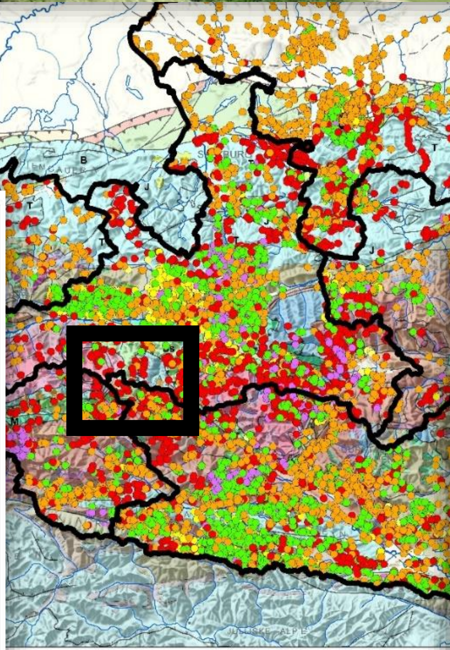
Inventory of different geohydrological processes in Austria

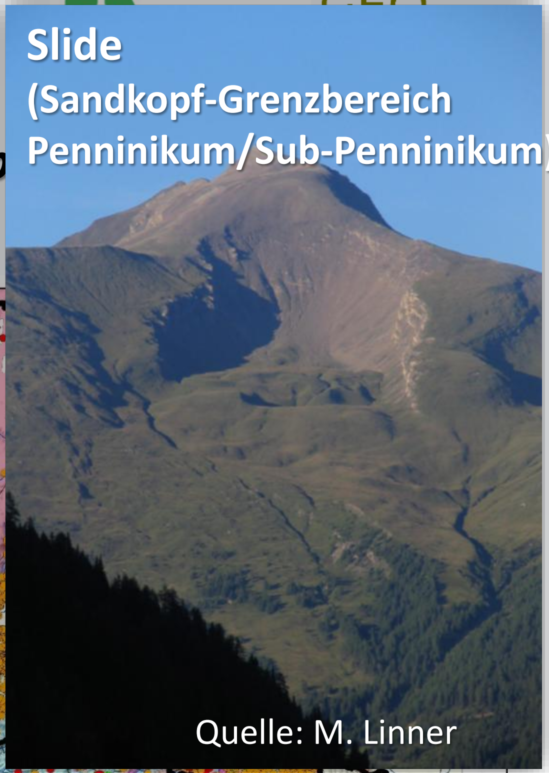


Melzner et al. (2025), Data by GeoSphere Austria, Geological Map by Schuster et al., (2013)

2. Geohydrological Processes

High mountains → oversteep ***ep***
slope deformation (DSGSD),

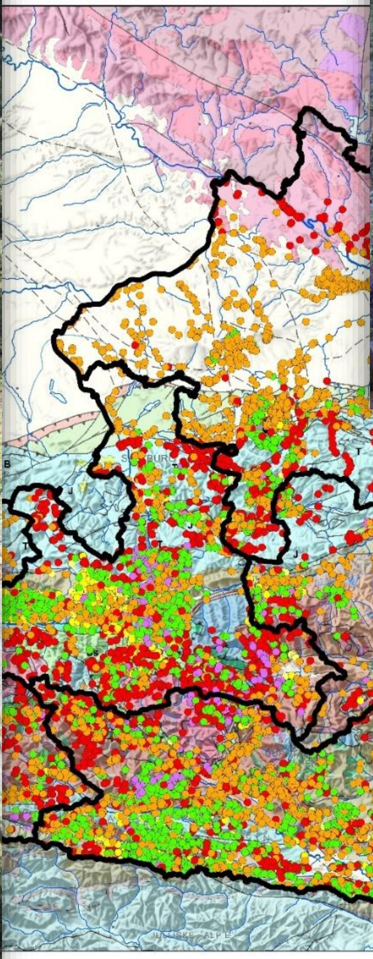




Austria, Geological Map by Sc

2. Geohydrological Processes

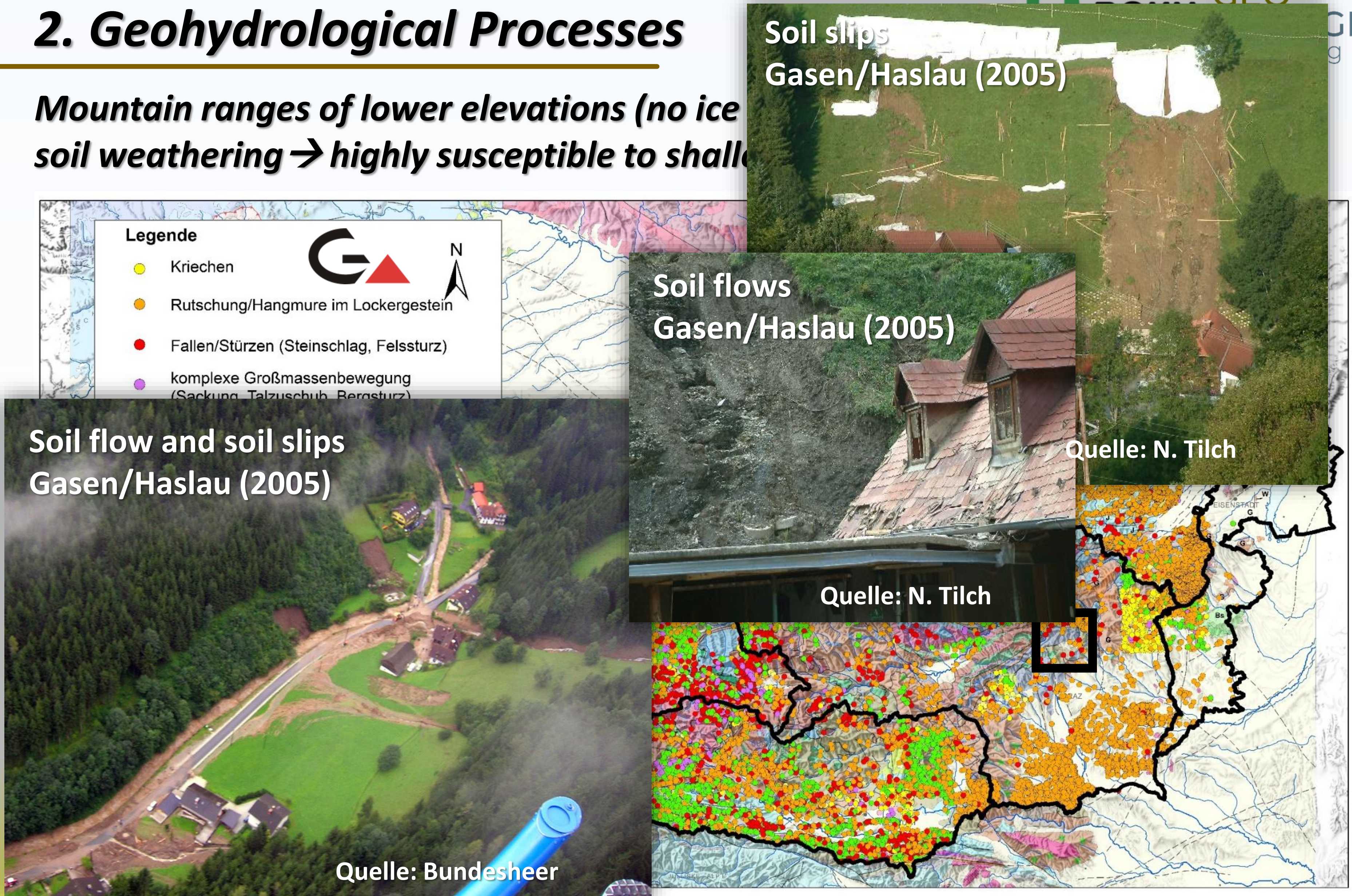
High mountains → debris flows



Melzner et al. (2025), Data by GeoSphere Austria, Geological Map by Schuste

2. Geohydrological Processes

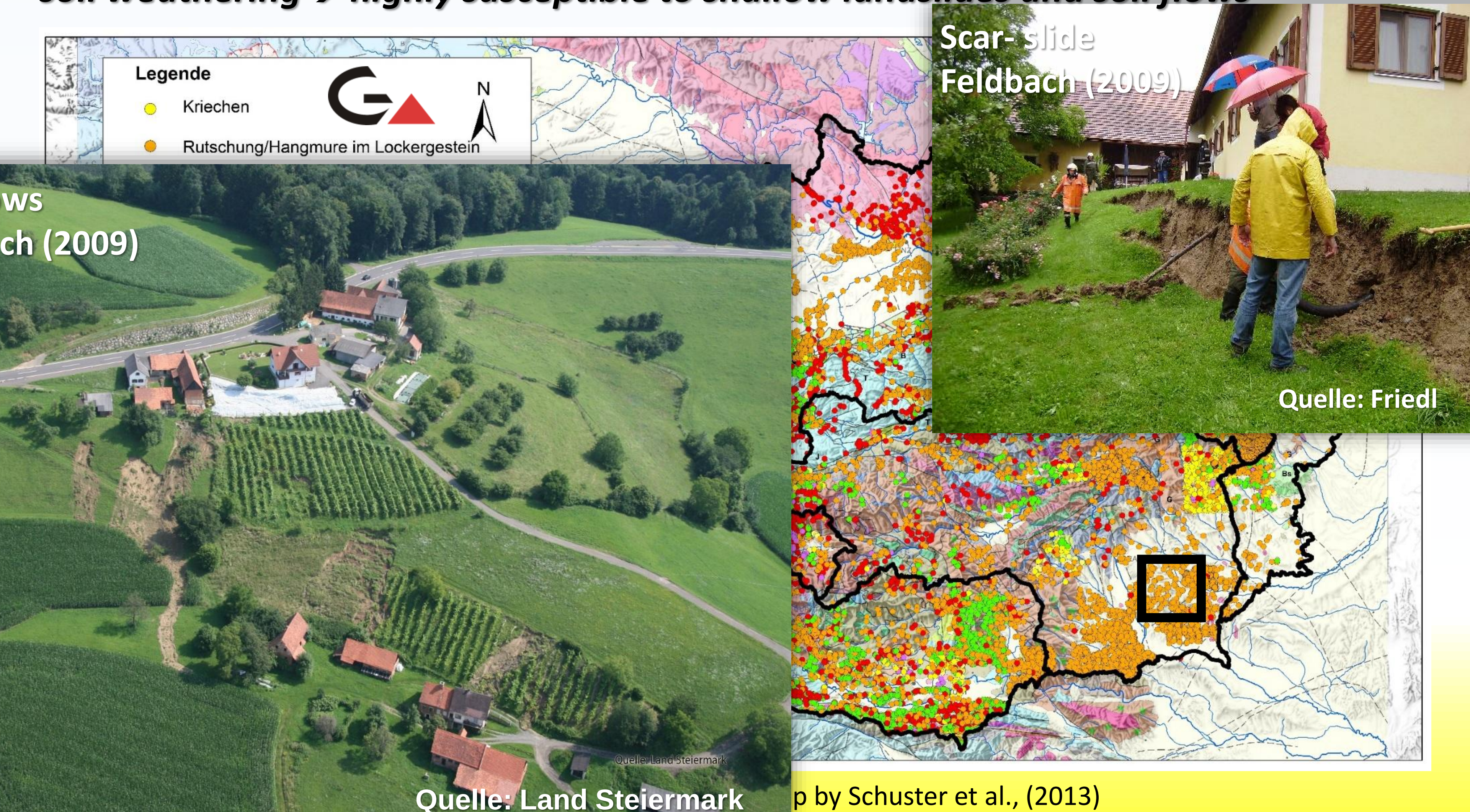
Mountain ranges of lower elevations (no ice
soil weathering → highly susceptible to shall



Melzner et al. (2025), Data by GeoSphere Austria, Geological Map by Schuster et al., (2013)

2. Geohydrological Processes

Mountain ranges of lower elevations (no ice cover during Pleistocene)→ deep soil weathering→ highly susceptible to shallow landslides and soil flows



p by Schuster et al., (2013)

3. Hazard potential and risk

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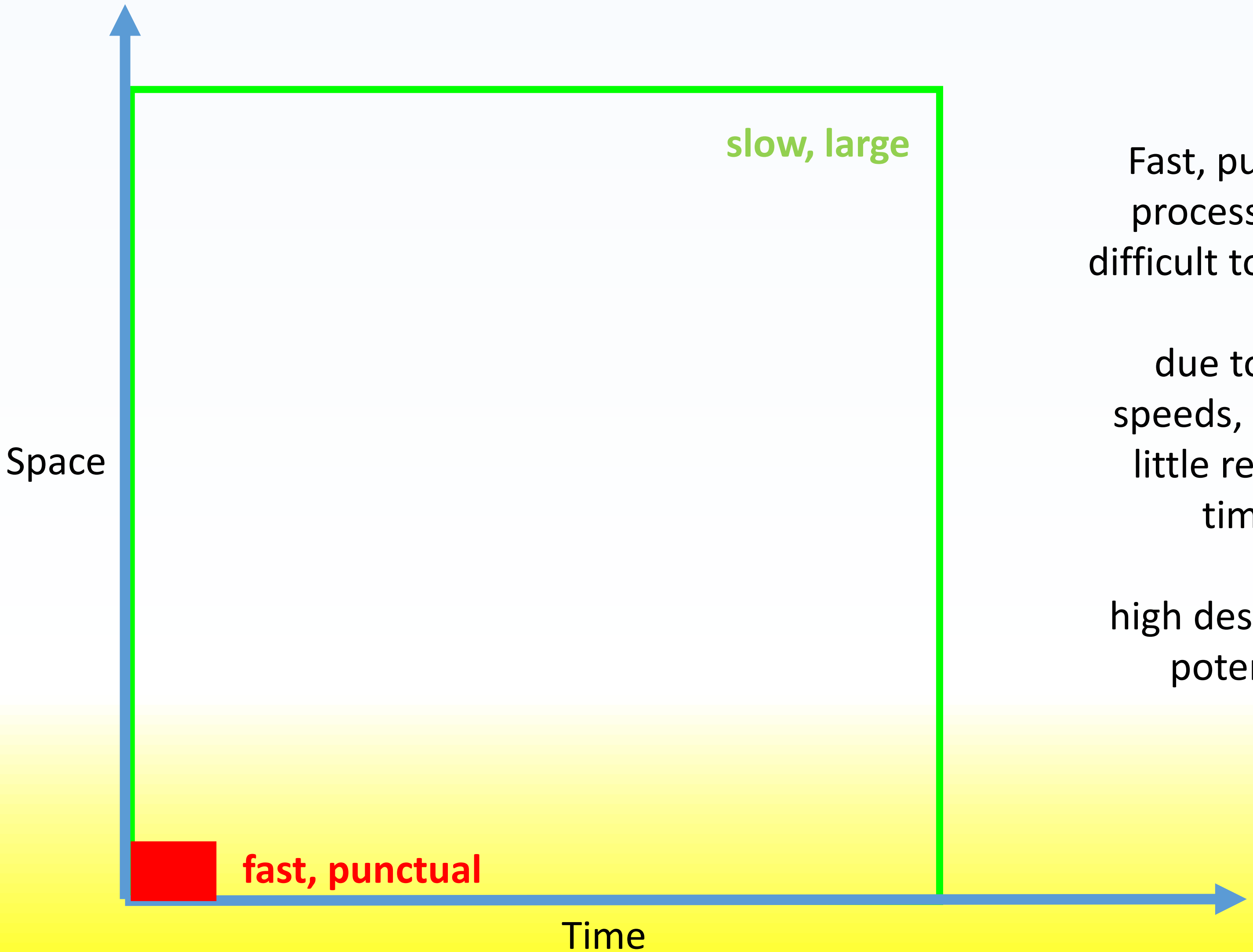
Geohydrological processes vary in terms of speed and size



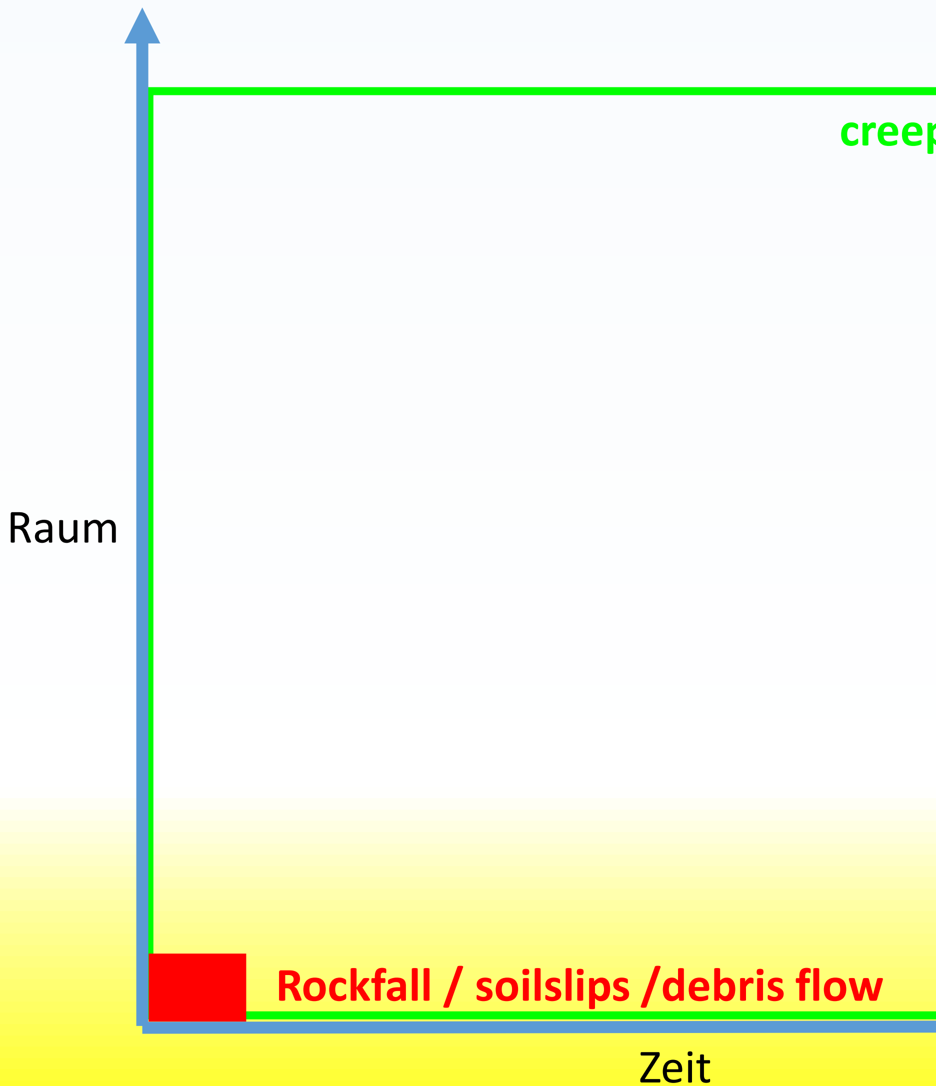
Fast, punctual processes are difficult to predict;

due to high speeds, there is little reaction time;

high destructive potential

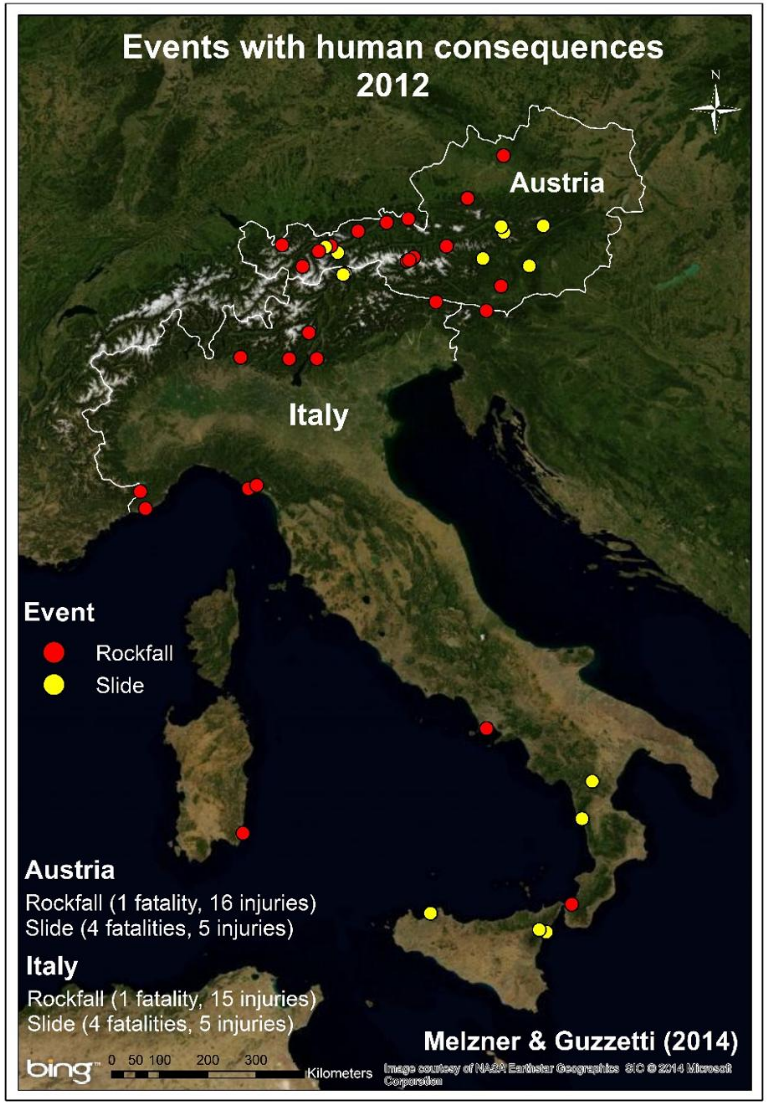
3. Hazard potential and risk

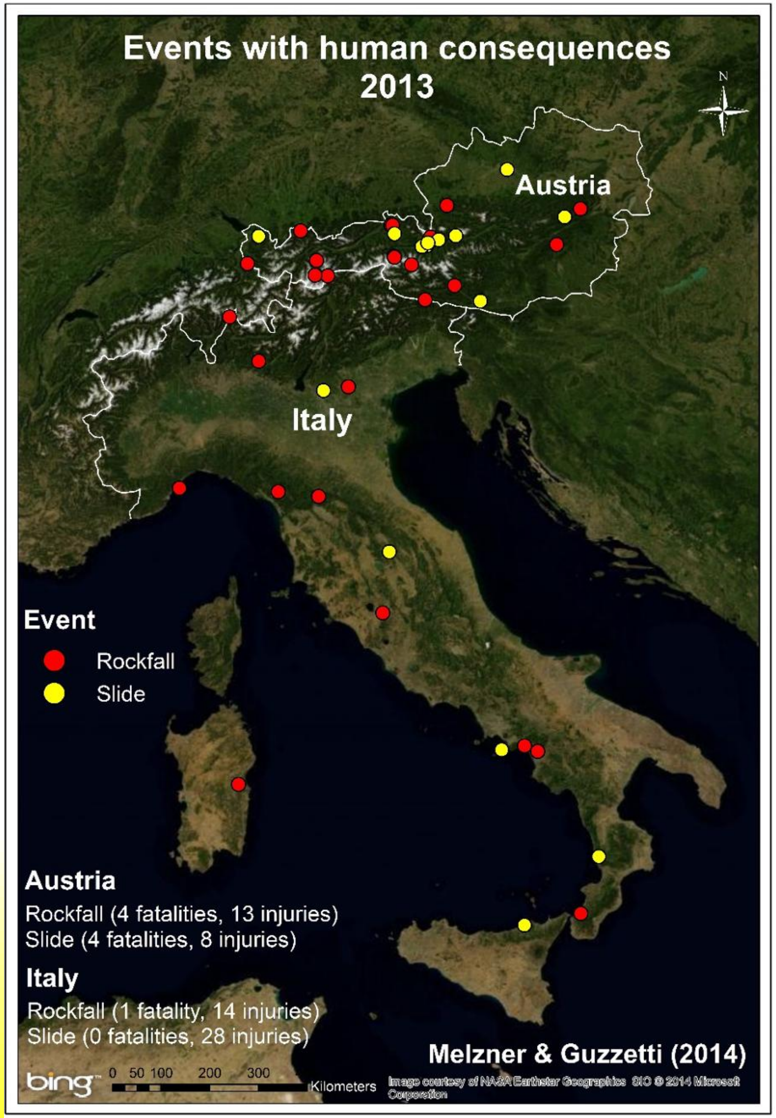
Rockfall and shallow soilflows are fast and can be very destructive



3. Hazard potential and risk

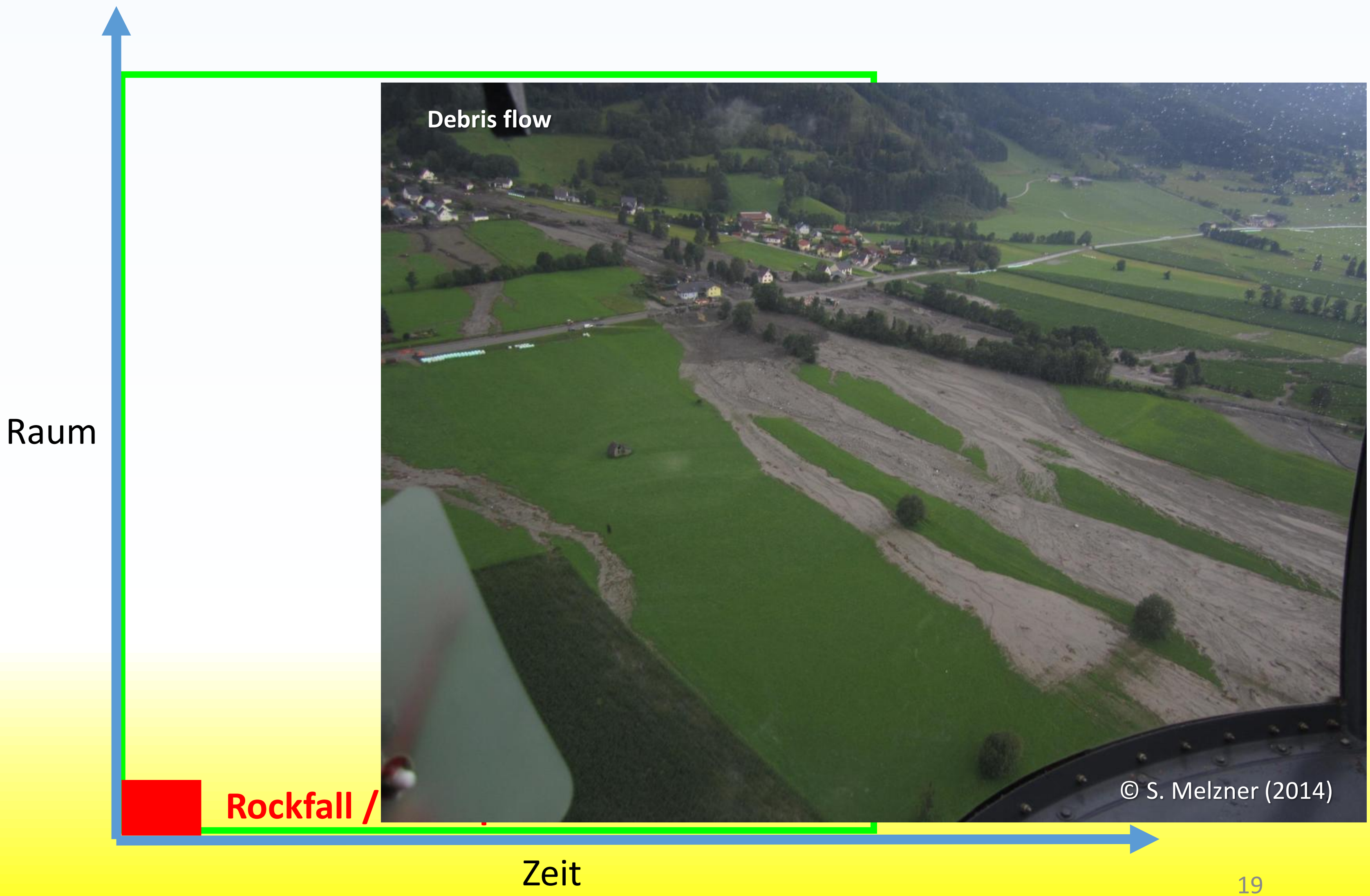
Rockfall and landslide events with human consequences in 2013 and 2014





3. Hazard potential and risk

Debris flow disasters that affect entire settlements



4. Hazard and risk assessment

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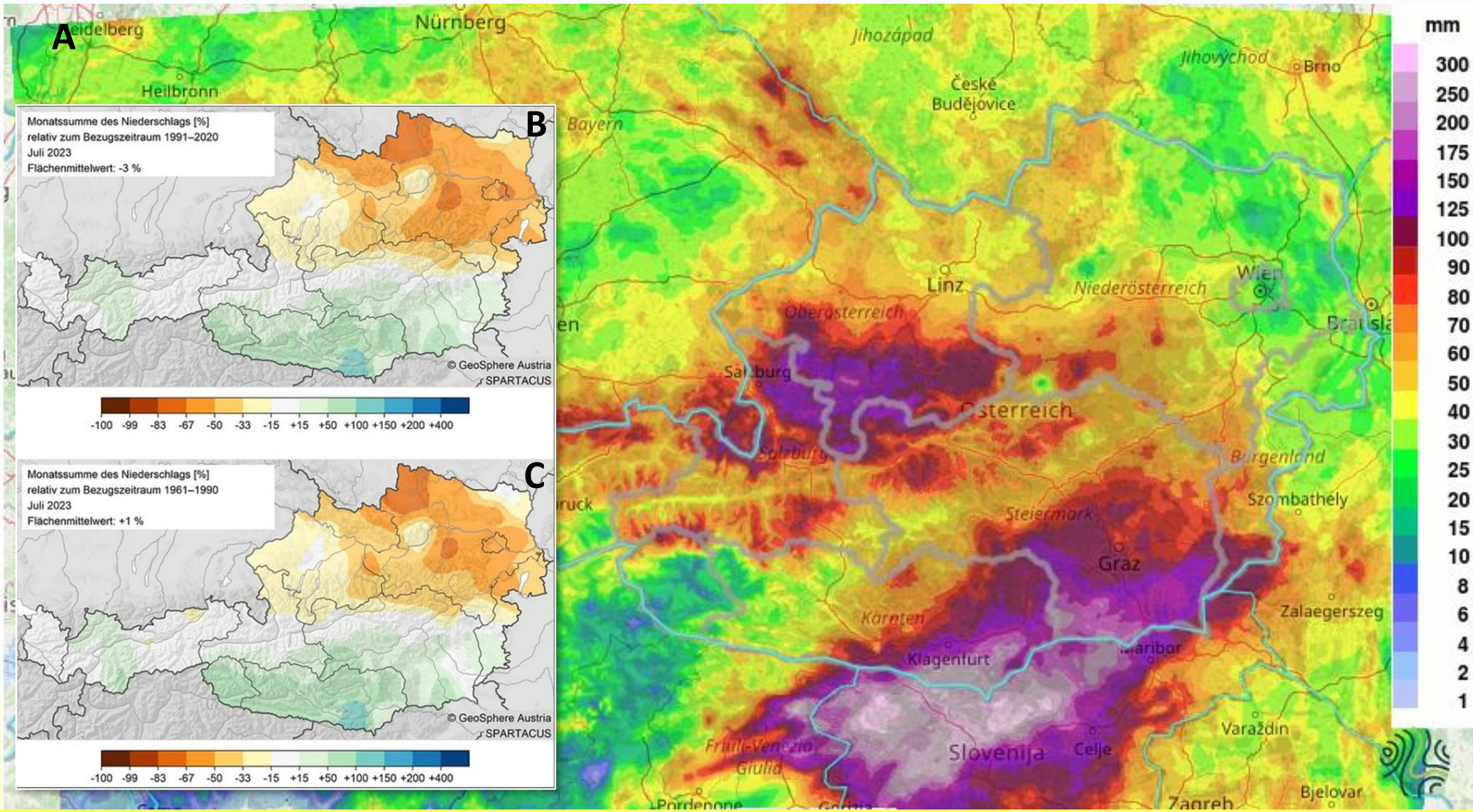
Challenge: Increase in local weather extremes causing disasters in areas which have not been affected in the past



The precipitation sum for five days, created on 7 August 2023 (Source: GeoSphere Austria).

4. Hazard and risk assessment

Challenge: Major changes in the protective forest function

4. Hazard and risk assessment

Challenge: Development of new models for the simulation of combined processes

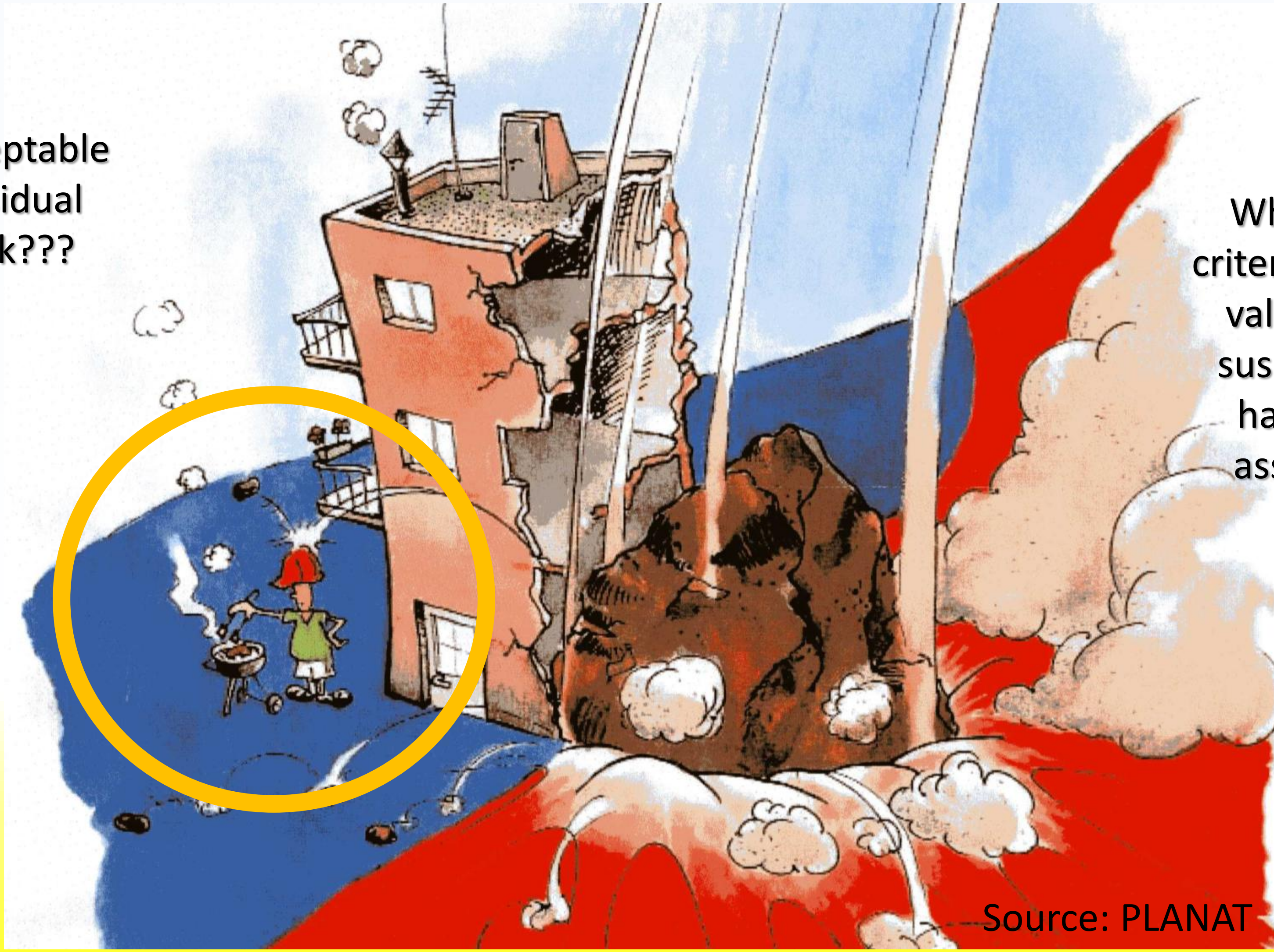
4. Hazard and risk assessment

Challenge: Integration of high-magnitude scenarios into hazard zonation?

4. Hazard and risk assessment

Challenge: adaptation of existing methods, tools and standards

Acceptable residual risk???

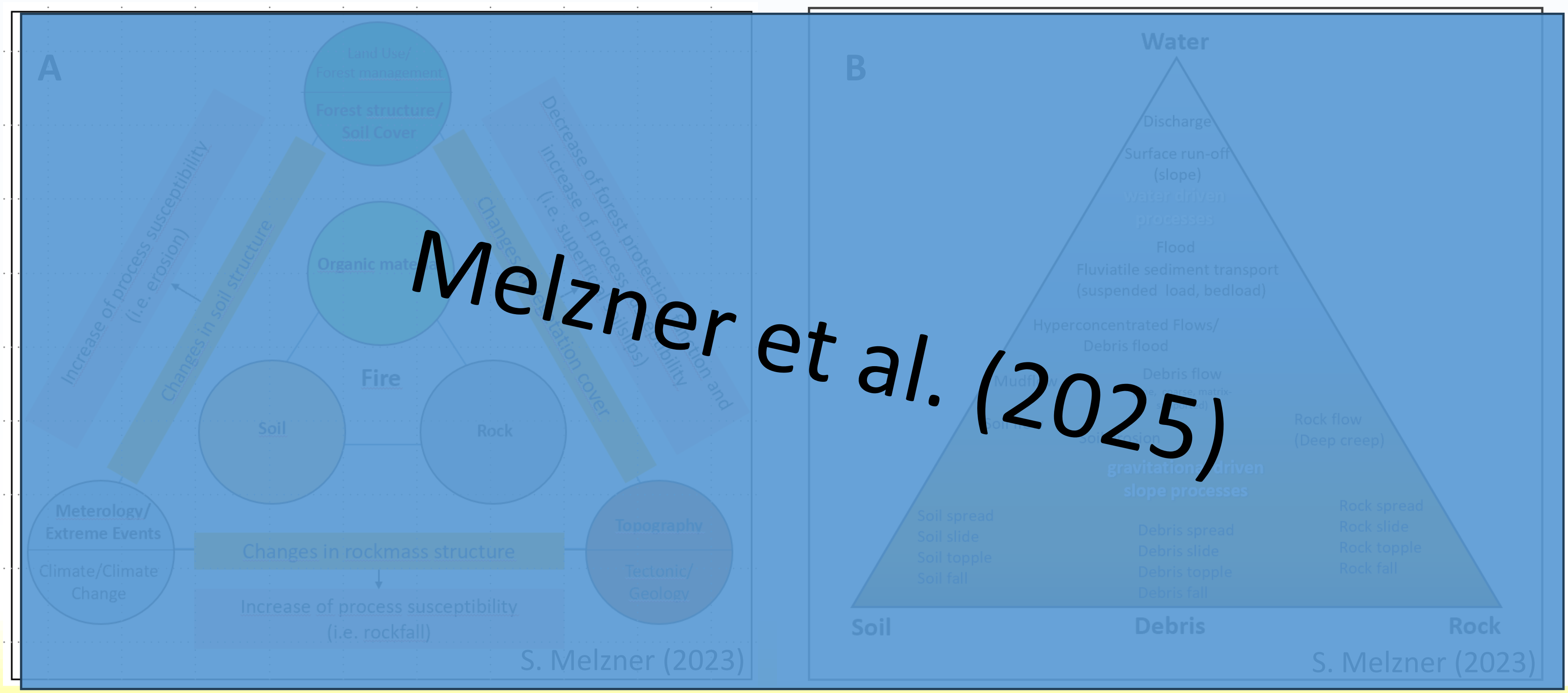


What are the criteria/threshold values for the susceptibility / hazard / risk assessment?

Source: PLANAT

5. Wildfires induced geohydrological risk

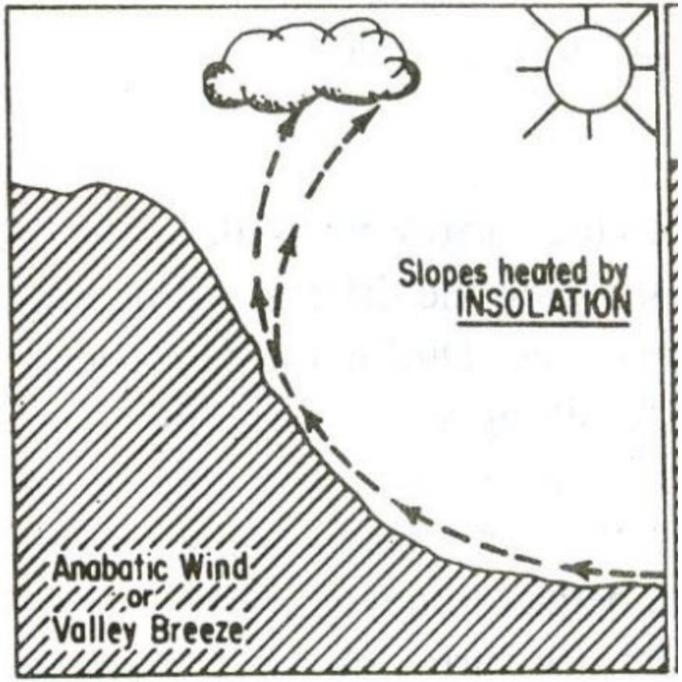
Impact of fire on rock, soil and vegetation (A) and the associated geohydrological processes (B)



Melzner et al. (2025): Wildfire-induced geohydrological risk in the Alps, Landslides.

5. Wildfires induced geohydrological risk

Impact topography on wildfire charcteristics (e.g. fire intensity and burn severity)



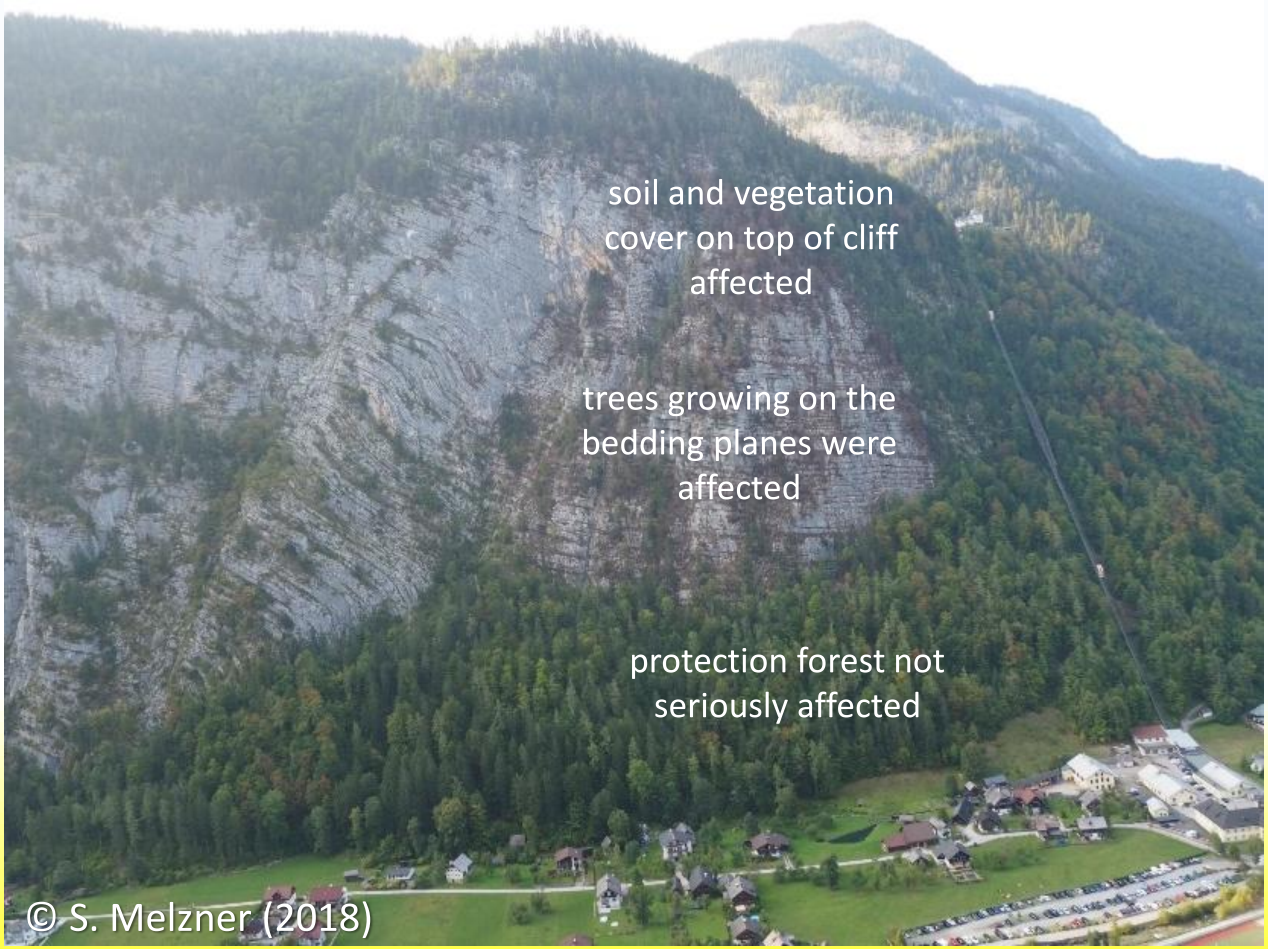
Valley and Mountain Winds

- *Daily thermally driven circulations.*
- During the day: warm air rises up valleys (*anabatic winds*).
- At night: cool air sinks down valleys (*katabatic winds*).

5. Wildfires induced geohydrological risk

Impact topography on wildfire charcteristics (e.g. fire intensity and burn severity)

28. and 29. August, 2018: mapping of post- wildfire risk→ formed the basis for the planning of preventive measures (duration of evacuation of houses, etc.)



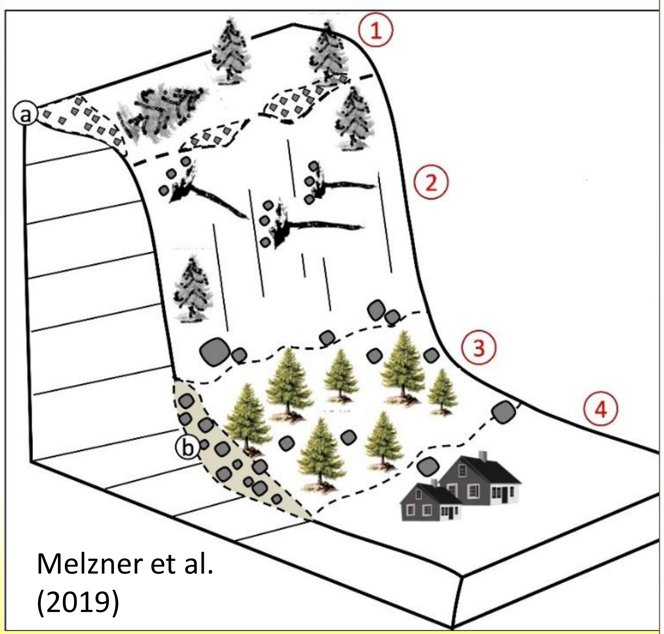
5. Wildfires induced geohydrological risk

Wildfire in the world heritage site «Hallstatt»

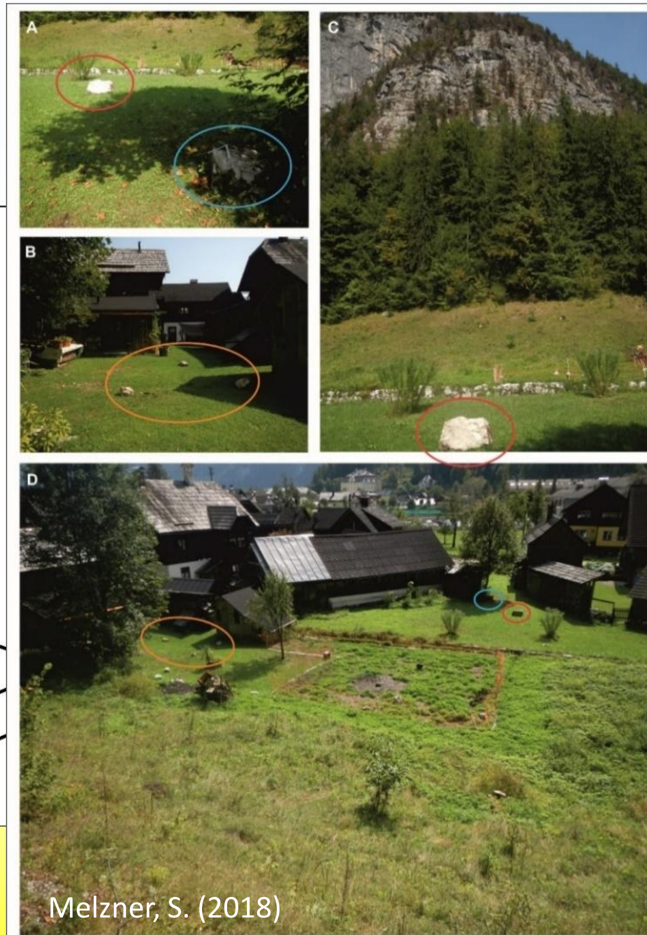
Mapping results: Rockfalls occured during the fire, boulders < 0,5m³ reached the houses; potential for future rockfalls and debris flows

Melzner, S. (2018)

Melzner, S. (2018)



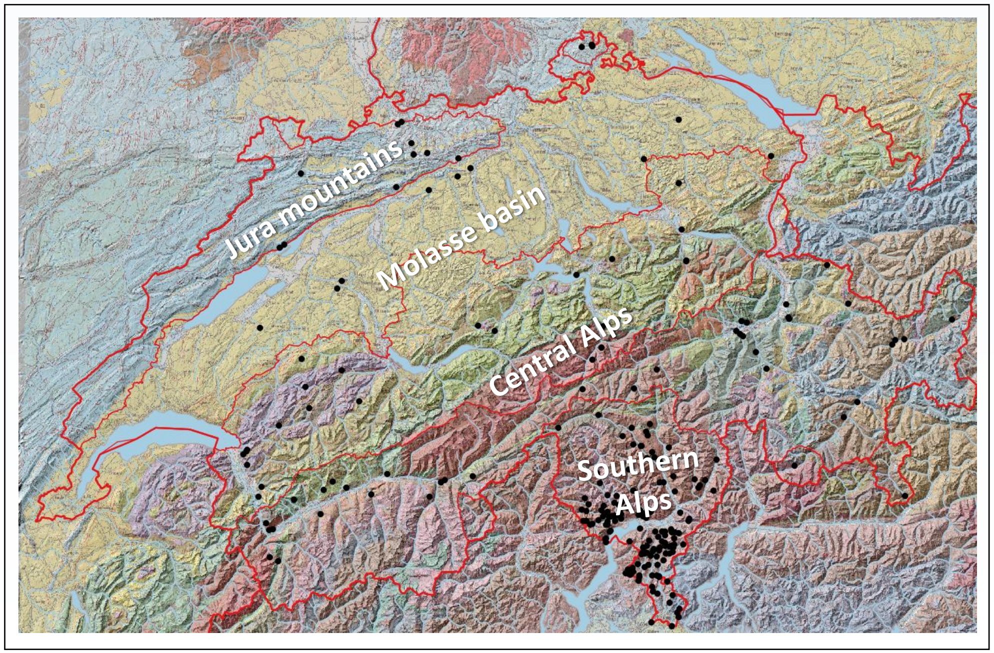
Melzner et al. (2019)



Melzner, S. (2018)

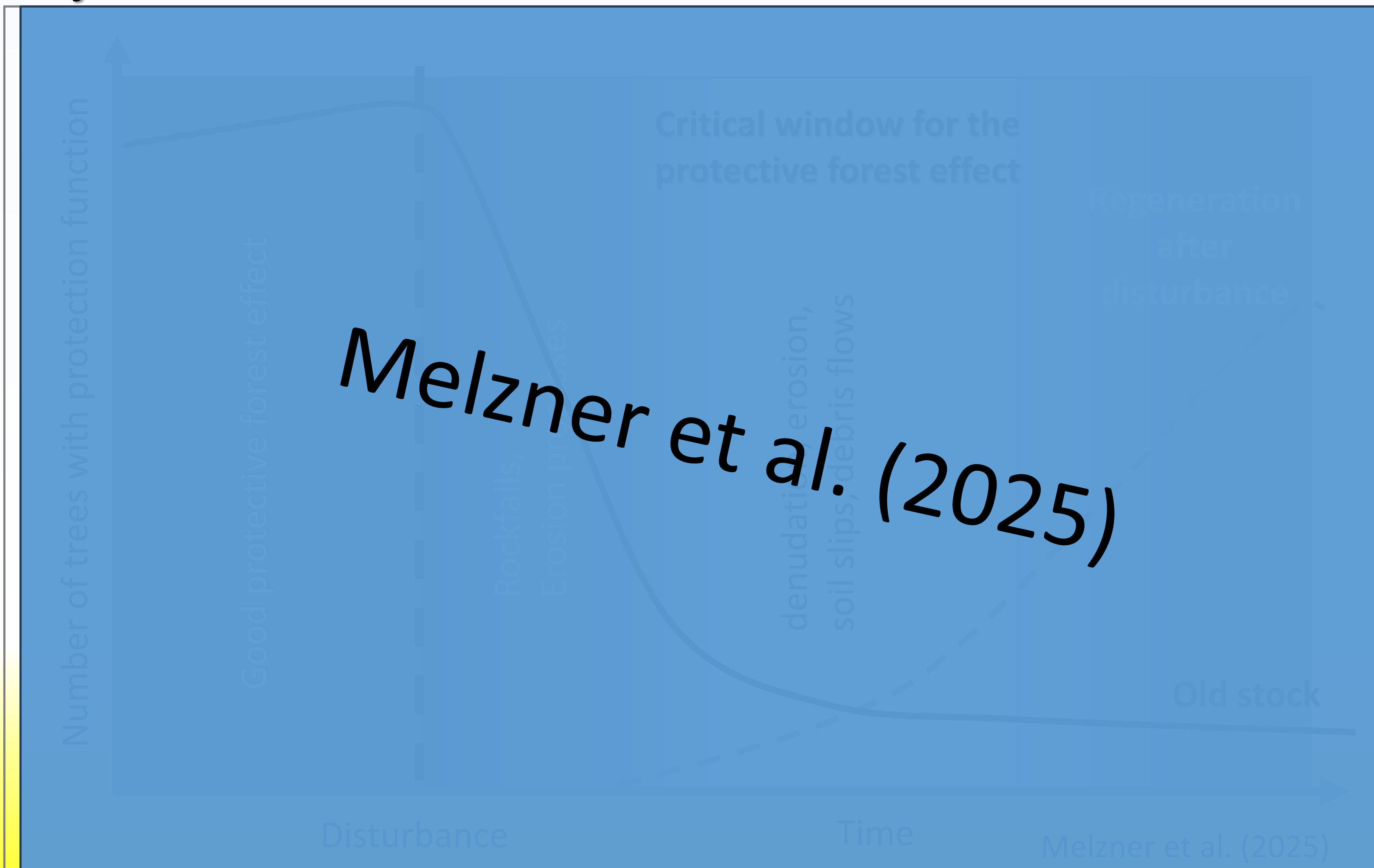
5. Wildfires induced geohydrological risk

Post wildfire risk in the Swiss mountains



Melzner et al. (2022): Post wildfire risk in the Swiss mountains. Journal of Austrian Torrent and Avalanche Control.

Spatial and temporal occurence of geohydrological processes during and after a wildfire



5. Wildfires induced geohydrological risk

Indicators of burn severity for vegetation, soil and rock in the field

Melzner et al. (2025)

Melzner et al. (2025)

Thank you very much for your attention!

New publication ☺

Melzner, S., Peduto, D., Hübl, J., Fiorucci, F. & Phillips, C. (2025): Wildfire-induced geohydrological risk in the Alps, Landslides.

The paper addresses the **multidisciplinary** issue of wildfire-induced geohydrological risk in the Alps by

- synthesizing publications in the Alps,
- presenting characteristic conditions in the Alps impacting the spatial distribution of wildfires and geohydrological processes,
- proposing a systematic procedure for documenting the identification of indicators for burn severity and the estimation of post wildfire risks,
- first inventory of fire-induced geohydrological processes,
- identifying future challenges.

References

Melzner, S., Peduto, D., Feruccio, F., Hübl, J. & C. Phillips (2025): Wildfire induced geohydrological risk in the Alps. Journal Landslides.

Melzner, S., Conedera, M. & Pezzatti, B. (2022): Post Waldbrand Risiko in den Schweizerischen Gebirgen. Journal des Vereins der Diplomingenieure der Wildbach- und Lawinenverbauung. 86. Jahrgang, Jänner 2023, Heft Nr. 190, Salzburg, Österreich. https://www.geochange-consulting.com/wp-content/uploads/2023/08/Melzner_etal_2023-1.pdf

Melzner, S., Rossi, M. & Conedera, M. (2022): Summary 1st Alpine Workshop on „Fire- induced geohydrological hazards in mountainous area", Klagenfurt, Vienna https://www.geochange-consulting.com/wp-content/uploads/2023/08/Summary_1rstAlpineWorkshop_KlagenfurtAustria.pdf

Melzner, S., Conedera, M. & Pezzatti, B. (2022): Post Waldbrand Risiko in den Schweizerischen Gebirgen. Poster beim Geoforum Umhausen, Niederthai, Österreich. https://www.geochange-consulting.com/wp-content/uploads/2023/08/Melzner_etal_2022.pdf

Melzner, S., Shtober-Zisu, N., Katz, O. & Wittenberg, L. (2019): Brief communication: Post-wildfire rockfall risk in th eastern Alps. Nat. Hazards Earth Syst. Sci., 19, 2879-2885, https://doi.org/10.5194/nhess-19-2879-2019,2019. https://www.geochange-consulting.com/wp-content/uploads/2023/08/Melzner_etal_2019.pdf