TECHNISCHE UNIVERSITÄT MÜNCHEN
Chair of Landslides Research

Mechanical changes in thawing permafrost rocks and their influence on rock stability at the Zugspitze summit - a research concept

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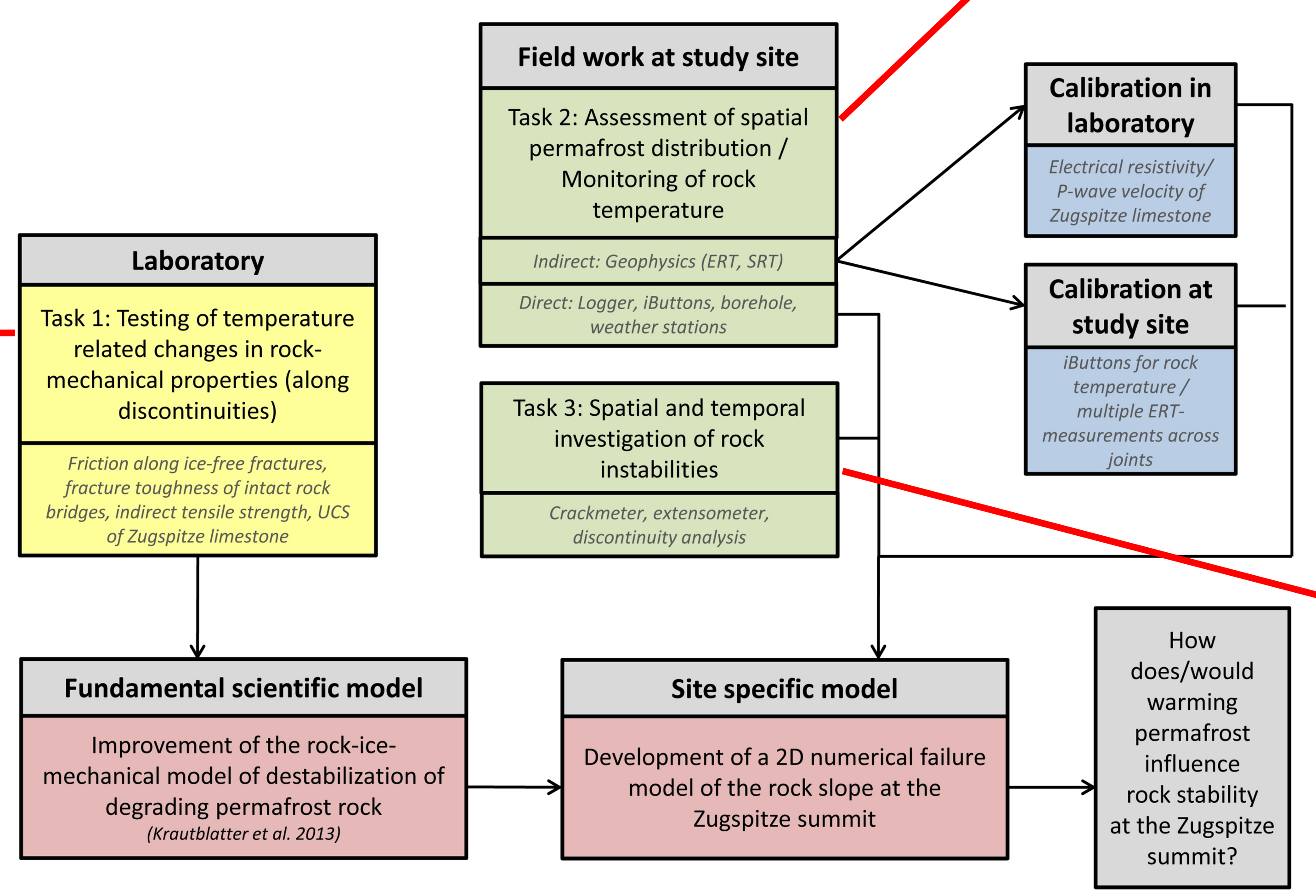
Background

- climate-induced degradation of permafrost can influence stability of rock slopes in alpine environments
- increasing number of rockfalls/rockslides of all magnitudes originate from permafrost-affected rock faces
- shear resistance of rocks reduces under thawing conditions:
- fracture toughness of intact rock bridges, compressive strength, tensile strength and shear strength
- impact of thawing rock on its mechanical properties that control early stages of destabilization remains poorly understood

Aim of study

- How is the impact of thawing rock on its mechanical properties?
- --> focus on deformations and stability changes along discontinuities
- Zugspitze summit lies close to lower permafrost extension limit in northern Alps (NOETZLI et al. 2013)
- --> sensitive for permafrost degradation and rock instability
- **How could / actually does permafrost degradation influence rock slope instability at the Zugspitze summit crest?**

Research concept



Task 1: Temperature related changes in rock-mechanical properties

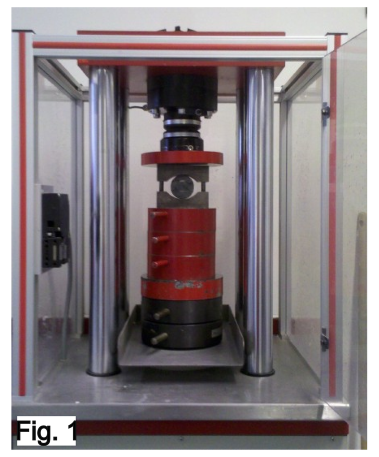


Fig. 1

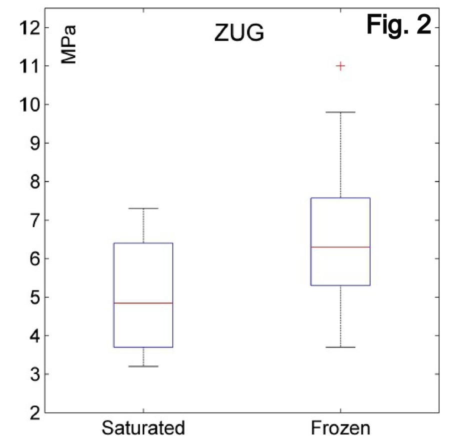


Fig. 2

Results for Brazilian tests / indirect tensile strength of Wetterstein limestone:

- decrease of 30% from saturated frozen to saturated unfrozen condition
- average for frozen samples: 6.6 +/- 2 Mpa
- mean for unfrozen samples: 5.1 +/- 1.4 MPa

Fig. 1: Instrumentation for Brazilian tests in the laboratory (Photo: R. Scandroglio).
Fig. 2: Boxplot of Brazilian tests with 29 Zugspitze limestone samples.


Fig. 3

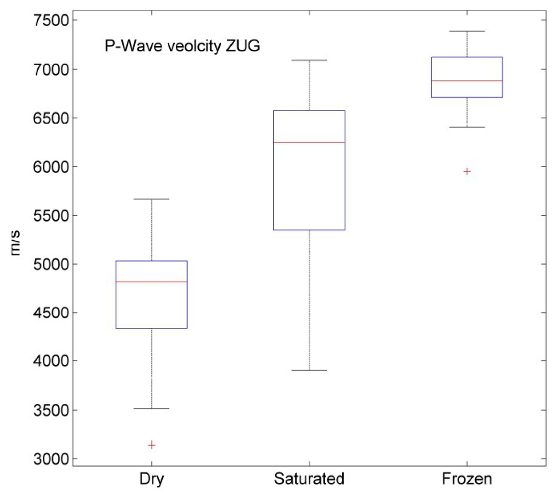


Fig. 4

Results for p-wave velocity of Wetterstein limestone:

- decrease of 15% from saturated frozen to saturated unfrozen condition
- average for frozen samples: 6877 +/- 337 m/s
- mean for unfrozen samples: 5959 +/- 818 m/s
- DRÄBING & KRAUTBLATTER (2012) measure p-wave velocity of Wetterstein dolomite: increase of 70% (3723 to 6383 m/s) parallel to cleavage and increase of 220% (1879 to 6068 m/s) perpendicular to cleavage when freezing

Fig. 3: Seismic measuring device in the laboratory (Photo: R. Scandroglio)
Fig. 4: Boxplot of p-wave velocities in 51 Zugspitze limestone samples.

Next steps:

- tests on i) **mode I and II fracture toughness *(Kic and Kiic)*** of intact rock bridges and ii) **friction along rock discontinuities** without ice infill (3 and 4 in fig. 6)
- tests under positive and sub-zero temperatures with i) **compressive loading device** (fig. 1) and ii) **direct rock shearing machine** in cooling box (fig. 5)

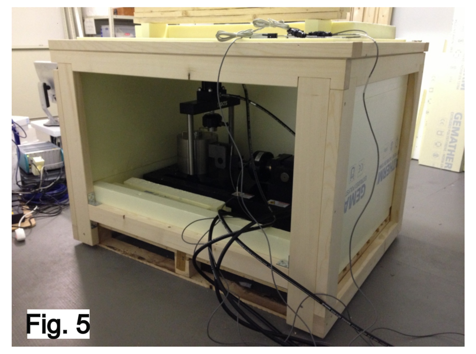


Fig. 5

- **P-wave velocity**: indicator of rock resistance to fracturing/failure due to its close correlation to mode I fracture toughness (CHANG et al. 2002)
- SRT along transect A-B (task 2) combined with mode I fracture touhgness lab-tests --> degree of rock slope resistance to fracturing/failure at test site

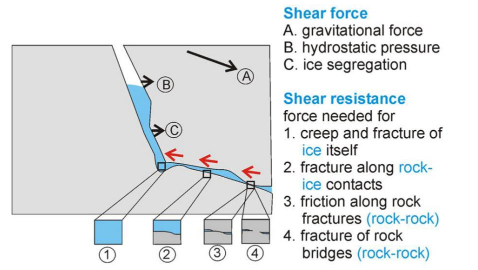


Fig. 6

Fig. 6: Sketch of rock-ice mechanical model referring to permafrost affected rocks (KRAUTBLATTER et al. 2013)

Study site

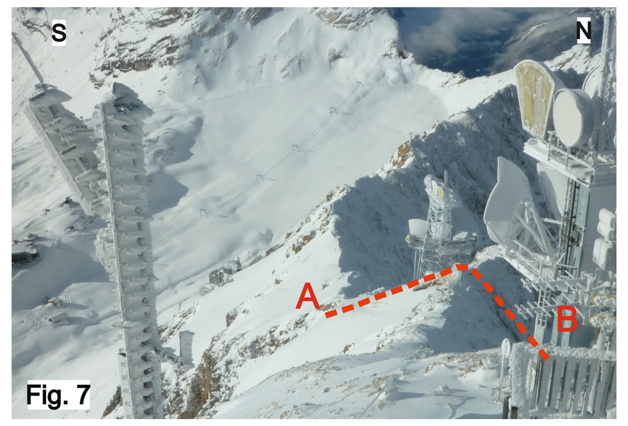


Fig. 7

- Wetterstein crest (2885 m a.s.l.), ca. 150 m south-west of Zugspitze summit, Germany
- **potential rockslide at the south face of the crest** that involves about **10^4 m³ of rock**
  - deep thermokarst caves, persistent faults and bedding planes which unfavourably dip out of the slope face
- **characterized by degrading permafrost**
  - mostly positive rock temperatures at south slope (GUDE & BARSCH 2005)
  - persistent ice-filled cave and joints confirm presence of ice at the crest


Fig. 8

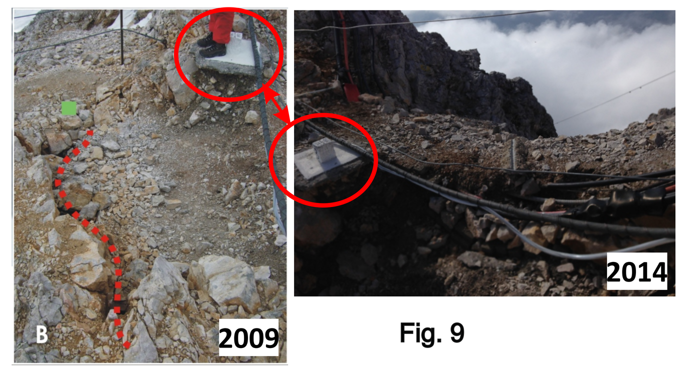


Fig. 9

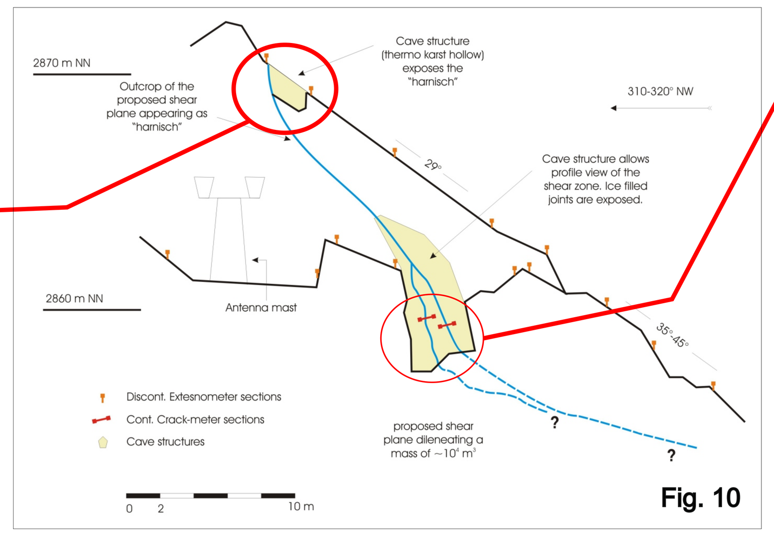


Fig. 10

Fig. 7: View from Zugspitze summit onto study site. Red dotted line presents transect A-B of geophysical permafrost monitoring.
Fig. 8: One of the most persistent faults at the site dipping into the southern slope face (photo: M. Krautblatter).
Fig. 9: Rock deformations at the crest (photos: M. Krautblatter).
Fig. 10: Cross-section of the crest showing one of the most persistent faults at the test site (fig. 8) delimiting the estimated 10^4 m³ of sliding rock mass.

Task 2: Assessment of spatial permafrost distribution

- Electrical Resistivity Tomography (ERT) and Seismic Refraction Tomography (SRT) along transect A-B (Fig. 11)
- Calibration of geophysics in the field: temperature measurements by iButtons/loggers (in 10-80 cm depth in the rock along transect A-B; Fig. 7)
- Calibration of geophysics in the lab: Resistivity and P-wave velocity measurements of Zugspitze limestone samples (Fig. 12)

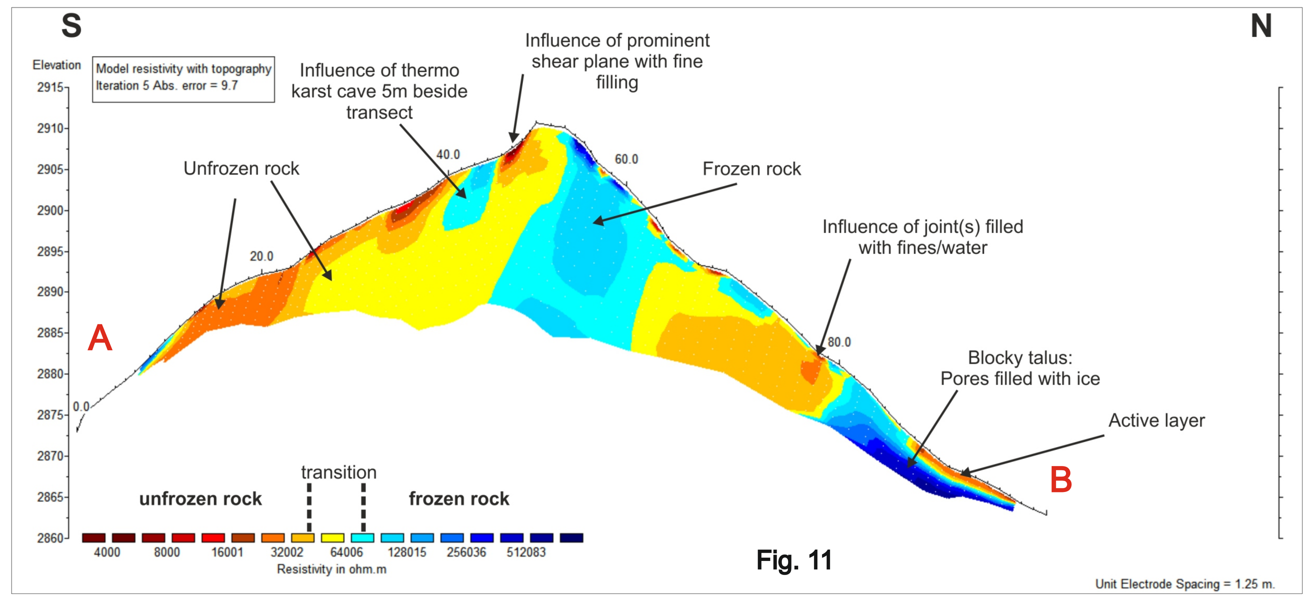


Fig. 11


Fig. 12

Result of ERT:

- large zones of high resistivity (> 60-100 kΩm) at the north face of the crest indicating frozen rock, and large zones of lower resistivity (< 60 kΩm) at the south slope indicating unfrozen conditions

Task 3: Spatial and temporal assessment of rock instabilities


Fig. 13

- **Spatial pattern of instability**
- discontinuity analysis (including orientation, persistence, spacing, roughness, aperture and filling)
- SRT (see task 2) --> spatial discontinuity pattern in the underground
- discontinuous extensometer measurements (since 2009)

Temporal pattern of instability

- continuous hourly crackmeter measurements (2009-2010 and since 08/2014; Fig. 13 and 14)

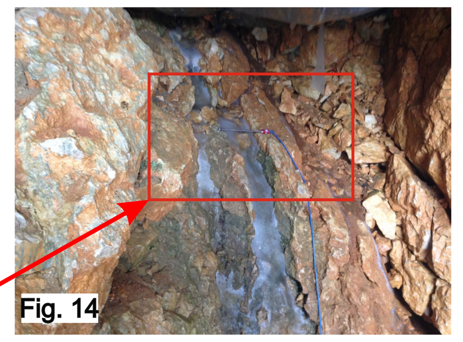


Fig. 14

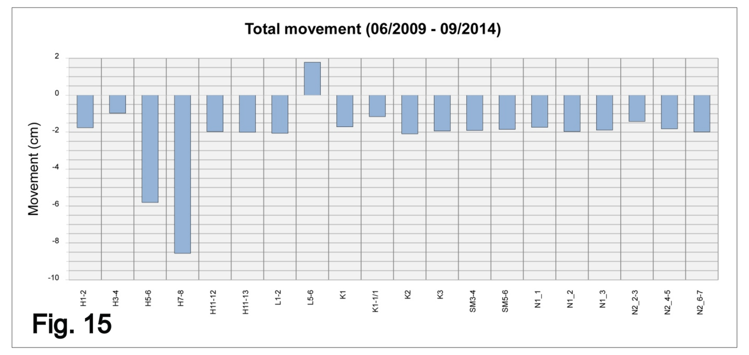


Fig. 15

- **Results for spatial pattern (2009-2014):**
- total deformations up to -8.5 cm
- deformation rates between -0.5 cm and -2 cm
- largest deformations (transects H5-6 and H7-8) at mostly unfrozen south slope across persistent

Fig. 15: Crack movements at extensometer sections adjacent to transect A-B.

Conclusion

- **we detected a potential rockslide (approx. 10^4 m³ of rock involved) at the Zugspitze summit crest**
- **first ERT measurement in August 2014 revealed a mostly frozen north slope and mostly unfrozen south slope of the crest**
- **tensile strength and P-wave velocity of Zugspitze limestone decrease respectively 15% and 30% from subzero (-20°C) to positive temperature (20°C)**
- **we want to develop and calibrate a rock-ice-mechanical model of stability changes in thawing permafrost rocks**
- **we plan to develop a 2D numerical failure model of the rock slope at the Zugspitze summit incorporating the influence of warming permafrost**
- **work is in progress due to the first year of my PhD**

References

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