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\textsuperscript{1}ETHZ, TIK -- \textsuperscript{2}UZH, Geography, 3G

Lab experiment

Reality

Murton et al. 2006
What stresses near-surface bedrock?
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Constant mechanical loads:
- Gravity
- (Overburden pressure)

A. Hasler
What stresses near-surface bedrock?

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Fluctuating loads:
- *Water pressure, Ice formation in pores/cracks*
- *Thermo-mechanical forcing*

Earthquakes
What stresses near-surface bedrock?

Constant mechanical loads:
- Gravity
- (Overburden pressure)

Fluctuating loads:
- Water pressure, Ice formation in pores/cracks
- Thermo-mechanical forcing

Earthquakes

A. Hasler
Theoretical & lab. insights:

(Hallet et al. 1991)

Temperature of Initial Freezing

(Murton et al. 2006)
State of the art

Theoretical & lab. insights:

![Graph showing number of AE's vs temperature](image)

Temperature of Initial Freezing (Hallet et al. 1991)

Transfer to field conditions, where rock already contains flaws/cracks?

![Diagram of Lucite block](image)

Lucite block

After 2 hours (Matsuoka 2001)

(Marton et al. 2006)
State of the art

Theoretical & lab. insights:

```
<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Number of AE's</th>
</tr>
</thead>
<tbody>
<tr>
<td>-8</td>
<td>1</td>
</tr>
<tr>
<td>-7</td>
<td>5</td>
</tr>
<tr>
<td>-6</td>
<td>10</td>
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<tr>
<td>-5</td>
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</tr>
<tr>
<td>-1</td>
<td>5</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
```

- Temperature of Initial Freezing

Transfer to field conditions, where rock already contains flaws/cracks?

- Range of temperature?
- Sensitivity to liquid water content?
- Nucleation of new cracks or propagation of existing ones?

Lucite block

After 2 hours

(Matsuoka 2001)

(Hallet et al. 1991)

(Murton et al. 2006)
Measurement strategy

Acoustic emission (AE) monitoring: 
*detect small “damage increments”*

Frequency range: 20-100 kHz
- Chose for expected source size
- Length scale 1-10cm
- Displacement scale 0.1-1μm
- Eq. magnitude -6 to -5

Detection range:
- controlled by freq. range
- expect most signals from <0.5 to 1m
AE monitoring system: instrumentation and field set-up

AE Sensors (at 10 & 50 cm depth)
Temperature probe
Capacitance probe
WSN nodes

12 V

AE node

Sensor cable
Lid
Spring
POM C tube
AE sensor
Couplant
Glue
Rock
Geo-Gel
O-ring
Alu. plate

Depth
20 cm
Measurement site at Jungfraujoch: 2 complete installations

Densely fractured crystalline rock:
- 5 - 20 clefts / meter
- Crack opening .1-1mm
AE signal characteristics

Signal waveform

Spectrogram

Hammer test
AE signal characteristics

Signal waveform

Hammer test

Acoustic emissions (real ones!)

Spectrogram
AE signal characteristics

Signal waveform

- Hammer test
- Acoustic emissions (real ones!)
- Noise (rubbish)
1 year timeseries: rock temperature, AE activity

Rock temperature
- 5 cm
- 10 cm
- 20-50 cm

Temp. gradient
- 5-10 cm
- 10-20 cm
- 20-50 cm

Spur site (M1)
- 10 cm
- 50 cm

Gully site (M2)

Data plotted over time from October to October, showing variations in temperature and energy rate.
1year timeseries: rock temperature, AE activity

Simple facts:
1 year timeseries: rock temperature, AE activity

Simple facts:

- Energy rates under frozen conditions are roughly 100 times larger than under thawed conditions

Sustained freezing vs. Freeze-Thaw:
- February = sustained freezing +1 cycle
- March = 17 cycles
- $E(\text{February}) > 15*E(\text{March})$
Simple facts:

- Energy rates under frozen conditions are roughly 100 times larger than under thawed conditions.

Sustained freezing vs. Freeze-Thaw:
- February = sustained freezing +1 cycle
- March = 17 cycles
- $E(\text{February}) > 15*E(\text{March})$

- Energy rates in the gully (M2) are 10 times larger than on the spur (M1) under frozen conditions.
Decrease in liquid water content during freezing

Measurements from capacitive probes (Envirosmart)
Influence of freezing on AE activity

- Only events at 50cm considered here

**Spur site (M1) 50cm**

**Gully site (M2) 50cm**
Are AE scaling properties affected by the loading mode?

Frozen = T<0 in the whole rock column (5cm – 100cm)
Thawed = T>0 at 5- 100cm

Micro-seismic events in large rock slide: 2.6
Earthquakes: 2.0
(Helmstetter & Garambois 2010, Kagan 1999)

➢ Energy, duration, waiting times also power-law distributed
Conclusions

At our site, frost cracking is the largest damage driver

- No frost cracking window
- Strong control of water availability on frost cracking
  Factor \( \sim 10 \) here

Rock damage dynamics appear independent of the loading mode (i.e. freezing vs. thermo-mechanical forcing)

- Similar flaws activated by both loading modes
- Damage induced by propagation of existing flaws/cracks
- Suggests the importance “Macro-gelivation”
Frost heave in soils: growth of ice lenses through cryo-suction

(Taber 1930, Rempel 2007, ...)

Diagram showing the flow of unfrozen water and the formation of ice lenses through disjoining forces and suction of liquid water.
Frost heave in soils: growth of ice lenses through cryo-suction

Ice

Unfrozen water

Colder

Warmer

Grain

Rupture

Ice lens

Heave

(Taber 1930, Rempel 2007, ...)
How can freezing deform materials?

When freezing, water expands by 9%

- expulsion of liquid water towards unfrozen zones
- in rapid freezing conditions: increase of pore pressure $\rightarrow$ damage?

Under sustained freezing: growth of ‘segregated ice’

- fueled by suction of water towards already frozen zones
- can fracture rock and heave soils

(Murton et al. 2006)
AE monitoring system

**AE sensor**
- Piezoelectric sensor R6α-sensor: 35-100 kHz, resonant at 55 kHz

**AE-rod**
- Houses the piezoelectric sensor
- Rock-sensor acoustic coupling with ~2 dB loss
- Adjustable sensor depth
- Other rod materials reflect & attenuate acoustic waves

**AE-node**
- Acquisition, processing and transmission of AE data
- 2 channels, 500 kHz sampling rate
- Wireless data transmission
- Threshold remotely adjustable
Estimating rock liquid water content

Sentek Envirosmart:
Material dielectric constant as a proxy for liquid water content

Generate electrical field in radio-freq range
- measure resonant frequency (and material capacitance)
- obtain material dielectric constant $\varepsilon_{\text{mat}}$
- $\varepsilon_{\text{mat}}$ strongly depends on liquid water content

Dielectric constants involved:
- $\varepsilon_{\text{rock}} = 2$–5
- $\varepsilon_{\text{air}} = 1$
- $\varepsilon_{\text{ice}} = 3$
- $\varepsilon_{\text{water}} = 80$–100

Freq. range 100-300 MHz

Real dielectric constant vs. Frequency (Hz)

Fabbi et al. 2006
AE signals: how to select the right ones?

> 650,000 events detected

Analogy to lab. rock fracturing experiments:

\[ D = k_1 \cdot A + k_2 \]

(Cox & Meredith 1993)
AE signals: how to select the right ones?

> 650 000 events detected

Ana to lab. rock fracturing experiments:

\[ D = k_1 \times A + k_2 \]

(Cox & Meredith 1993)

Event generated by an artificial rock fall (~50 liters)

- We cannot strictly exclude the effects of rock falls, or snow avalanches from our dataset!
Results: AE signals

Class 1
Class 2
Class 3
Class 4

Amplitude (V) vs. Duration (µs)

PDF vs. Amplitude (V)

PDF vs. Duration (µs)
Are AE scaling properties affected by the loading mode?

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Freezing vs. thermo-mechanical forcing

![Graphs showing temperature gradients and energy rates over time for wet site at 10 cm depth with warming and cooling phases.]