Hydrogeological Conditions at Åknes in a larger Alpine Framework

Simon Loew
Christian Frei
Reto Thoeny

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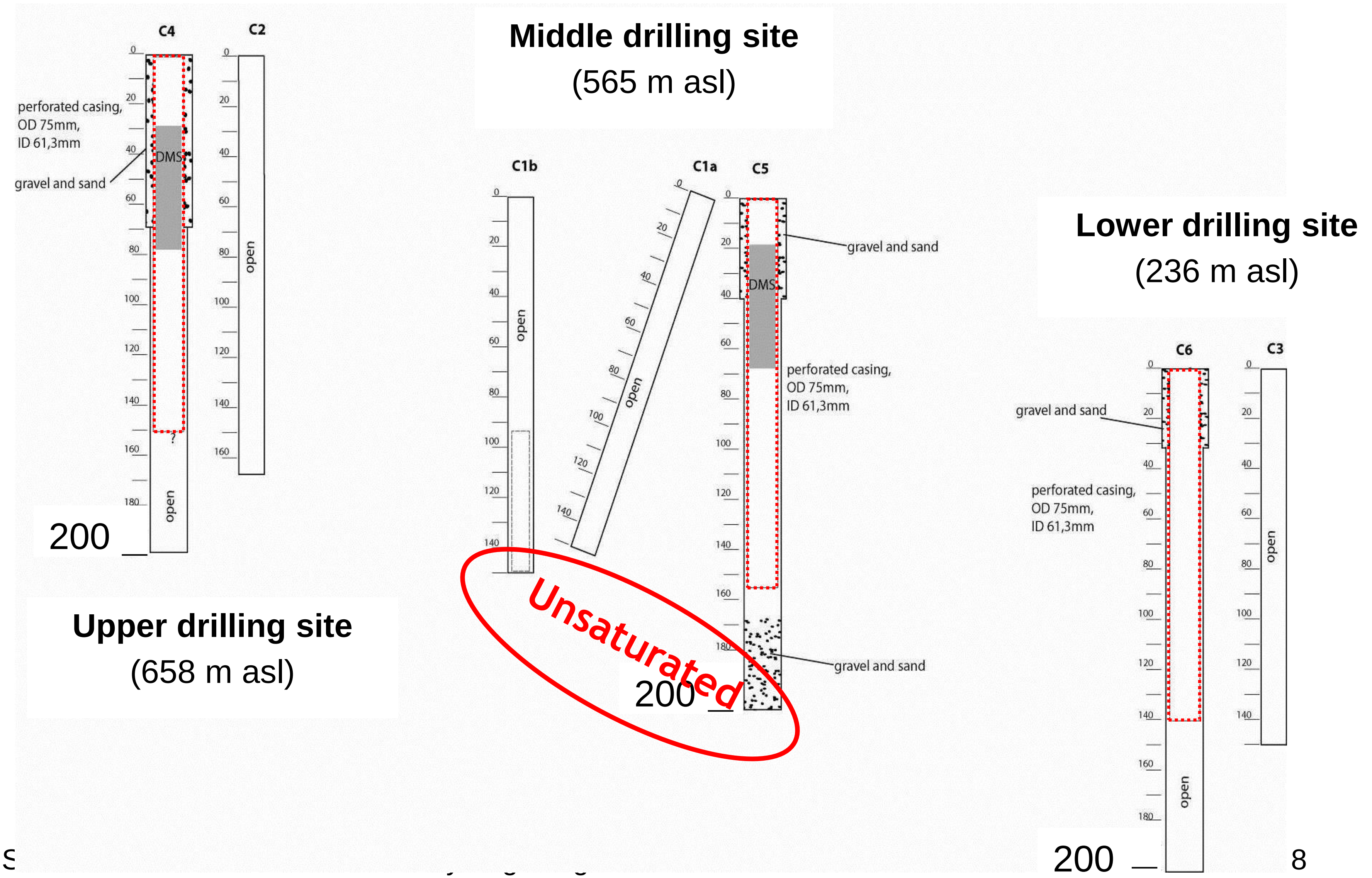
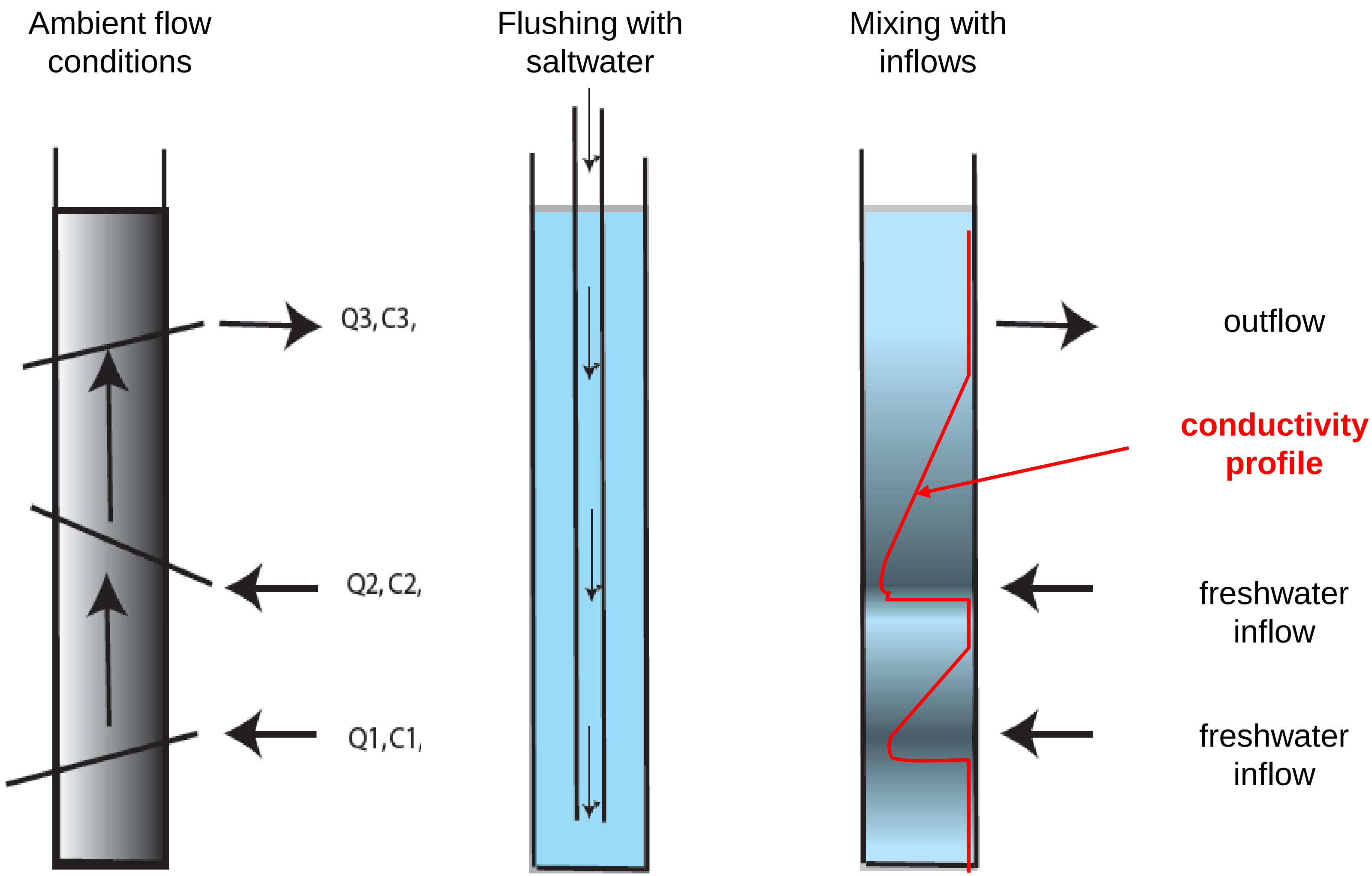
Roadmap

1. Hydraulic Borehole Investigations
2. Large Scale Multitracer Tests
3. Interpretation and Conceptual Flow Model for Aknes Rockslide
4. Hydromechnical Coupling and Comparison with other Alpine Rockslides
5. Summary and Important Open Questions

Borehole Characteristics

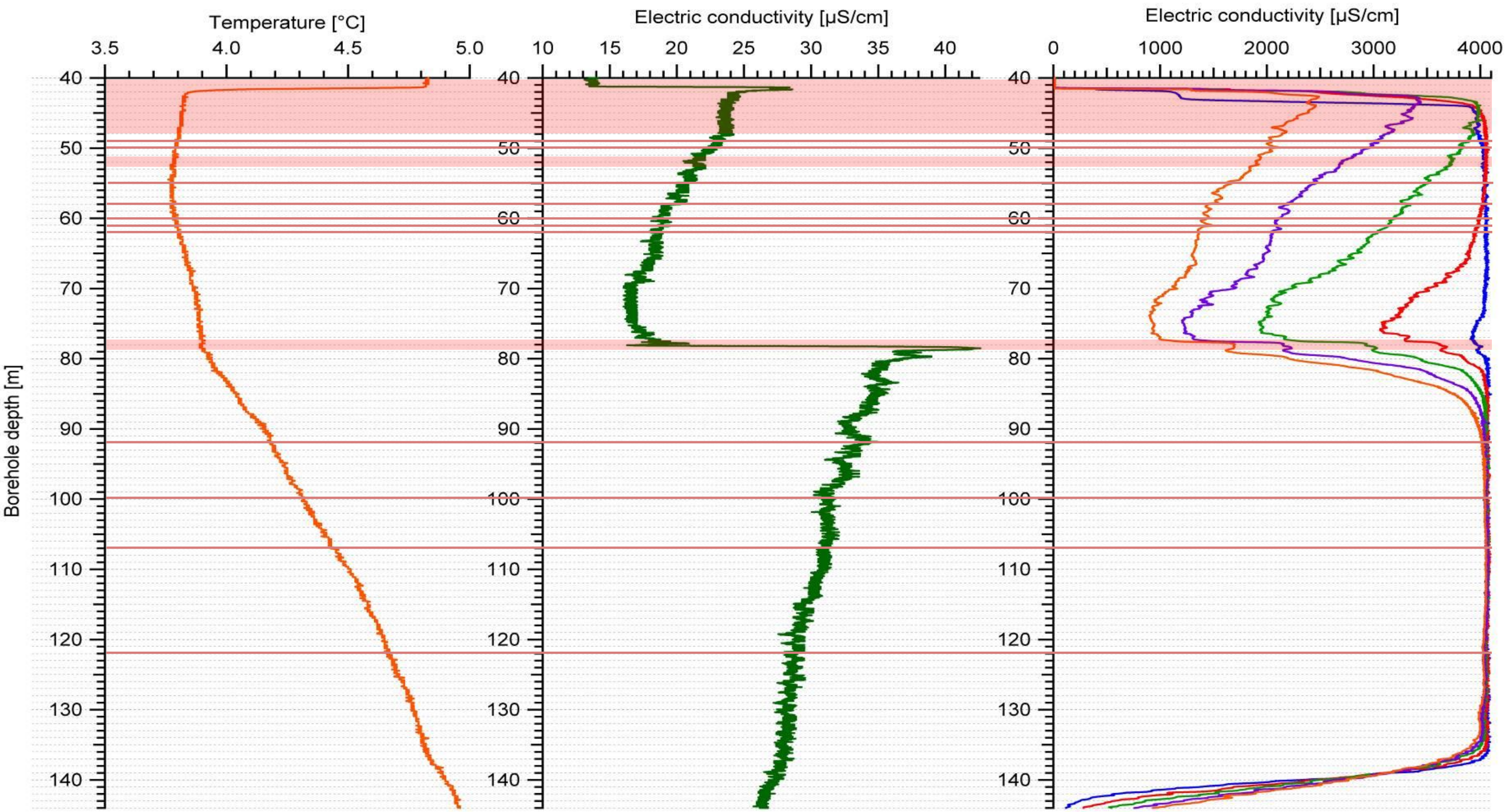


Dynamic Fluid Electric Conductivity Logging



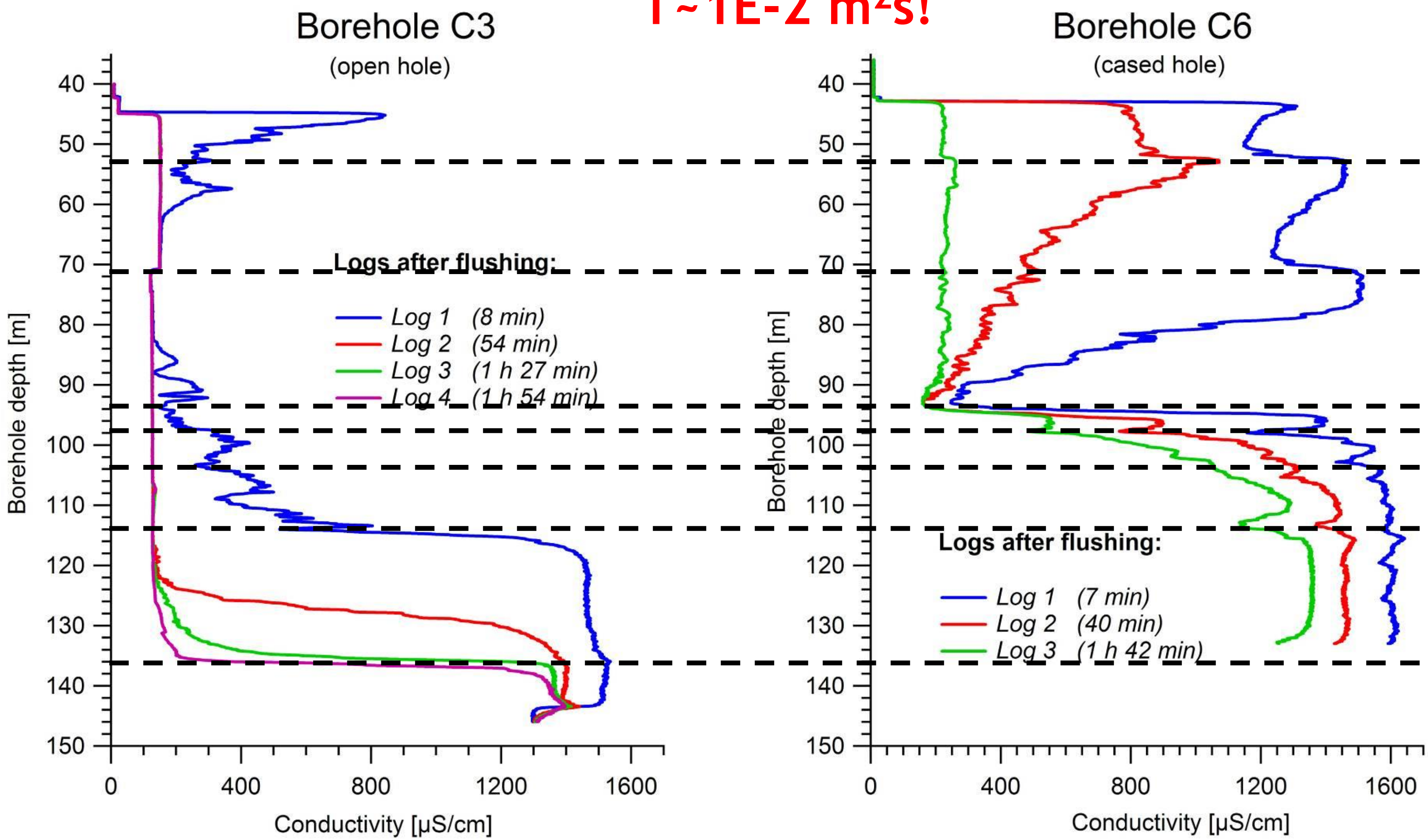
Experimental Setup

Example C5: Steady State & Dynamic El. Cond. Logs

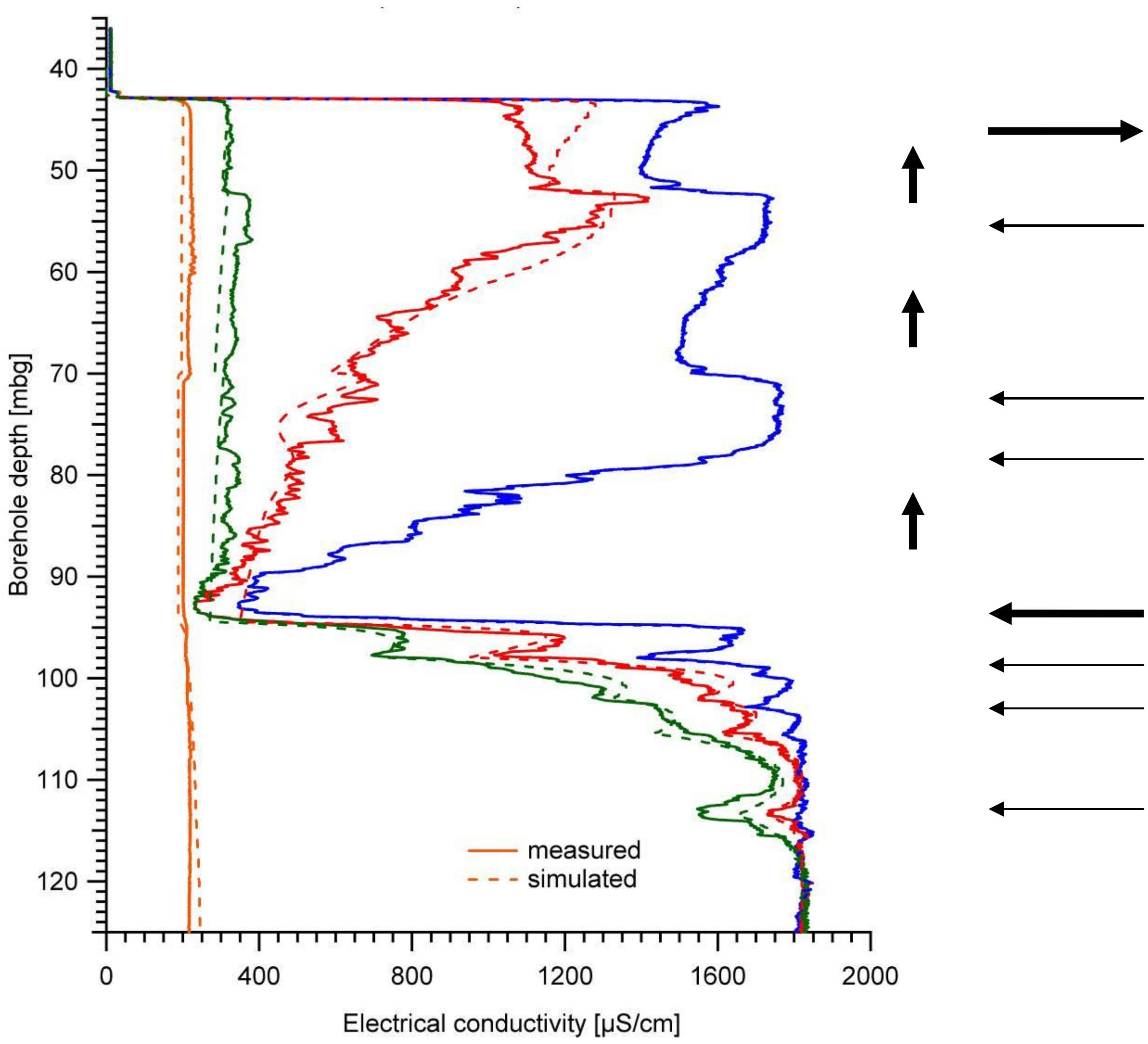


Comparison of Cased & Open Boreholes

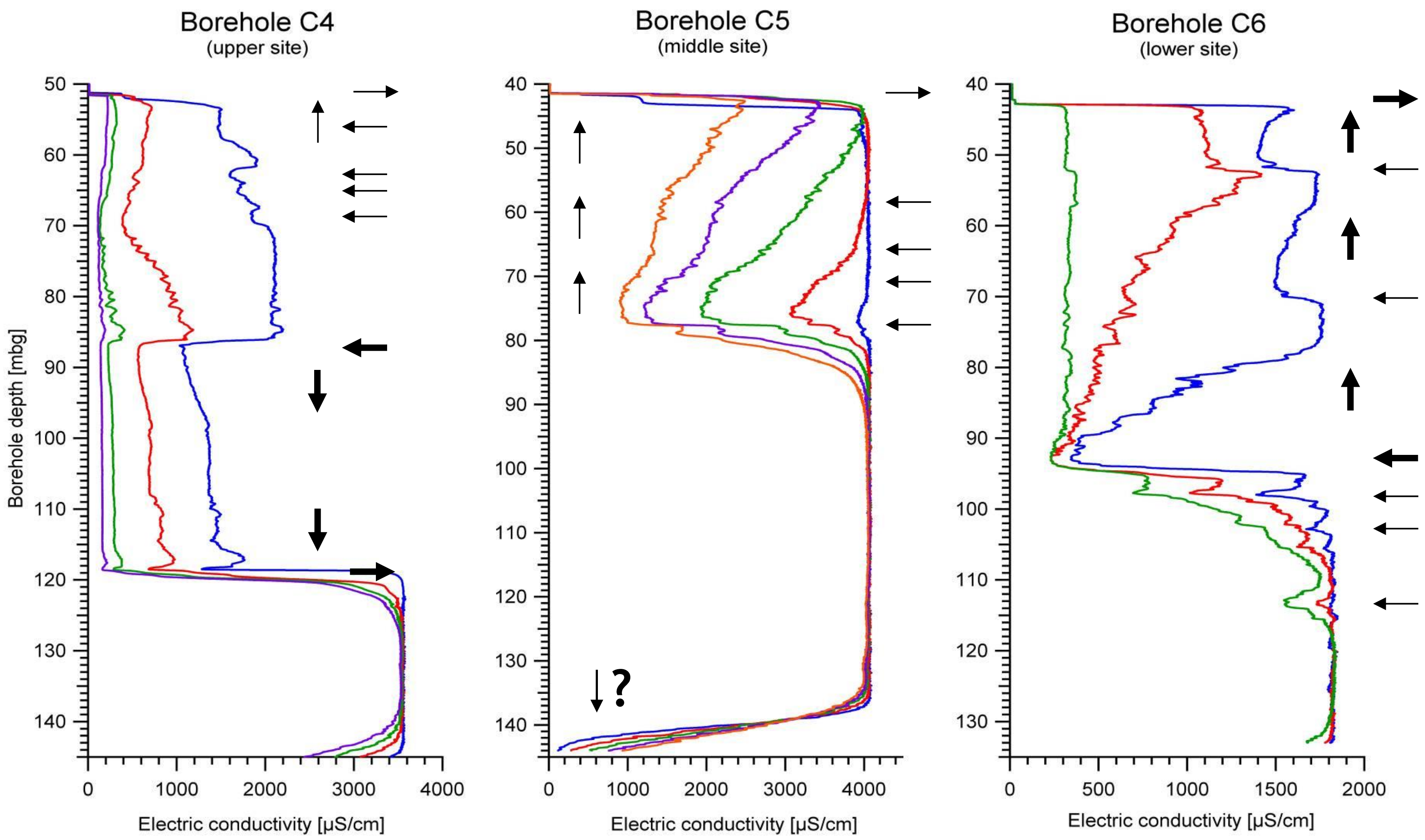
T~1E-2 m²s!



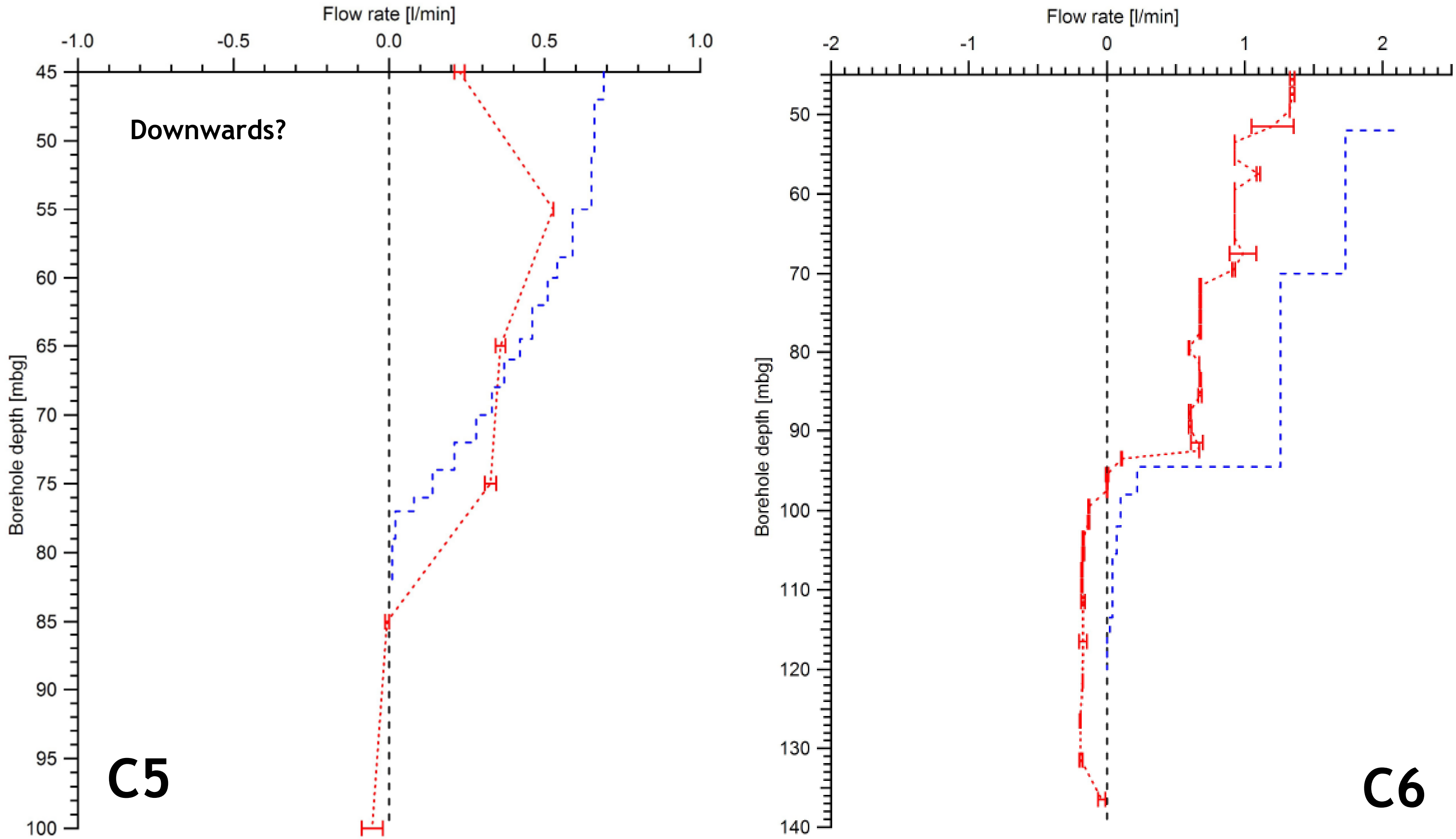
C6 Measured and Simulated EC Profiles



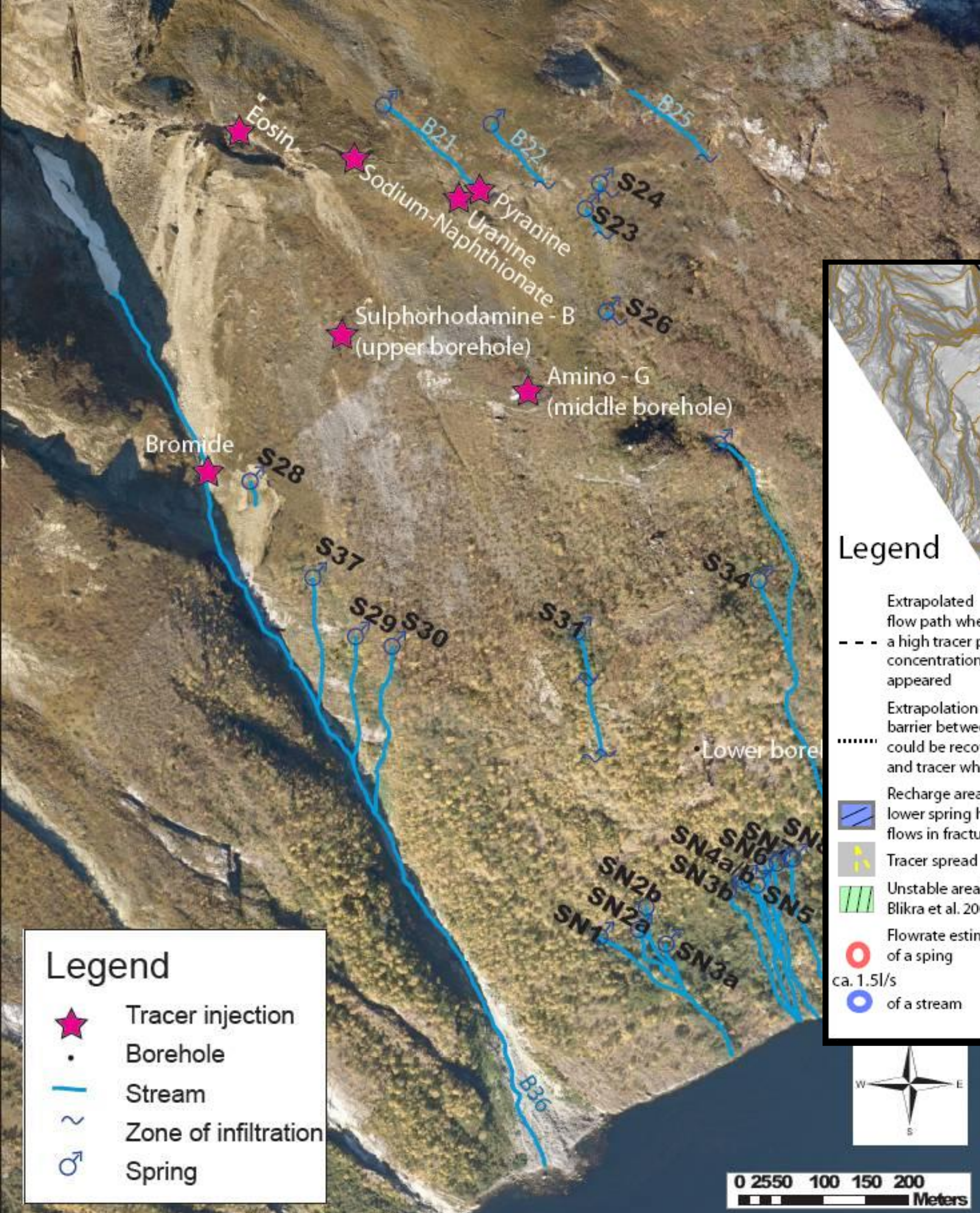
Summary Borehole Flow Directions

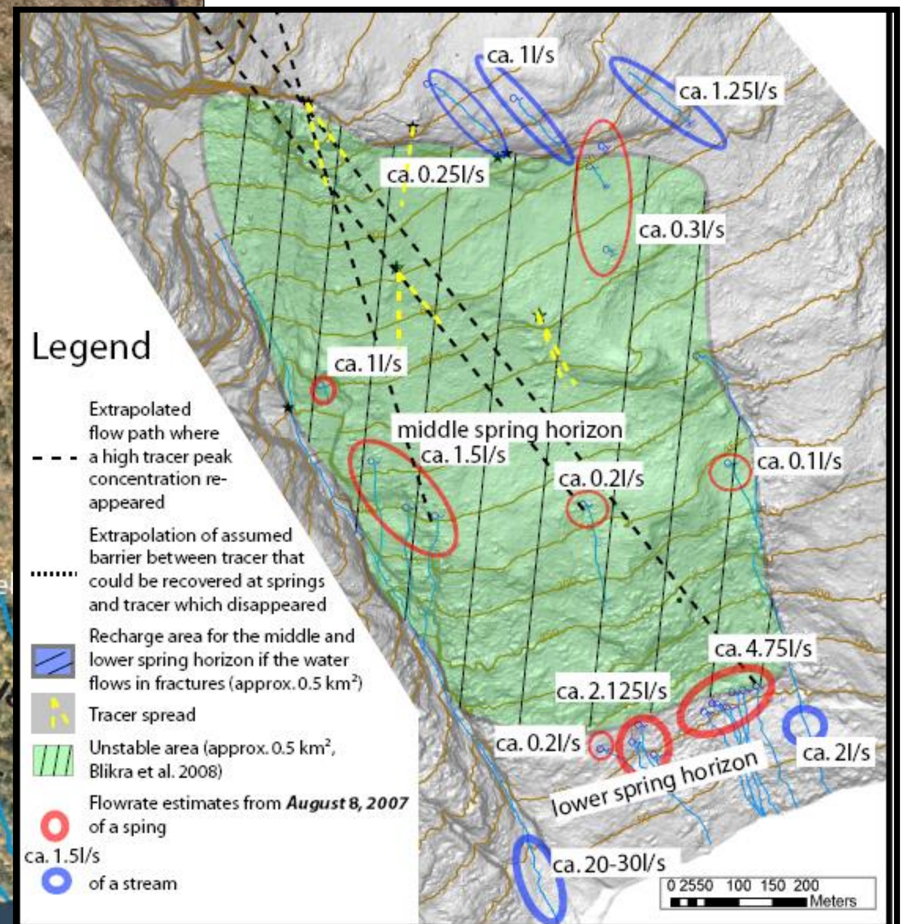


Comparison of FEC & HPFL Results



Surface Hydrology, and Tracer Test Locations





Aknes

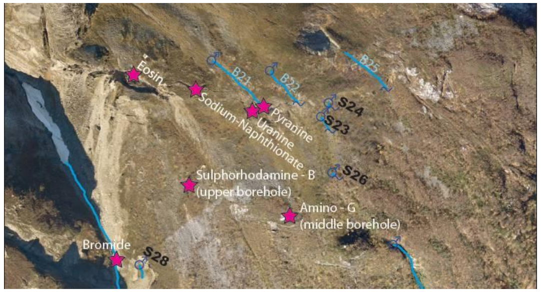
Spring Water Electrical Conductivity (1)

spring	elevation m asl		el. conductivity $\mu S/cm$
S23	645	Aknes, upper Spring	9
S24	658	Aknes, upper Spring	10
S26	577	Aknes, upper Spring	8
B25	>624	Aknes, stream	5

spring	elevation m asl		el. conductivity $\mu S/cm$
S37	463	Aknes, middle spring horizon (west)	27.7 (lab)
S29	405	Aknes, middle spring horizon	26
S30	406	Aknes, middle spring horizon	29
S31	369	Aknes, middle spring horizon	42
S34	339	Aknes, middle spring horizon (east)	13

Spring Water Conductivity (2)

spring	elevation m asl		el. conductivity μS/cm	
			8.8.2007	21.8.2007 with NGU*)
SN1	119	Aknes, lower spring line	57.1	53
SN2a	112	Aknes, lower spring line	95.5	
SN2b	118	Aknes, lower spring line	95.5	70
SN3a	91	Aknes, lower spring line	90.6	82.8 (lab)
SN3b	104	Aknes, lower spring line	46.1	40
SN4	106	Aknes, lower spring line	52.4	46
SN5	98	Aknes, lower spring line	52.4	45
SN6	111	Aknes, lower spring line	52.6	42
SN7	109	Aknes, lower spring line	51.7	32
SN8	107	Aknes, lower spring line	49.9	42
B32		Stream NE-side	13.0 (lab)	12



Injected Tracers

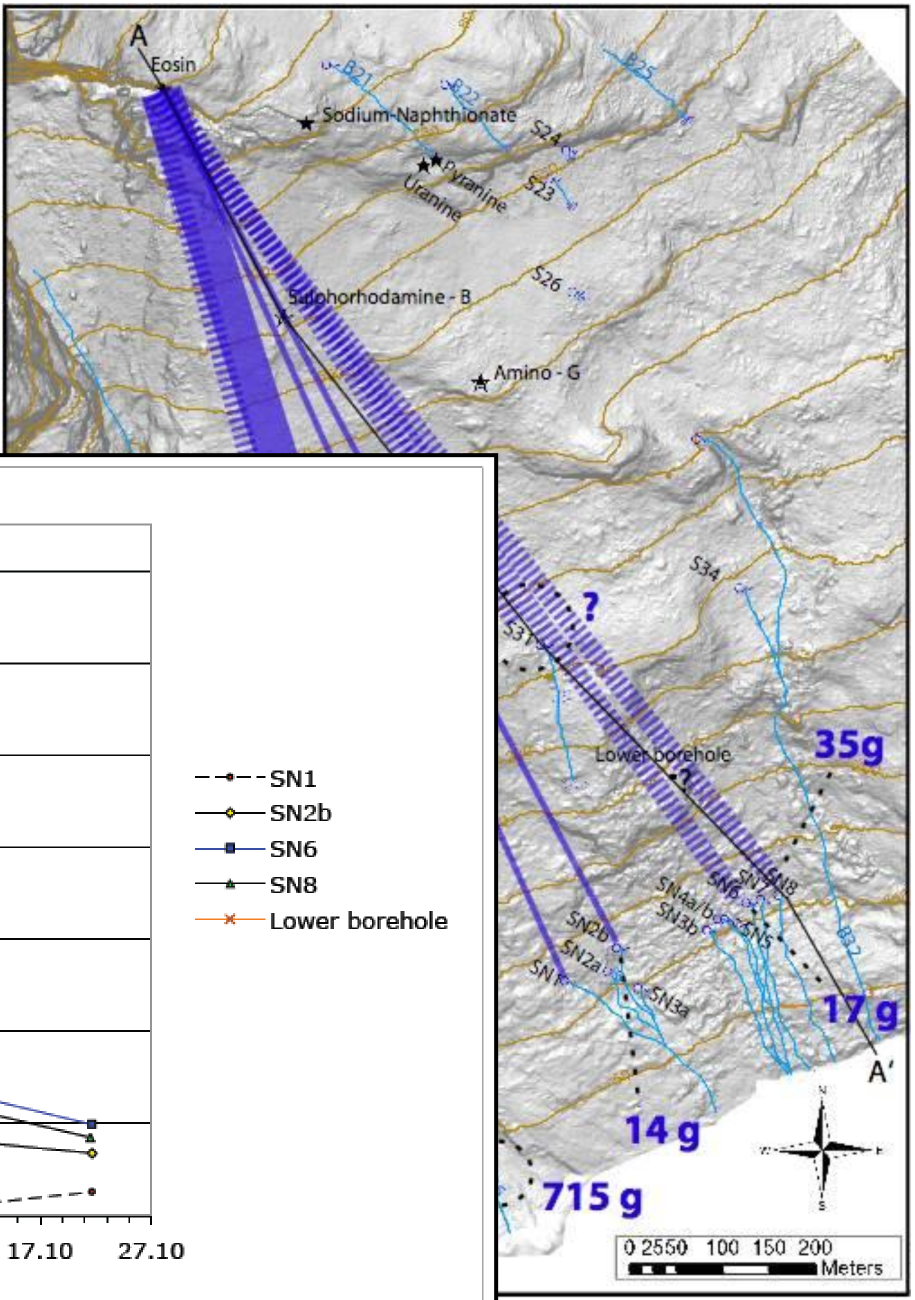
Tracer	Location	Injected amount of salt	Date of injection	Time of injection
Amino-G	middle borehole (40 m deep)	2.5-3 kg	18.8.2007	10:45-11:15
Eosin	scarp, below upper bunker (unsaturated zone)	3.1	16.8.2007	09:00-09:20
Sodium-Naphthionate	scarp (unsaturated zone)	$\approx$ 5 kg	17.8.2007	13:00-13:30
Pyranine	scarp (saturated zone)	0.46 kg	16.8.2007	16:30
Sulphorhodamine-B	upper borehole (120 m deep)	3.3 kg	15.8.2007	15:00-16:00
Uranine	surface near scarp	2 kg	16.8.2007	11:45
Sodium-Bromide (not fluorescent)	large trench "west side" at 503 m asl	25 kg	24.8.2007	$\sim$30% at 8:30 and $\sim$70% at 10:30-11:15

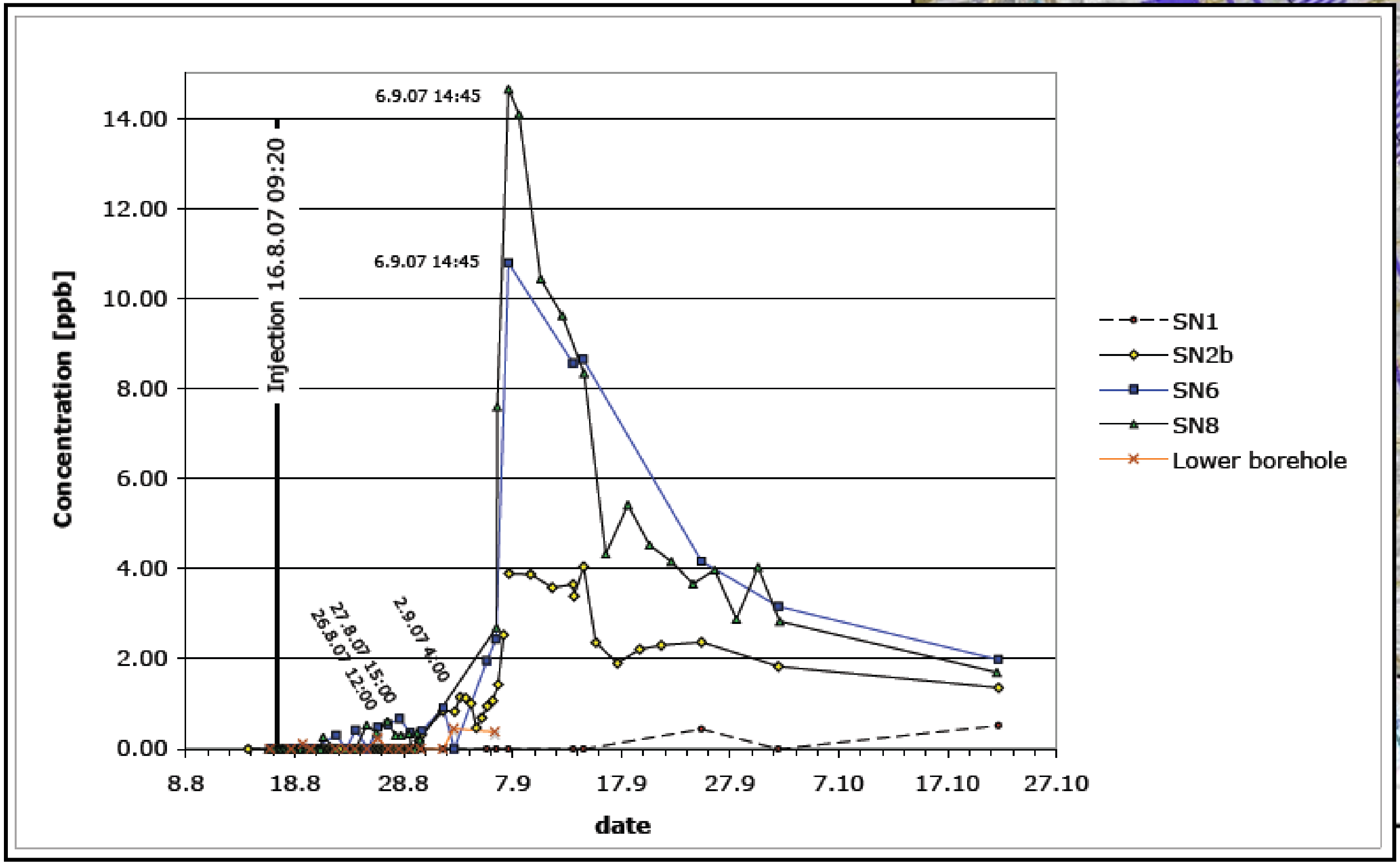
Eosin (Main Scarp)

Tracer recovered in MSH (large mass) and LSH (small mass)

Tracer Recovery > 27%

Peak breakthroughs after 21d



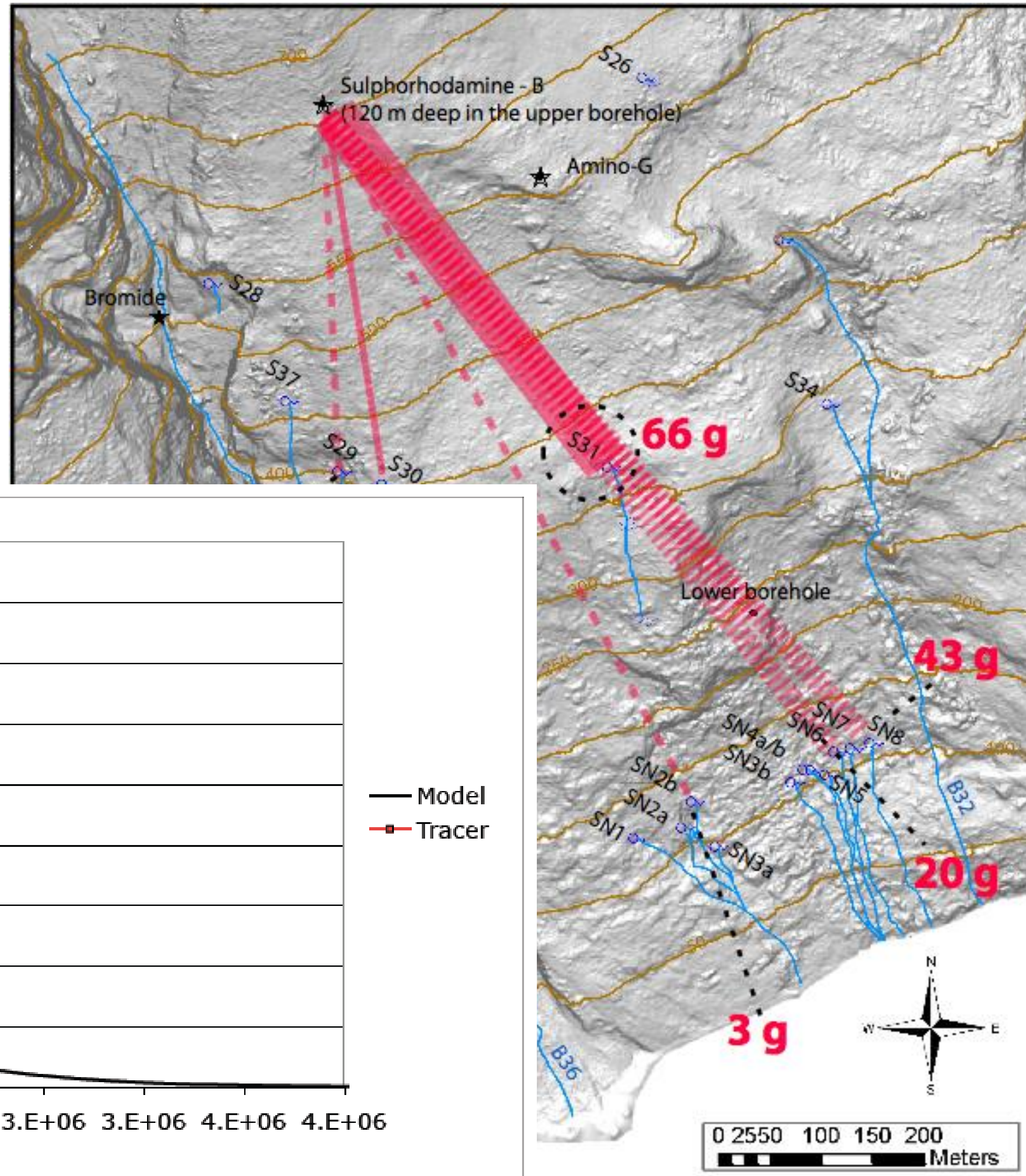


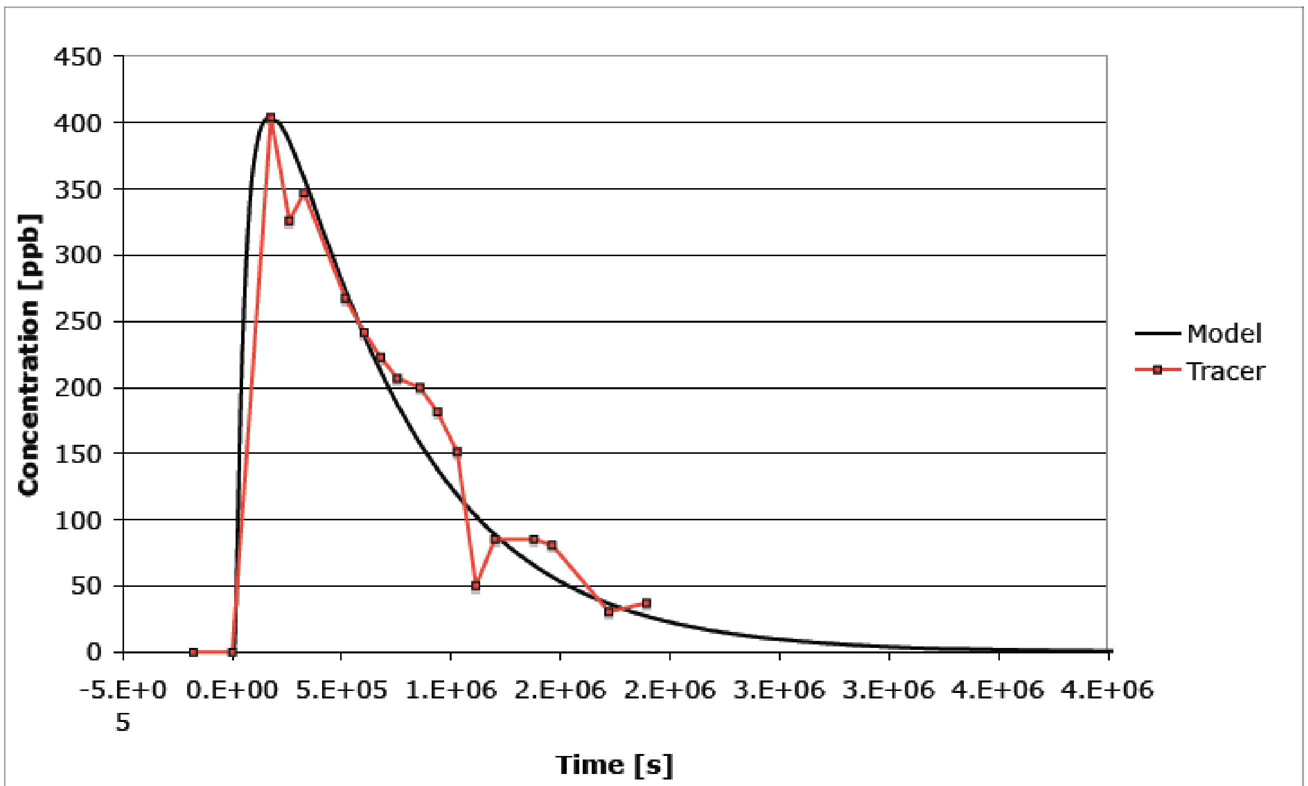
Sulphorhodamine-B

Tracer recovered in LSH & MSP (with equal masses)

Tracer Recovery > 6%

$V_{\text{Peak SN8}}$ = 17.4 m/h



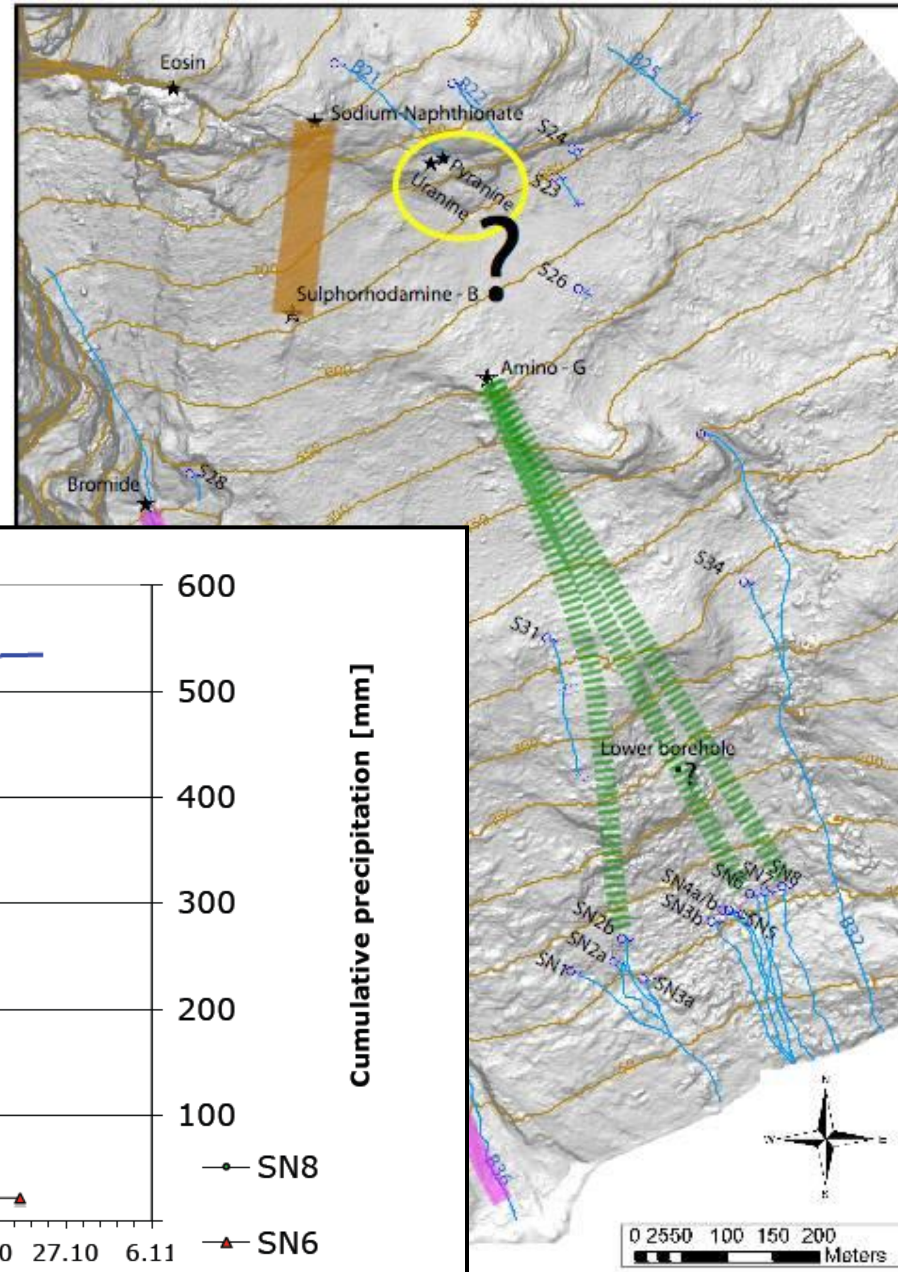


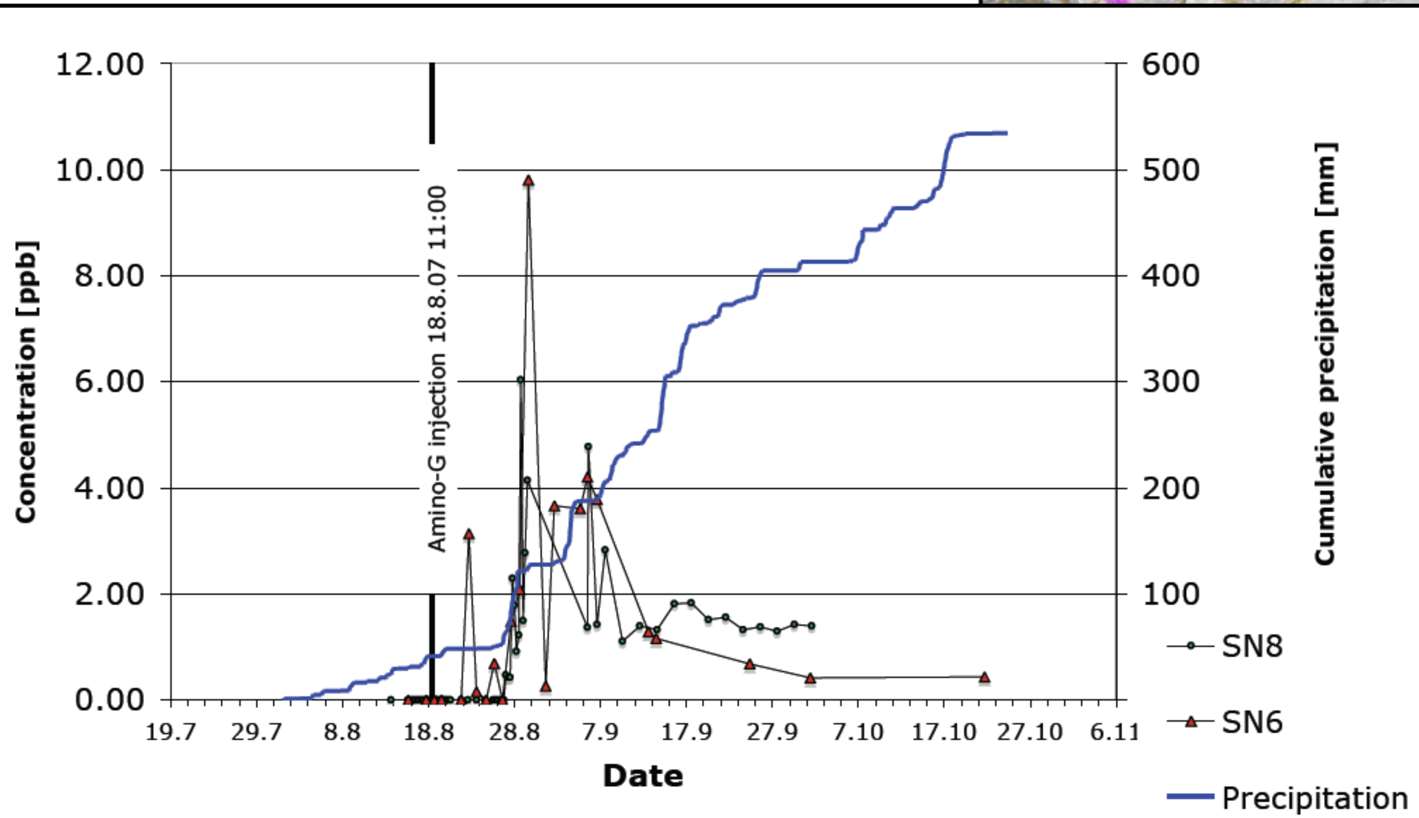
Amino-G (middle bh, 40 m)

Tracer only found in LSH

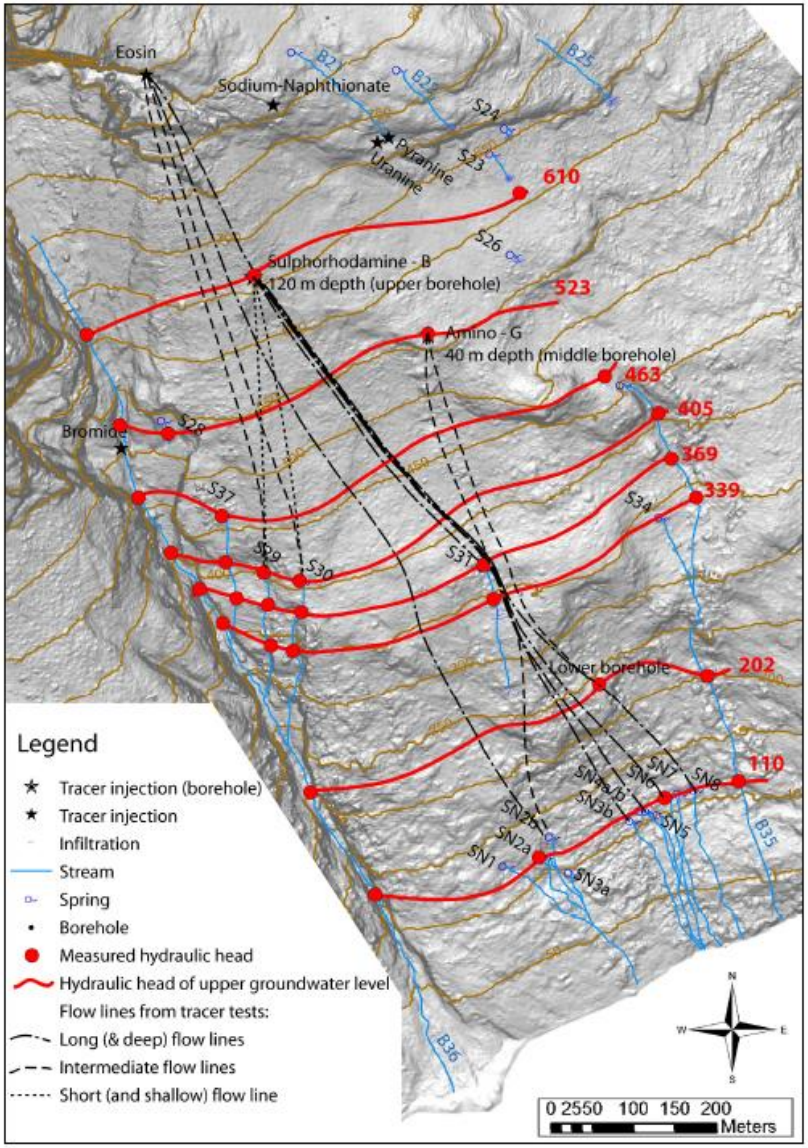
Tracer Recovery > 1-2 %

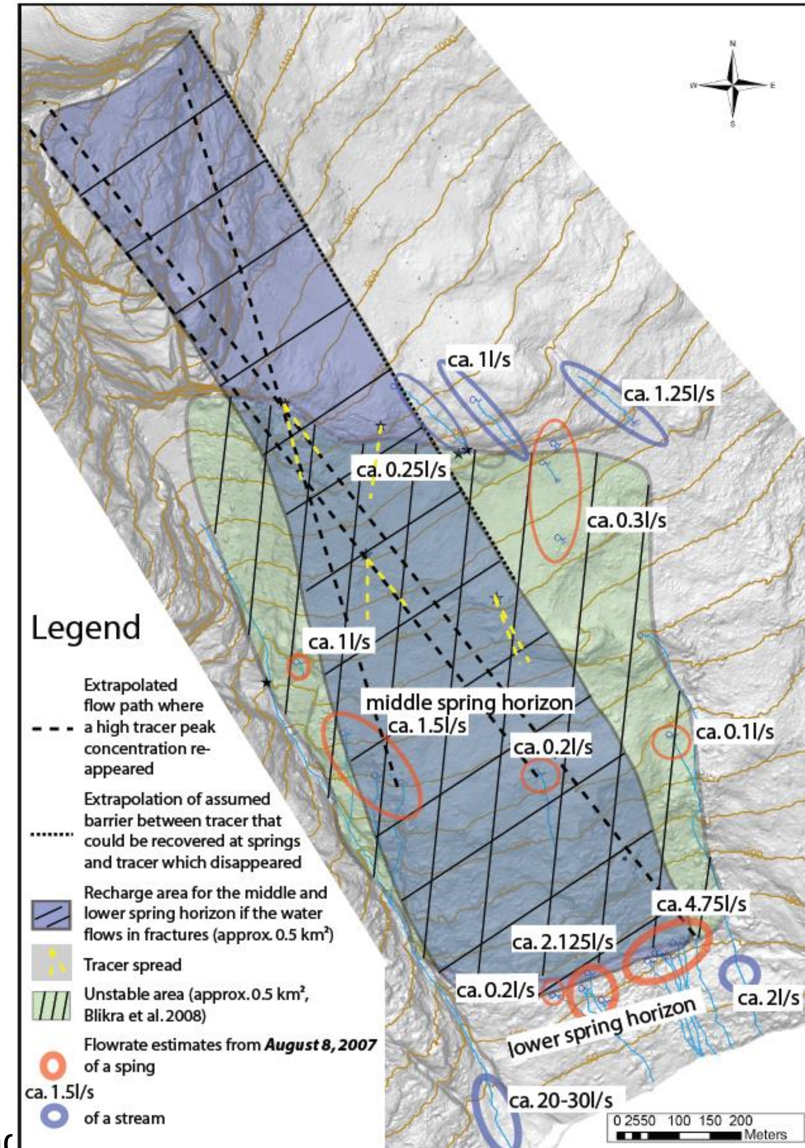
Peak breakthroughs after 10 d (Rainstorm influenced?)





Groundwater Flow Paths & Recharge Areas





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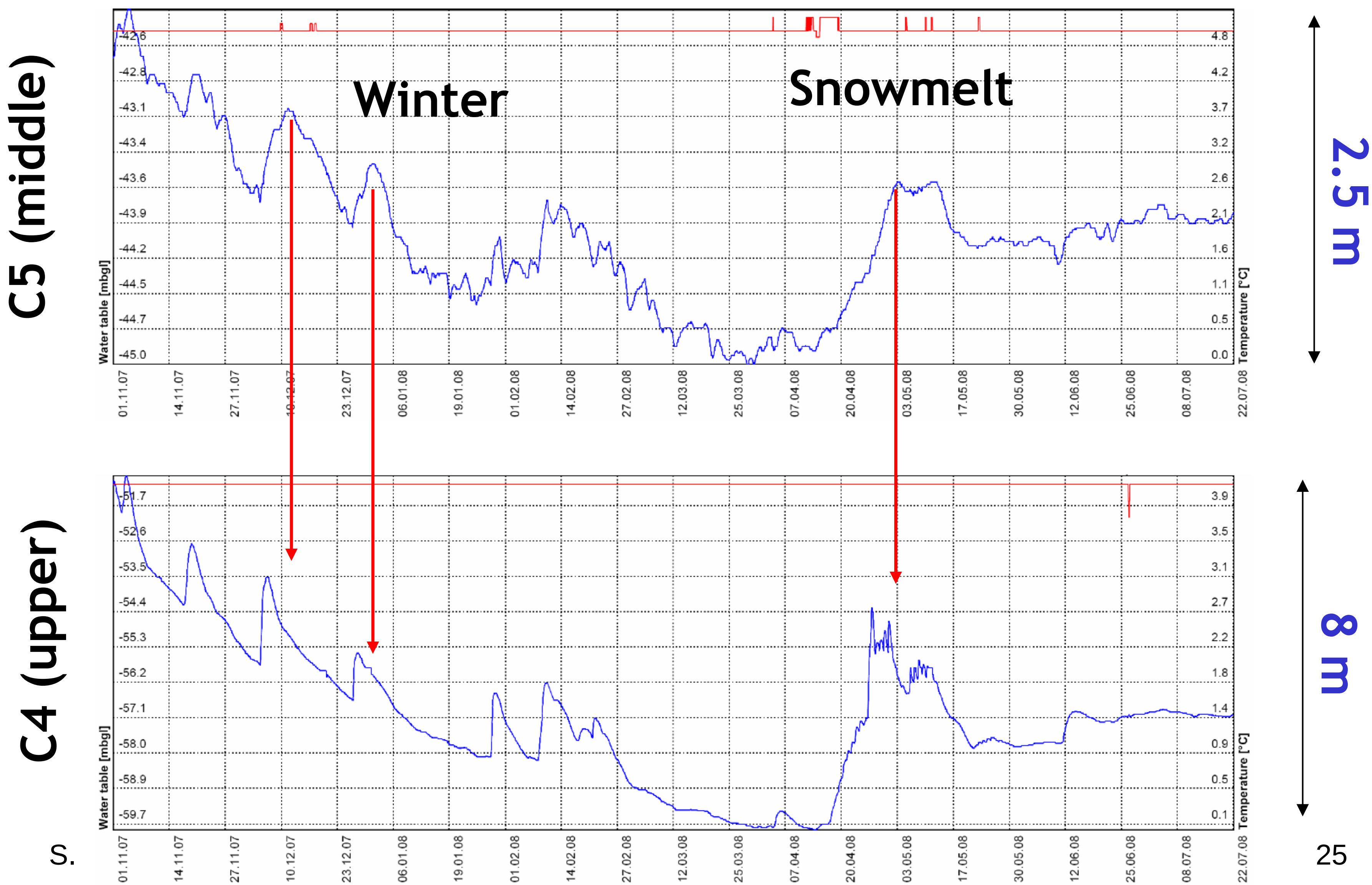
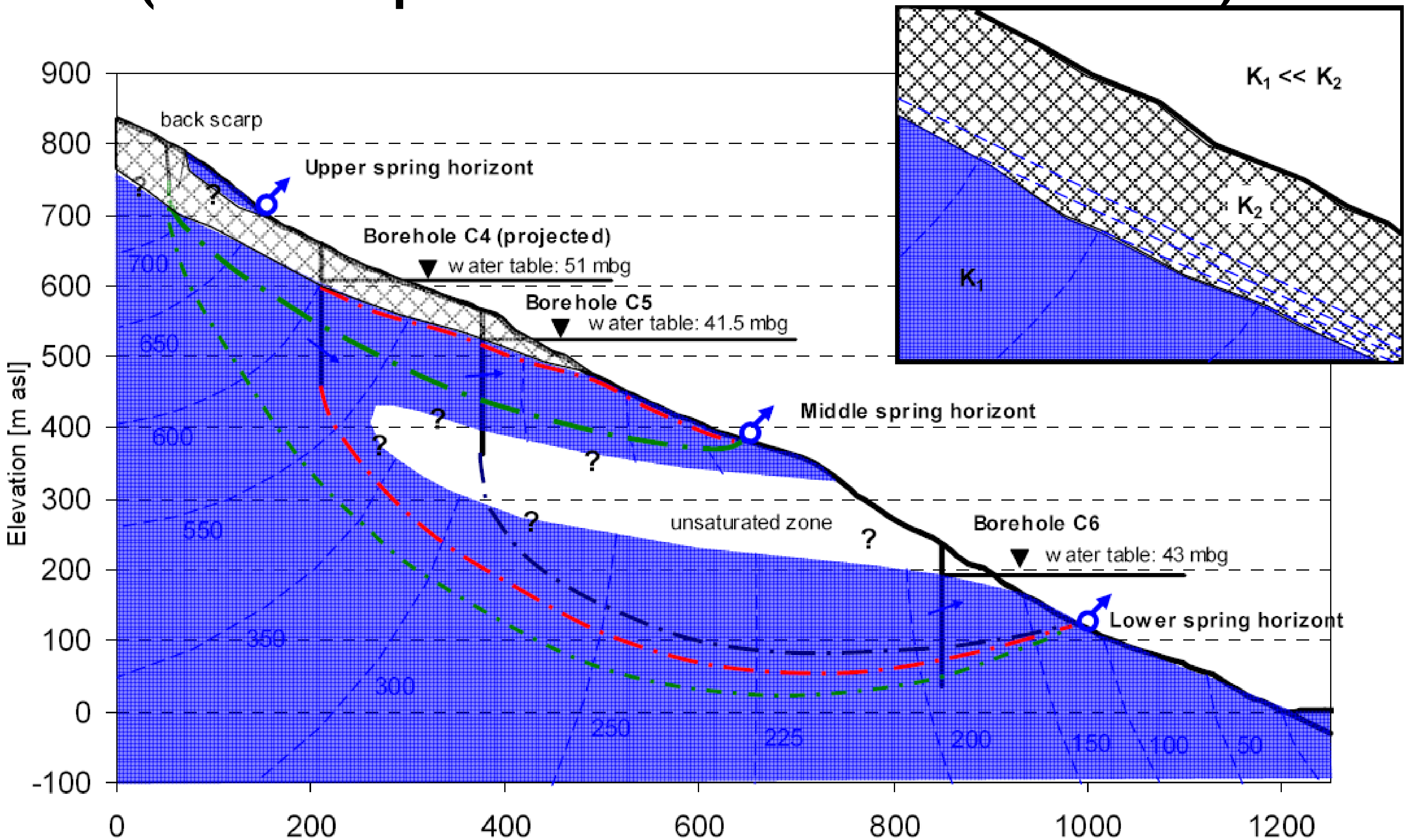
Water Table Evolution October 2007-July 2008

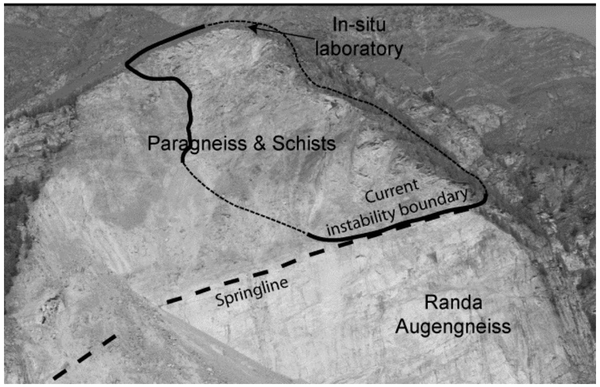


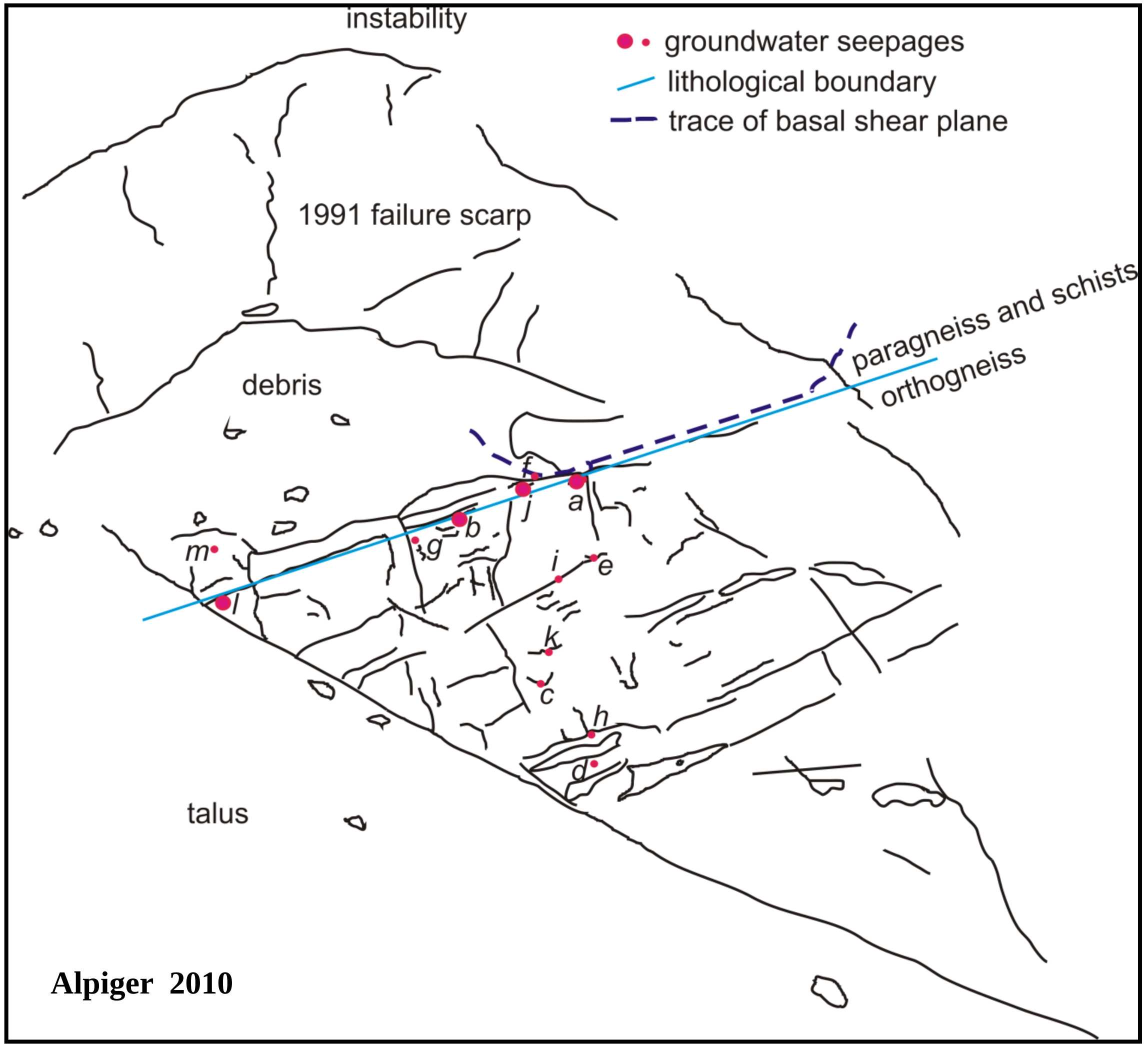
Conceptual Flow Model of Aknes Rockslide (without preferential flow in fractures)



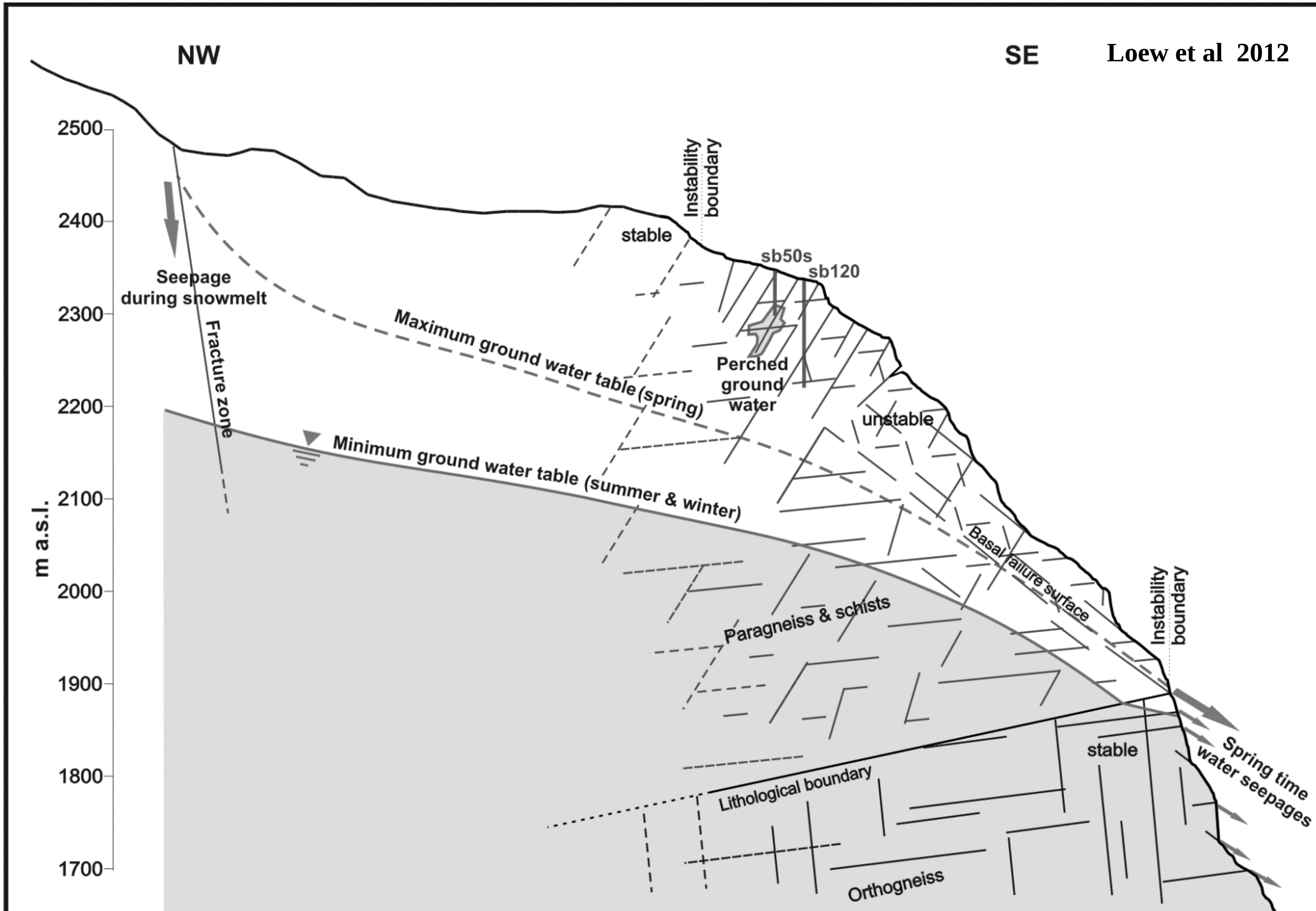
Current Rock Slope Instability at Randa

Spring Locations and Activity from TLC

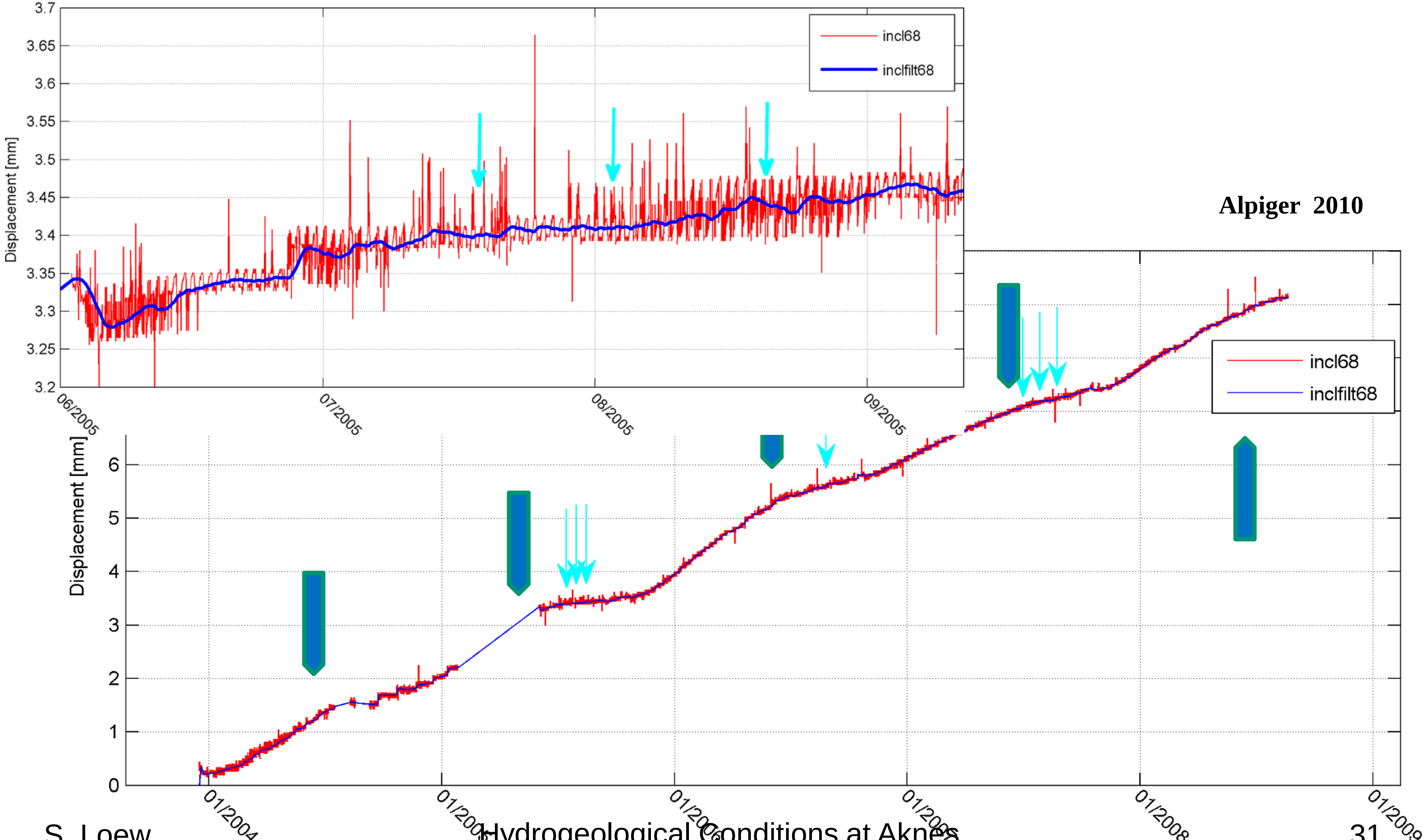


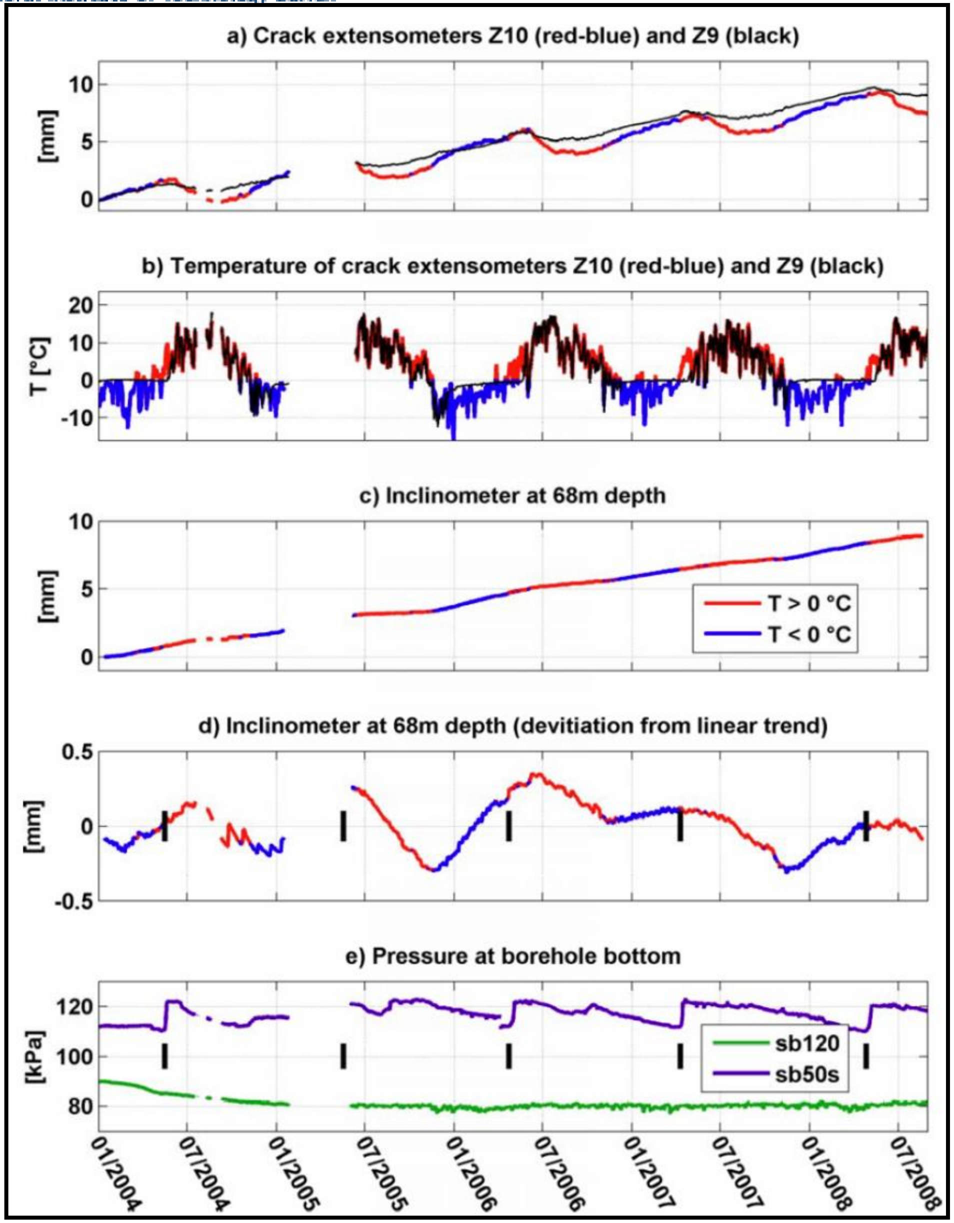


Conceptual Hydrogeological Model Randa



Transient Displacements in SB120 (68m), Rain Storms (>25 mm/d) and Snow Melt Periods



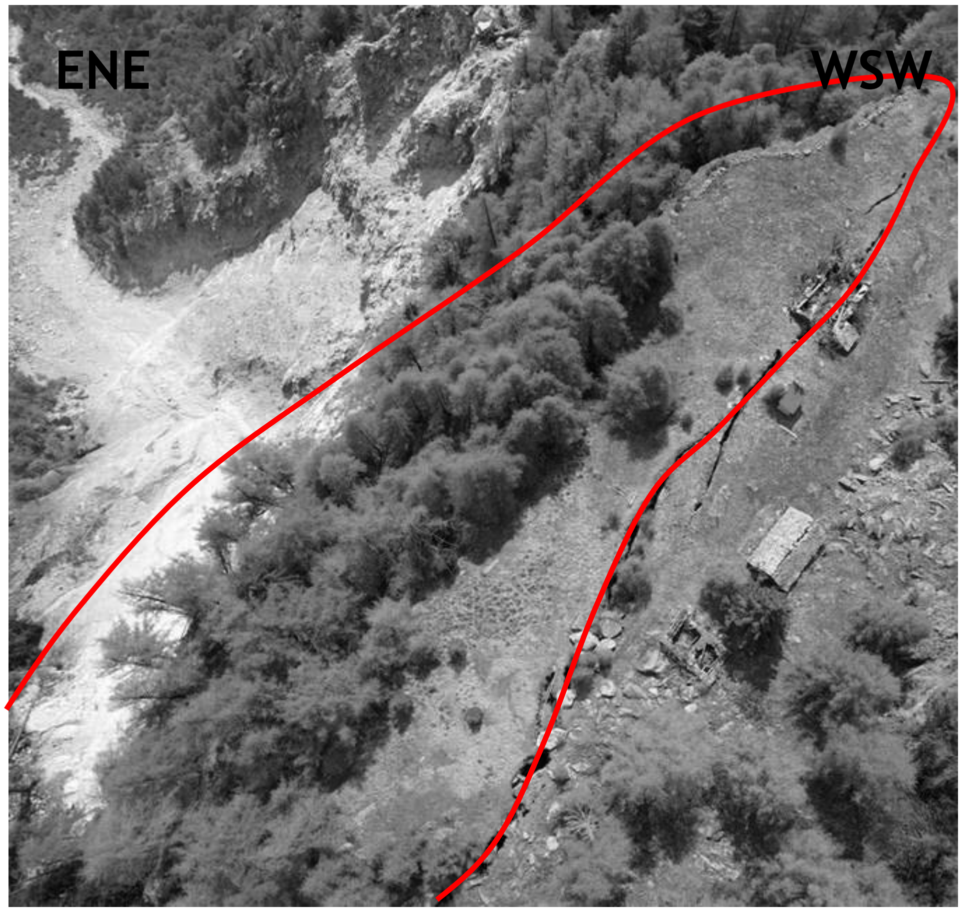


Thermo-mechanical Forcing controlls Displacements and Progressive Damage at Randa

Gischig et al. 2011b

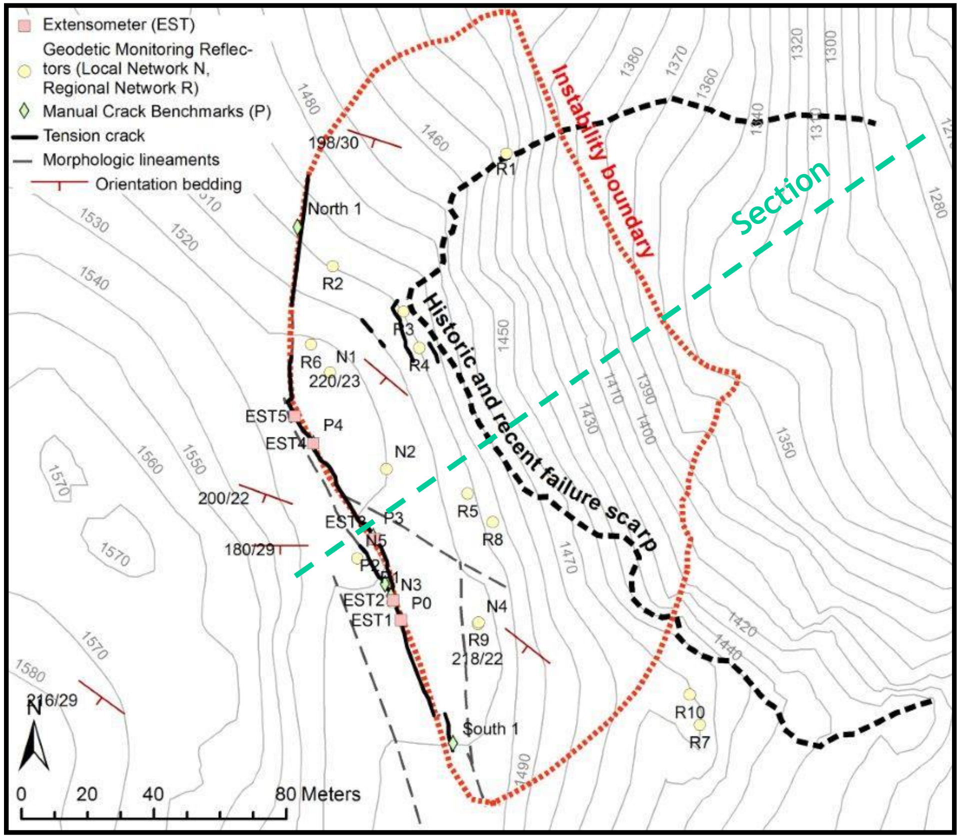
Rock Slope Instability above Preonzo (Before Failure of May 2012)

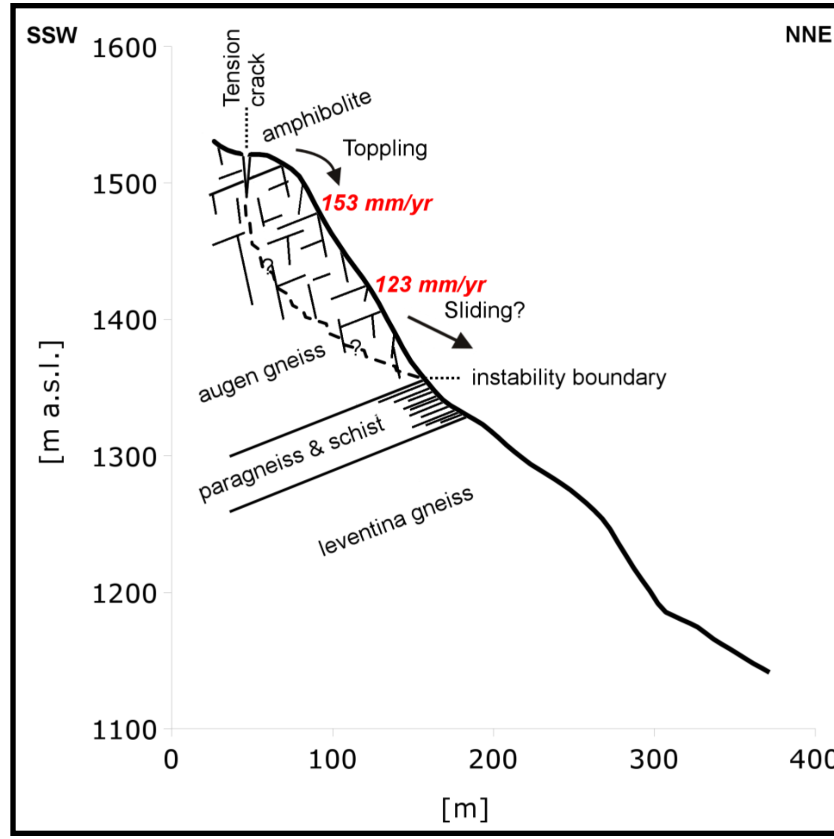
Vertical View



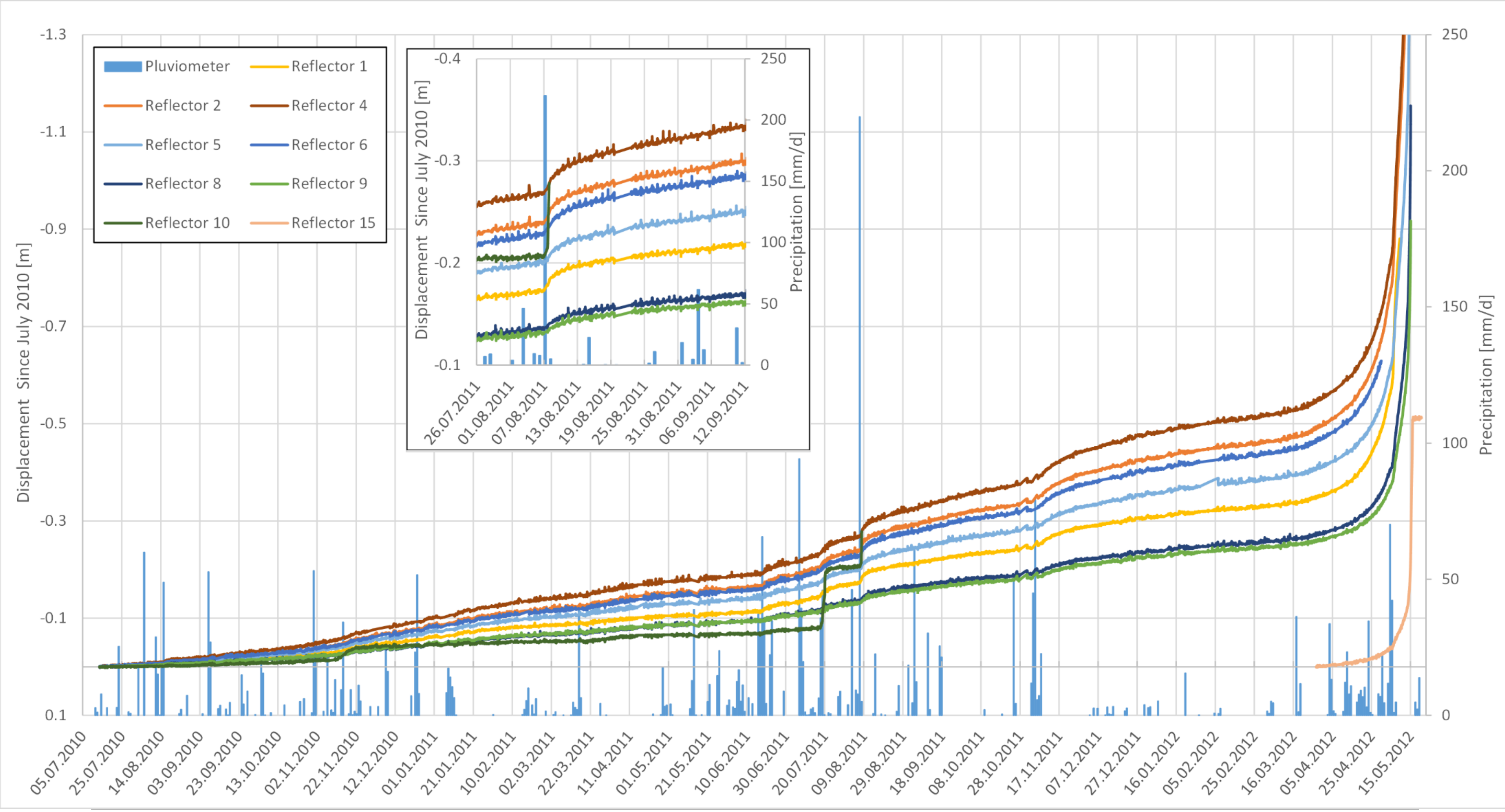
Horizontal View

Geological and Hydrogeological Predisposition at Preonzo

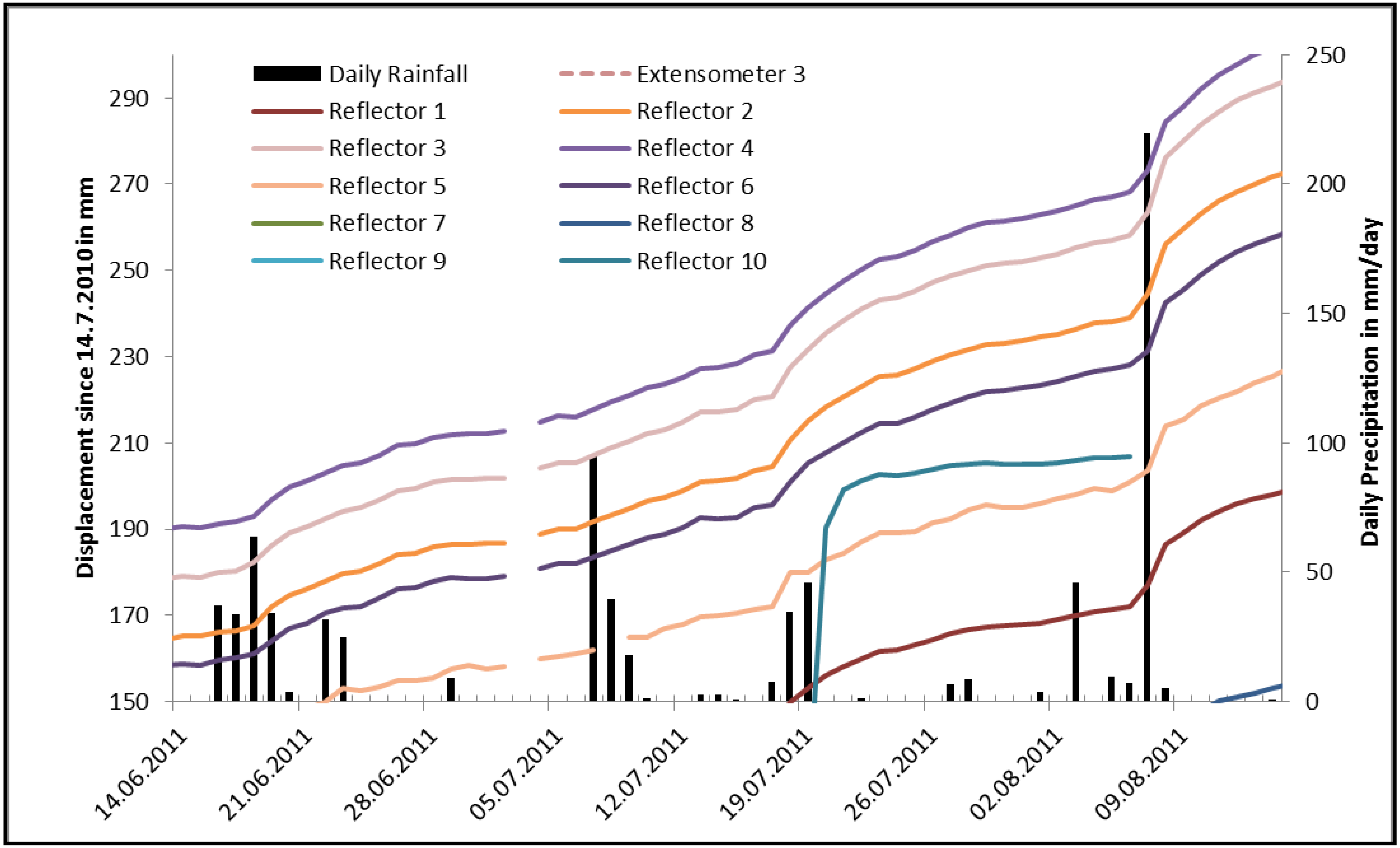




Hydro-mechanical Forcing Controlls Displacements and Progressive Damage



Local Rainfall Events of > 100 mm trigger Short Term Accelerations



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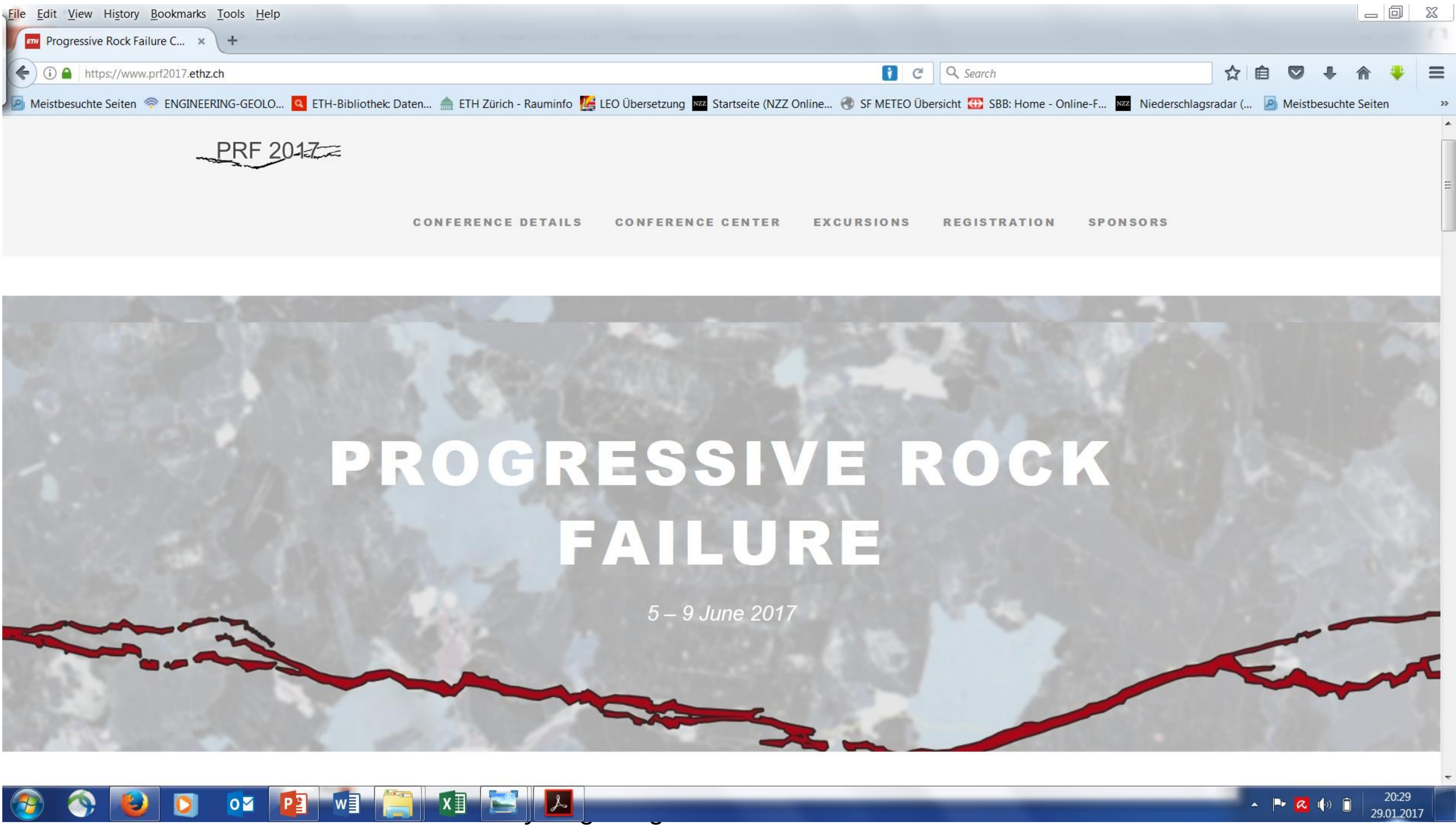

Summary of Groundwater Hydraulics at Aknes

- We observe a very transmissive & unsaturated layer in the uppermost 40-50 m bgs (transmissivity > 1E-2 m^2/s) corresponding to the heavily fractured part of landslide mass
- Strong ambient borehole flow between 40 and at least 200 m depth bgs indicates significant vertical head gradients, typical for steep slopes
- Reversal of flow direction in upper drilling site indicates a complex hydraulic head field and deeply infiltration
- The observed unsaturated zone at 190 m depth at the middle drilling site suggests a hydrogeologic stratification with a perched near surface aquifer feeding the middle spring horizon and a main aquifer feeding the lower spring horizon
- Clear differences in mineralization, head gradients and results from tracer tests show that recharge area is close to upper spring horizon and that lower spring horizon is located in the major dischrage area of the slope (and landslide mass?)
- Flow lines are localy diverted towards the western gully
- Fast downslope directed groundwater flow (17 m/d) is supported by 2 steeply dipping fracture sets

Important Open Issues Aknes Rockslide Hydrology

- Existing hydraulic measurements in deep open boreholes can not be interpreted quantitatively:
  - *We only know hydraulic head gradients (flow directions) but what are the absolute values of hydraulic head and pressure as a function of depth?*
  - *What are the absolute pore pressure variations and how do they quantitatively relate to transient recharge rates from snow melt and rain storm?*
  - *What are the hydraulic conductivity or transmissivity values of all relevant hydrostratigraphic layers?*
  - *What are the detailed relationships between water pressures variations and displacements?*
- Where are the main recharge areas and what are the main recharge mechanisms?

- We need multilevel hydraulic borehole monitoring and hydraulic testing systems (away from regions affected by open boreholes). A proposal for such measurements is presented on Tuesday.