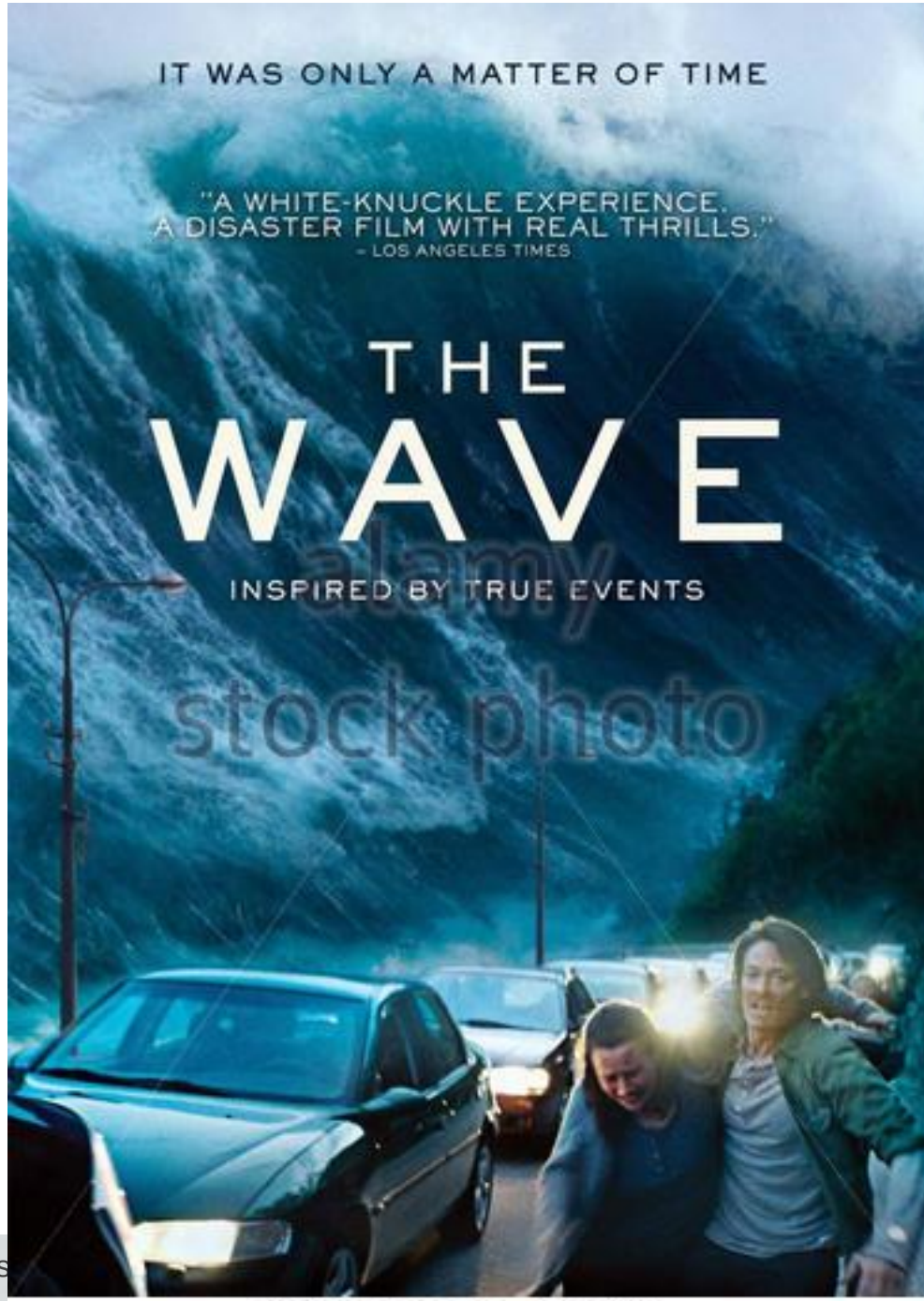
Åknes overview and status

Lene Kristensen
Section for Rockslide Management



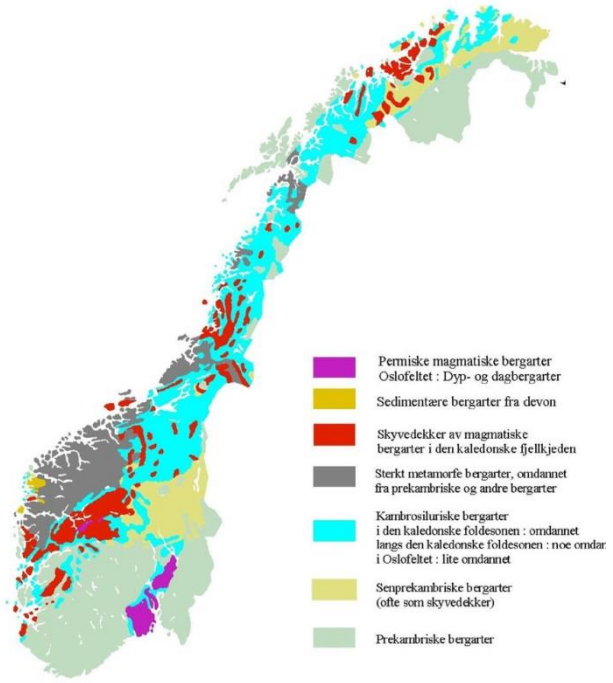
Tafjord disaster 1934

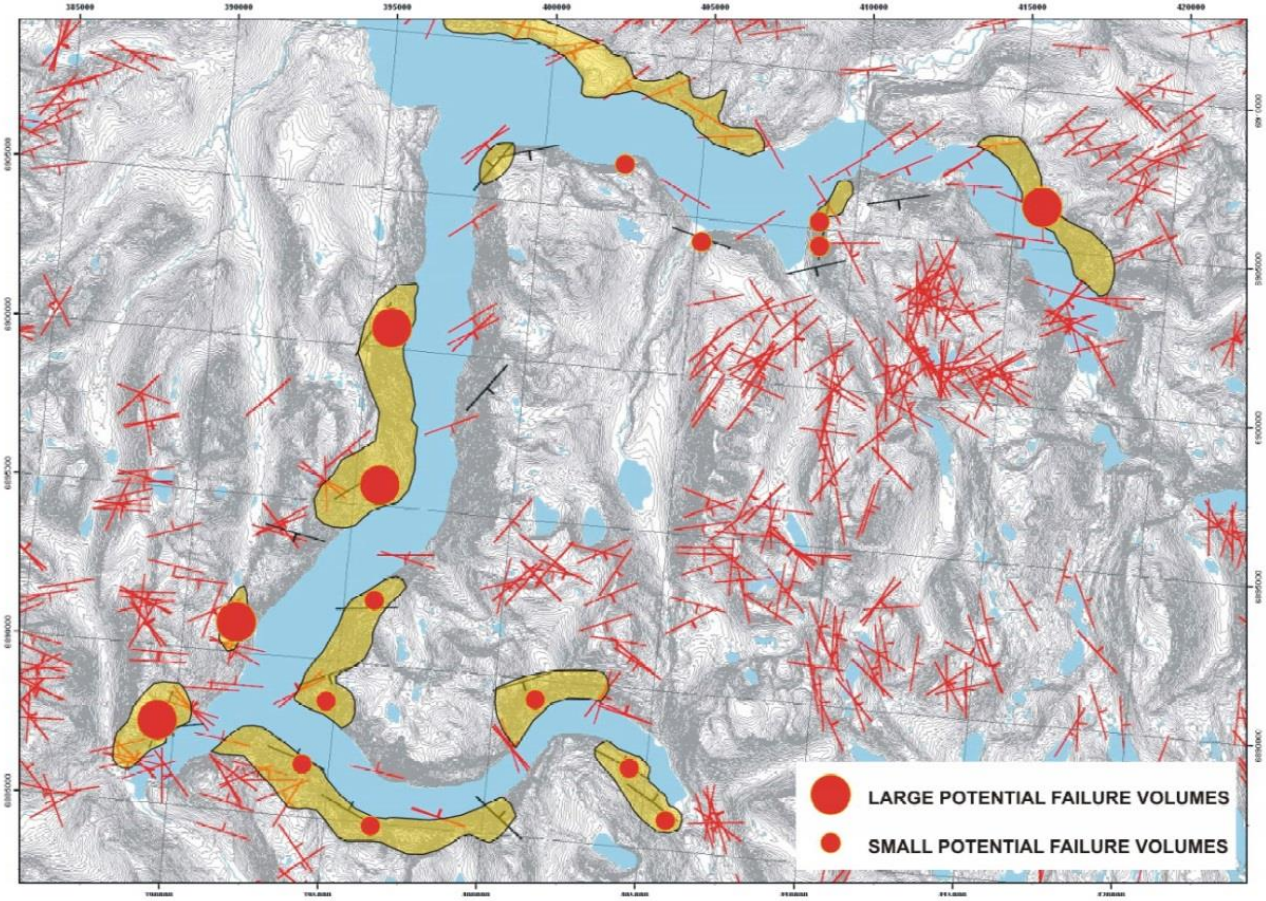
Outline of talk

- Åknes rockslide description and geology
- Investigations
  - Geophysics
  - Borehole logs and movement
  - Ground water investigations
- Surface movements
- Influence on movement from precipitation, snow melt, heavy rain and changes in ground water level

Location: Storfjorden Western Norway

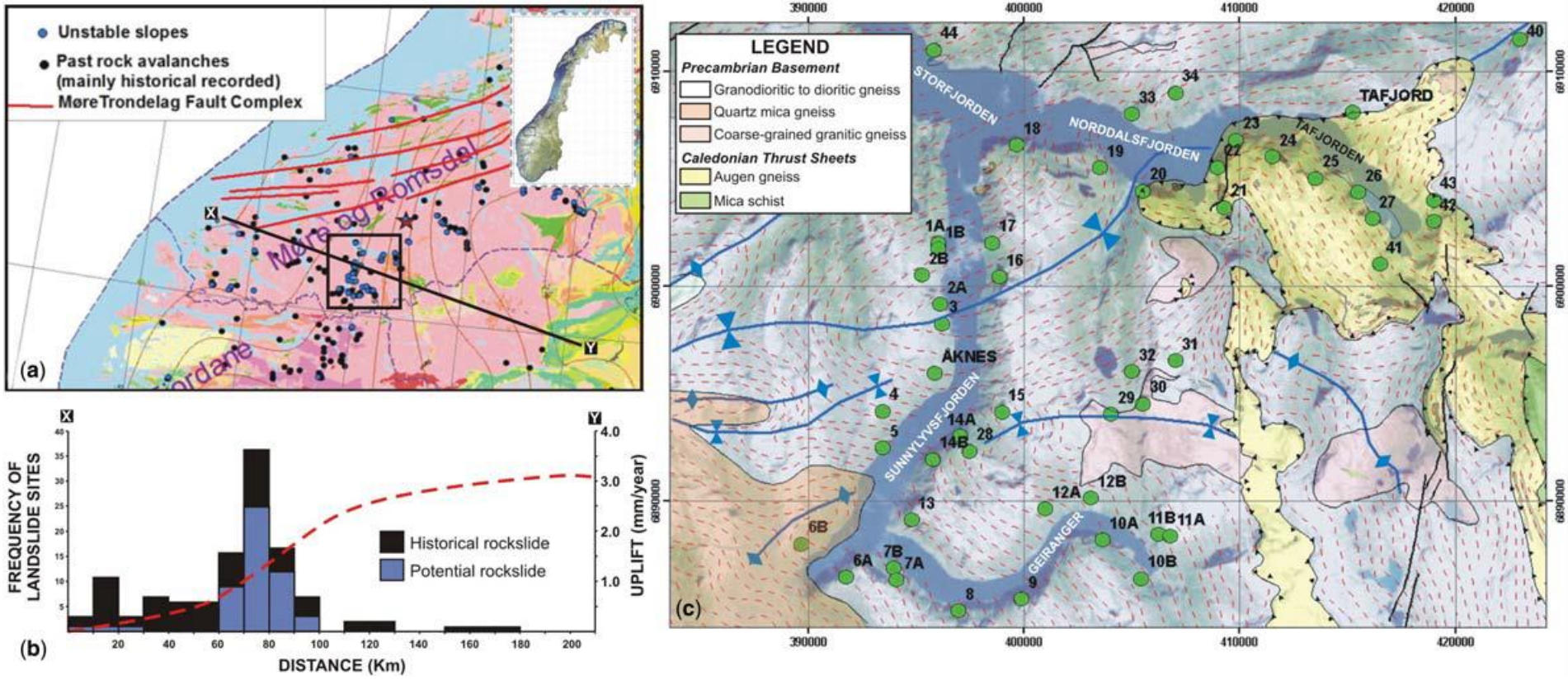
Bedrock and regional structures





Henderson et al. NGU report 2006.052

Bedrock and regional structures



Henderson & Saintot. 2011. Geological Society, London, Special Publication. 351.

Description

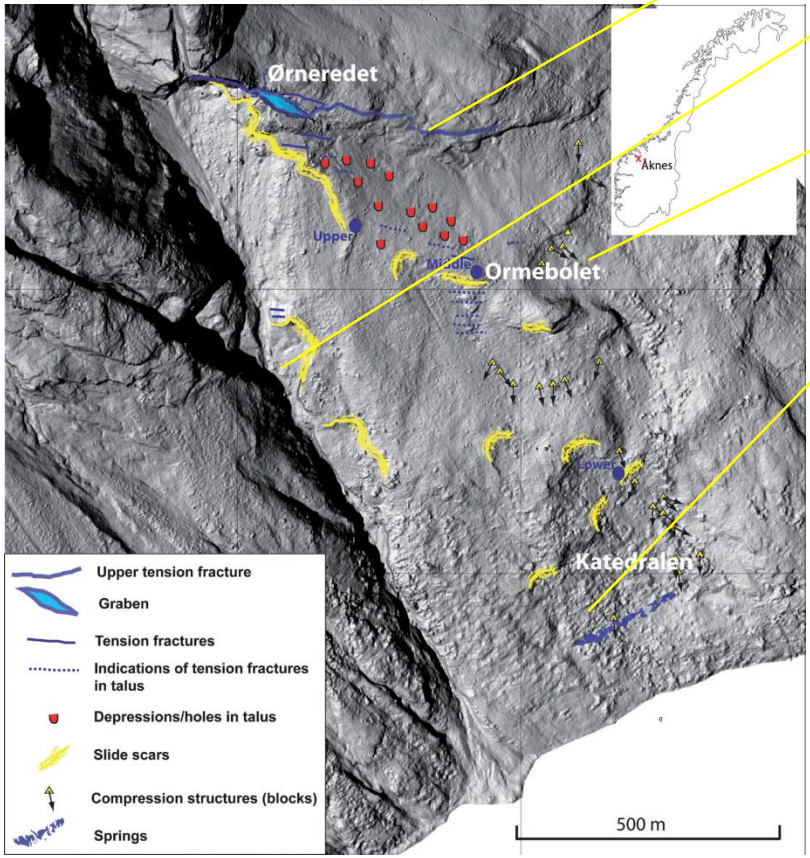
700 m long back scarp in 800 – 900 m asl.

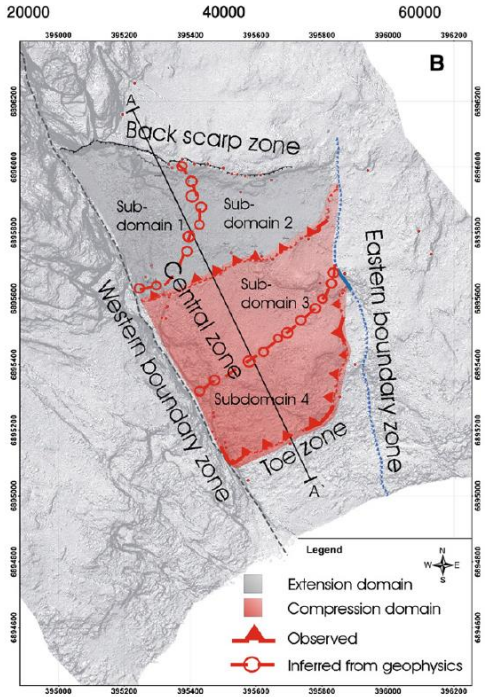
Western boundary: Strike slip fault

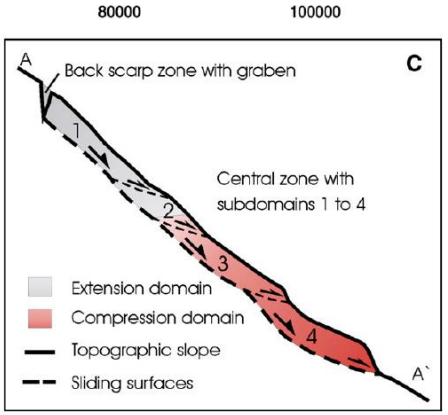
Eastern boundary: Preexisting fault dipping gently to the west

Toe zone 140 m asl.

Area and volume: 550 000 m^2 – 54 mil. m^3?

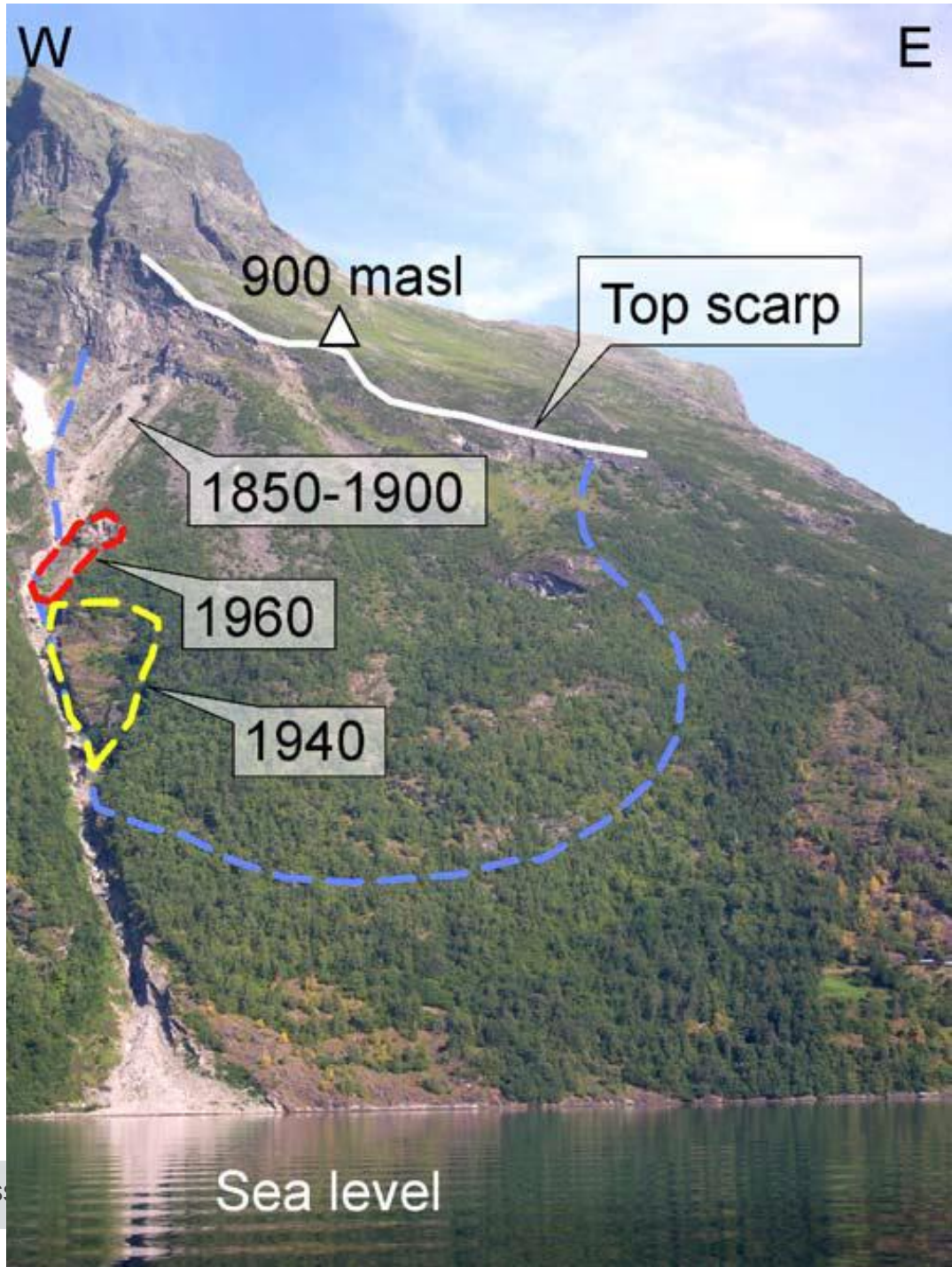






Ganerød et al. 2008. Engineering Geology vol 102.

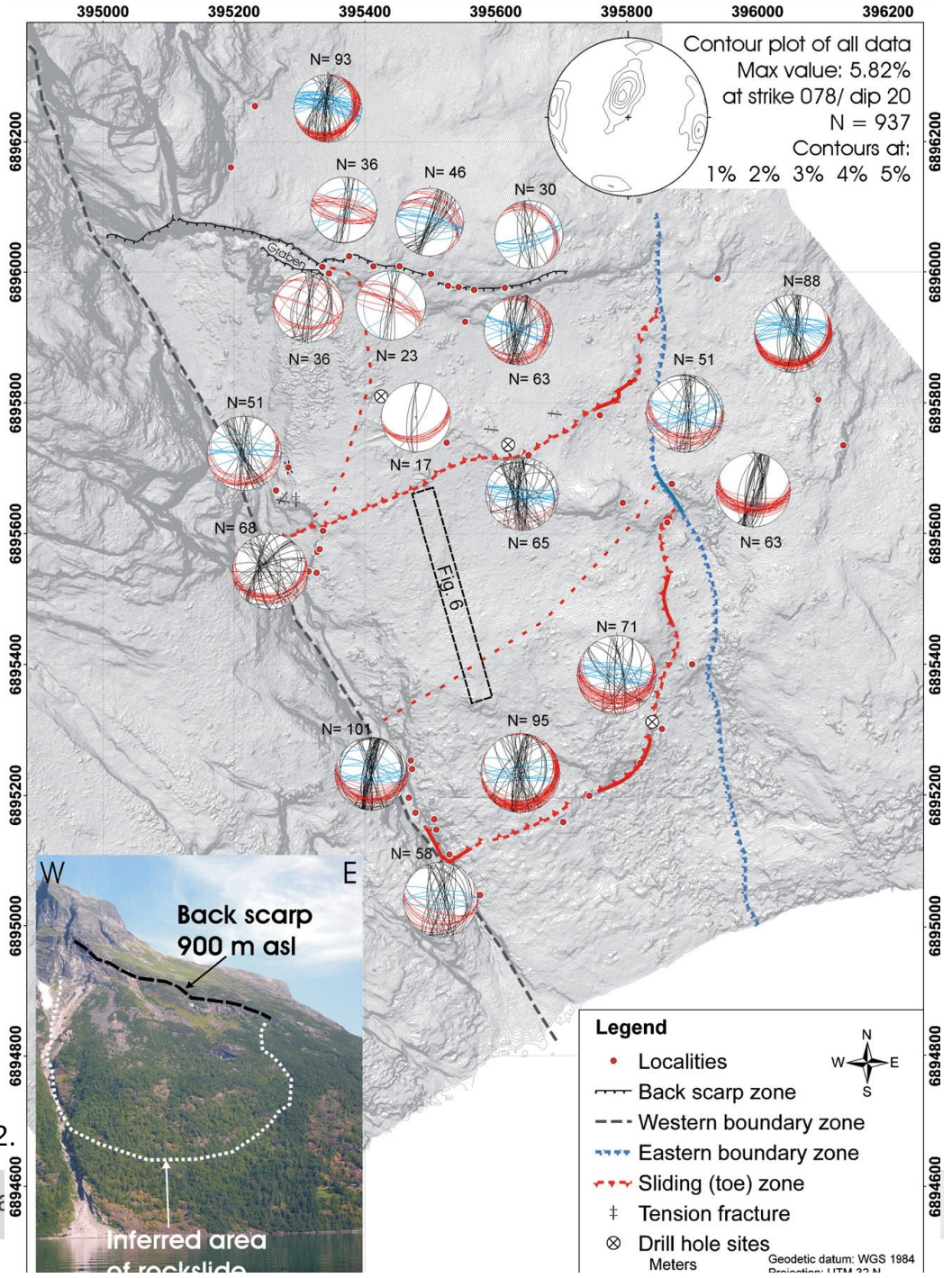
Historic slides



Kveldsvik et al. 2007. Landslides

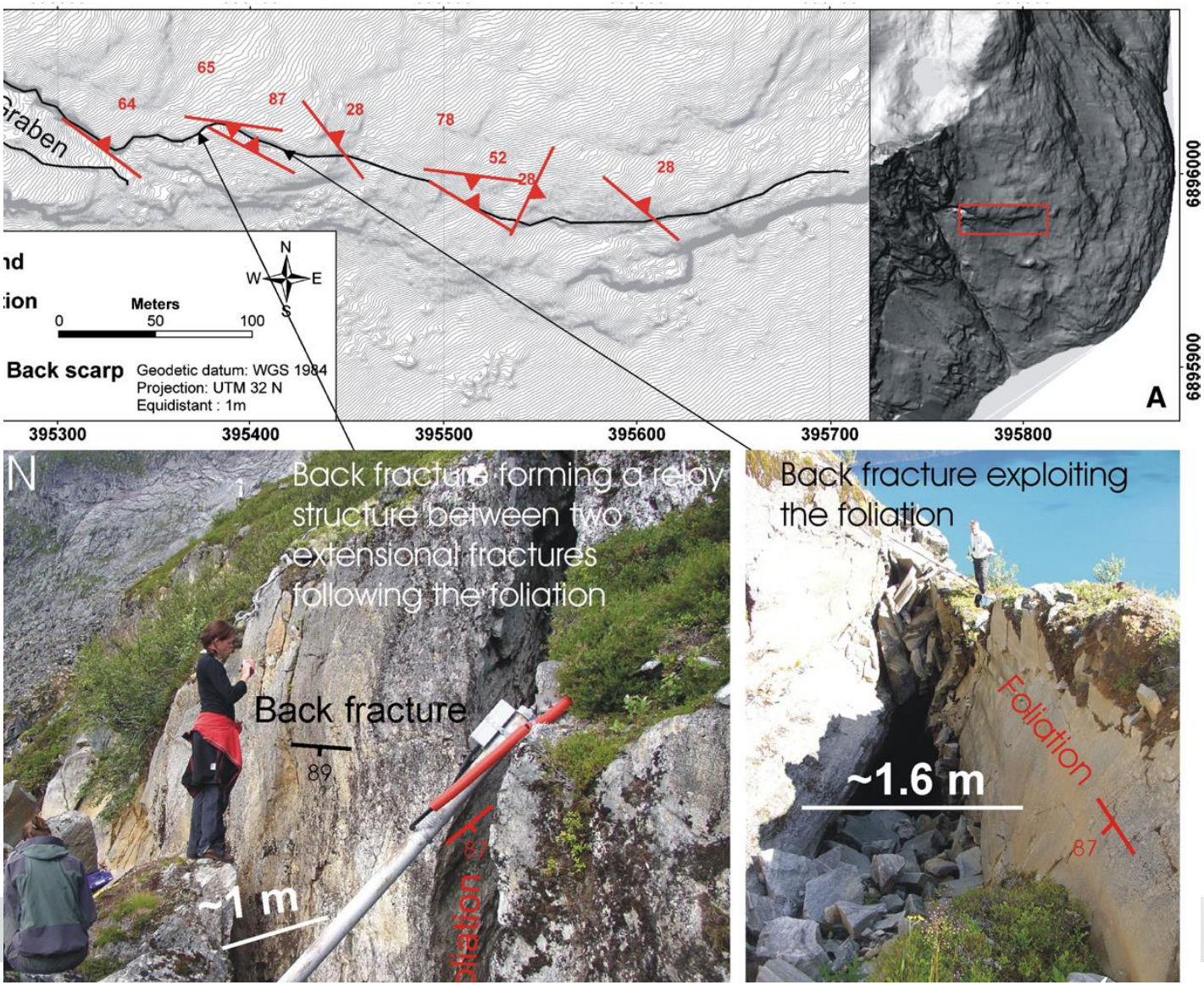
Structural mapping

- Folded gneis – foliation steep at upper fracture, dipping 30-35° south
- 3 fracture sets:
  - N-S steeply dipping
  - E-W steeply dipping
  - Foliation parallel
- Foliation near slope parallel – important for the sliding plane



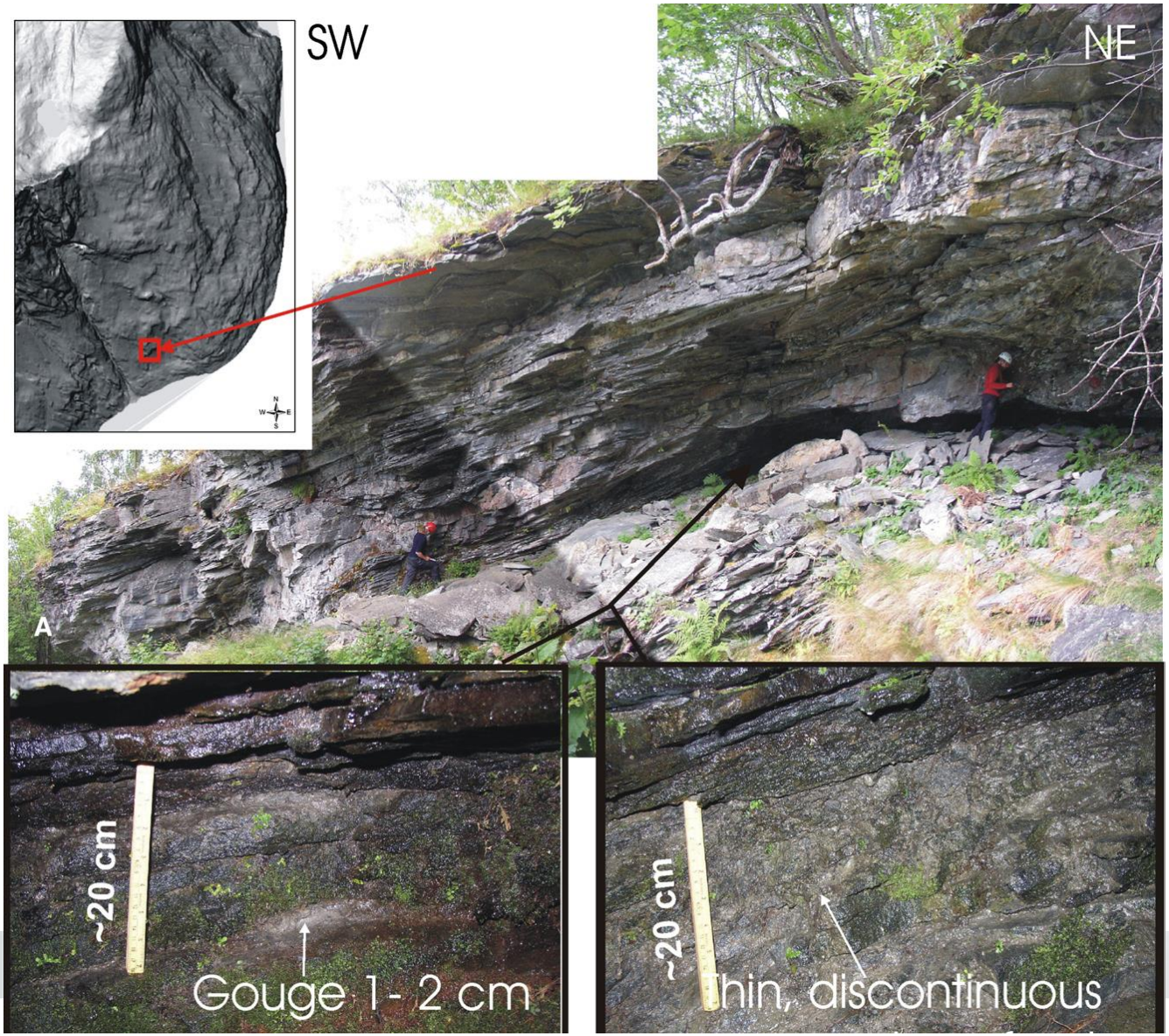
Ganerød et al. 2008. Engineering Geology vol 102.

Upper tension fracture



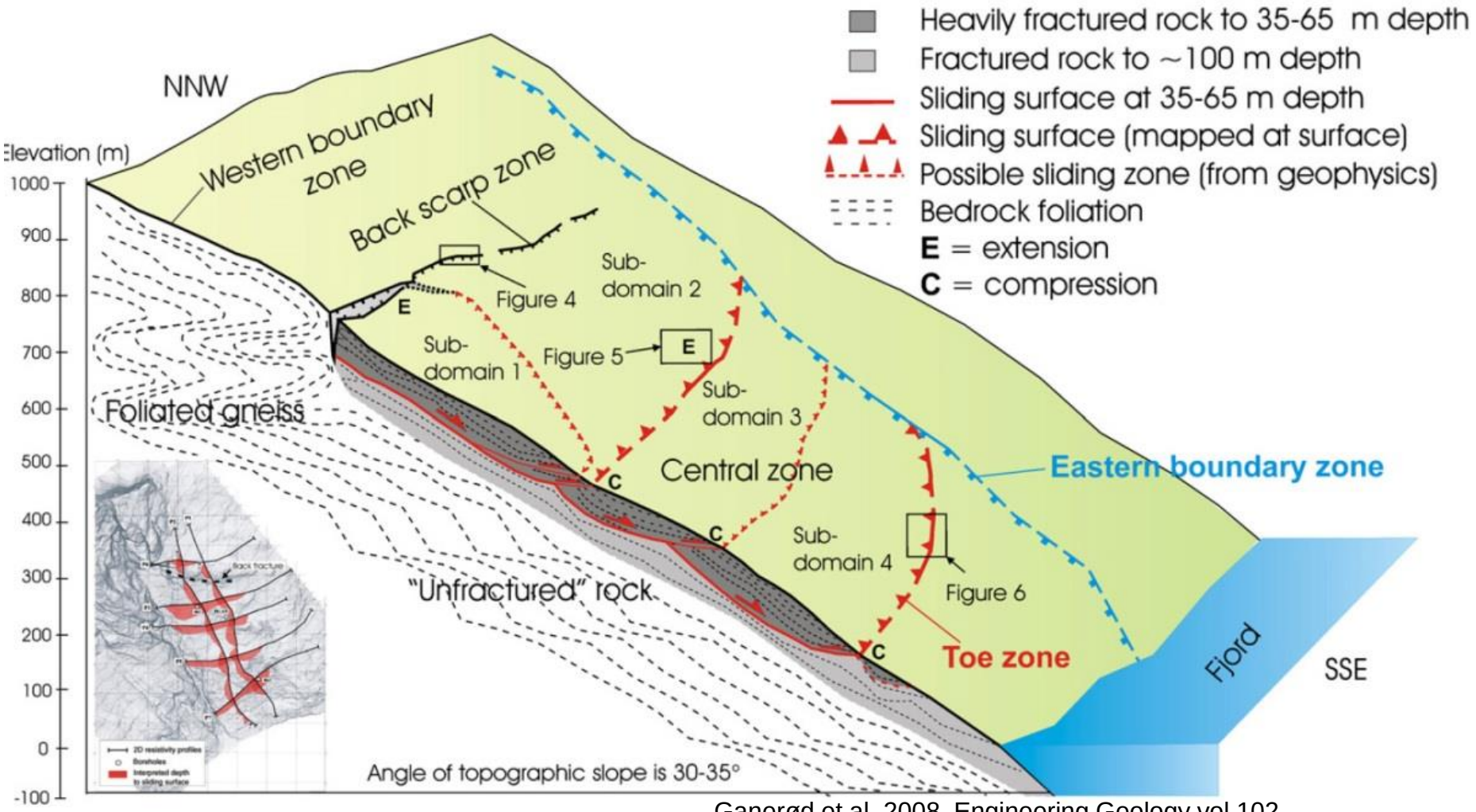
Ganerød et al. 2008. Engineering Geology vol 102.

Toe zone

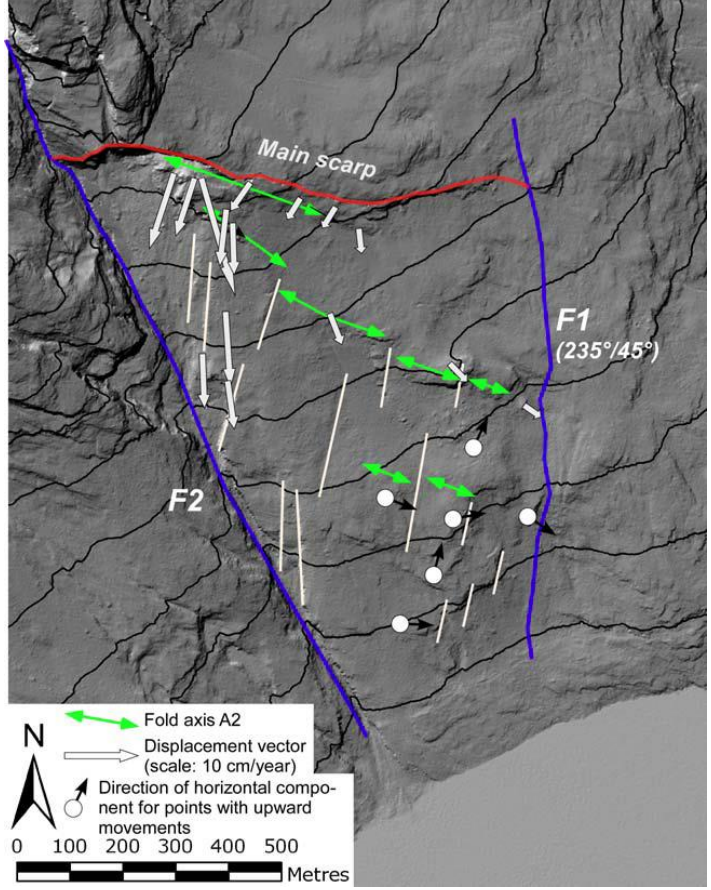


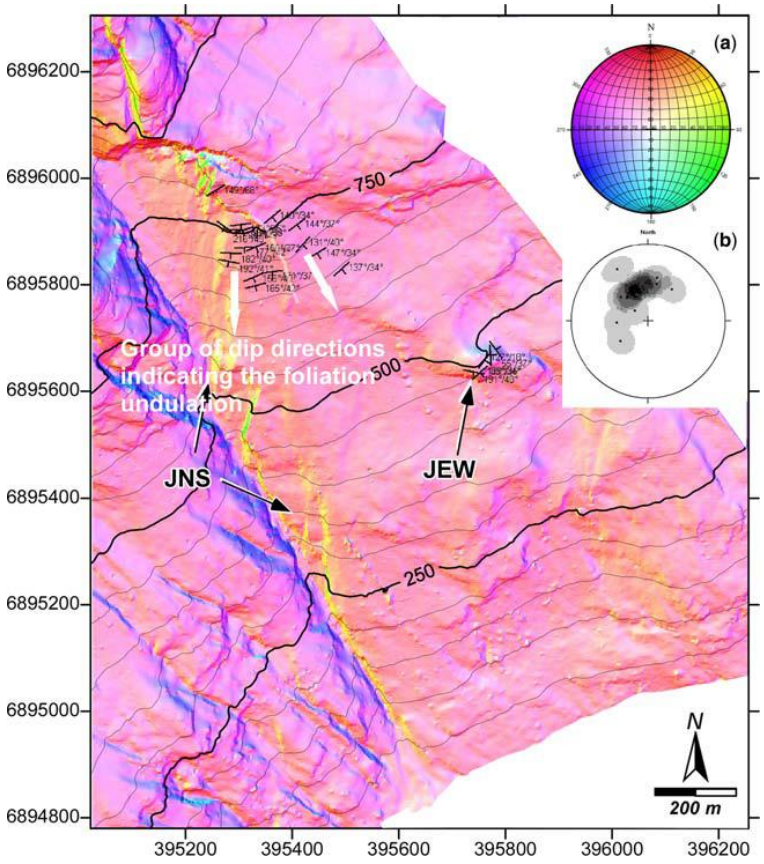
Ganerød et al. 2008. Engineering Geology vol 102.

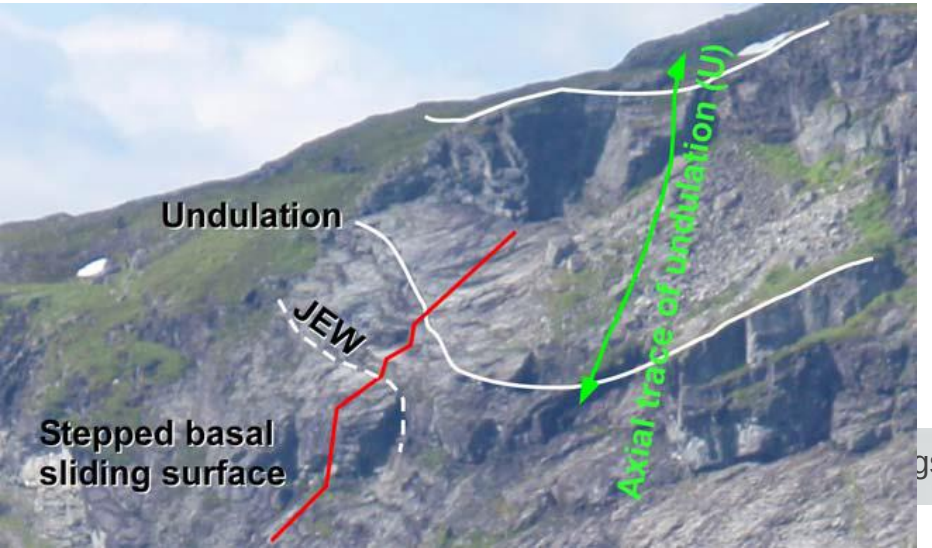
Geological models

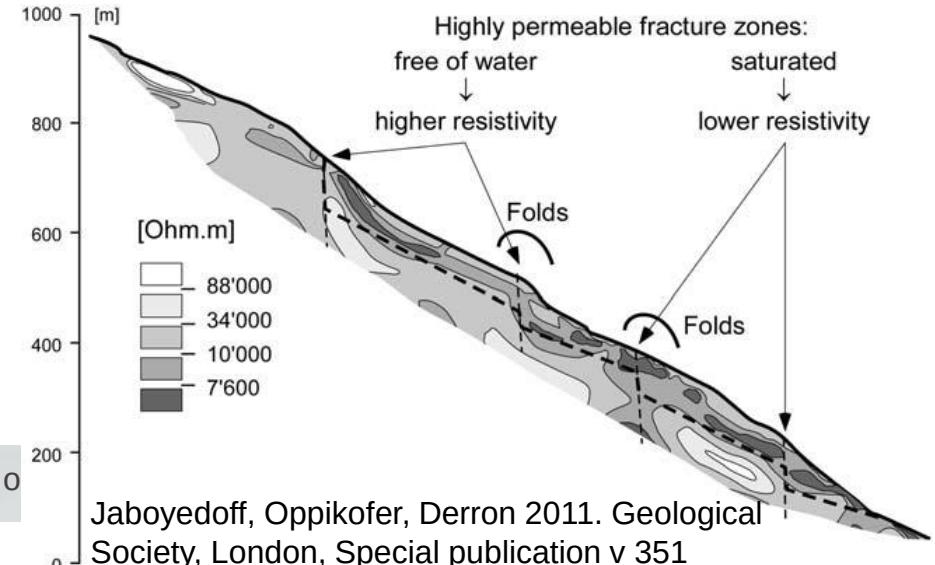


Ganerød et al. 2008. Engineering Geology vol 102.



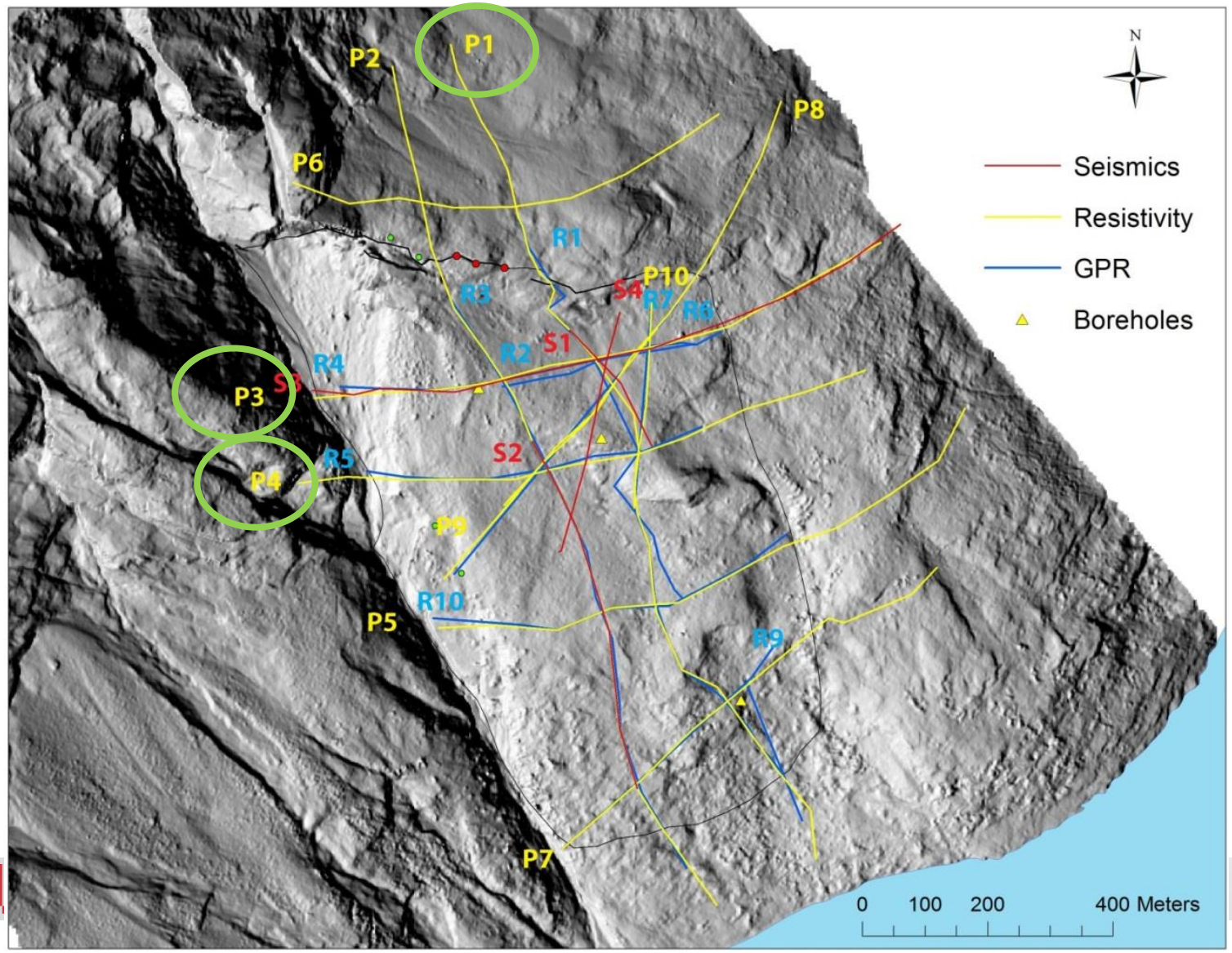




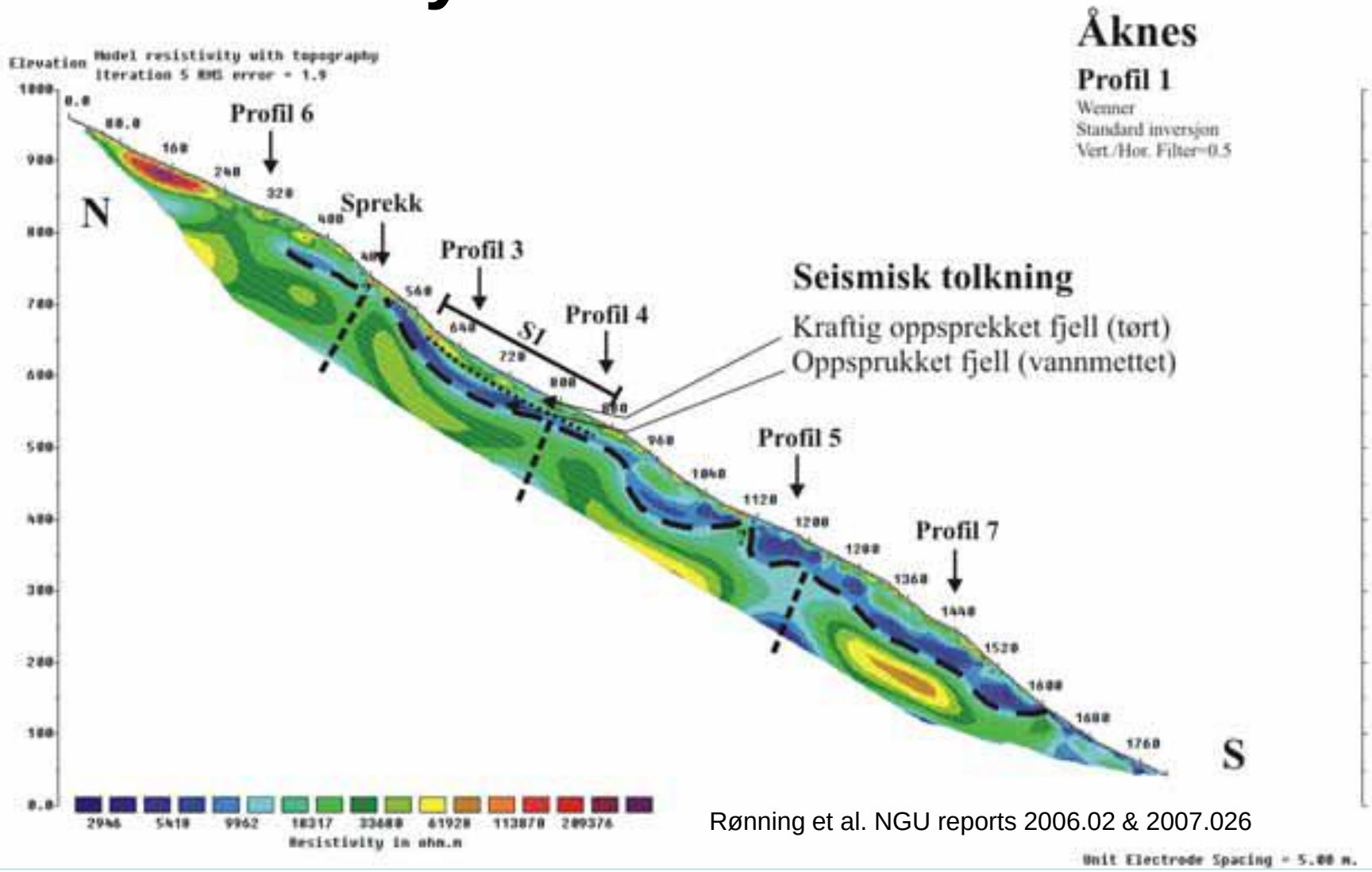


Jaboyedoff, Oppikofer, Derron 2011. Geological Society, London, Special publication v 351

Investigations - geophysics

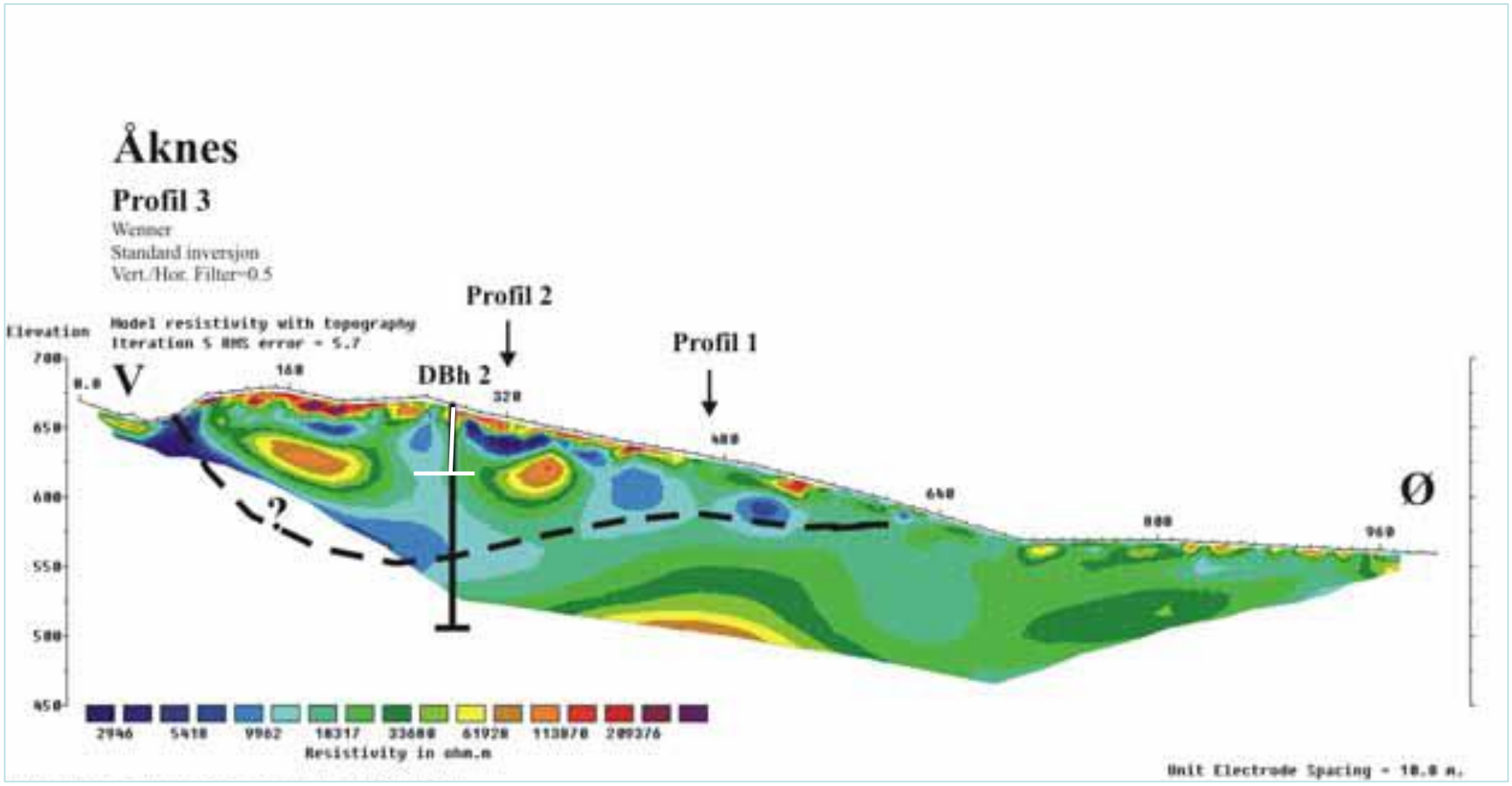


DC resistivity

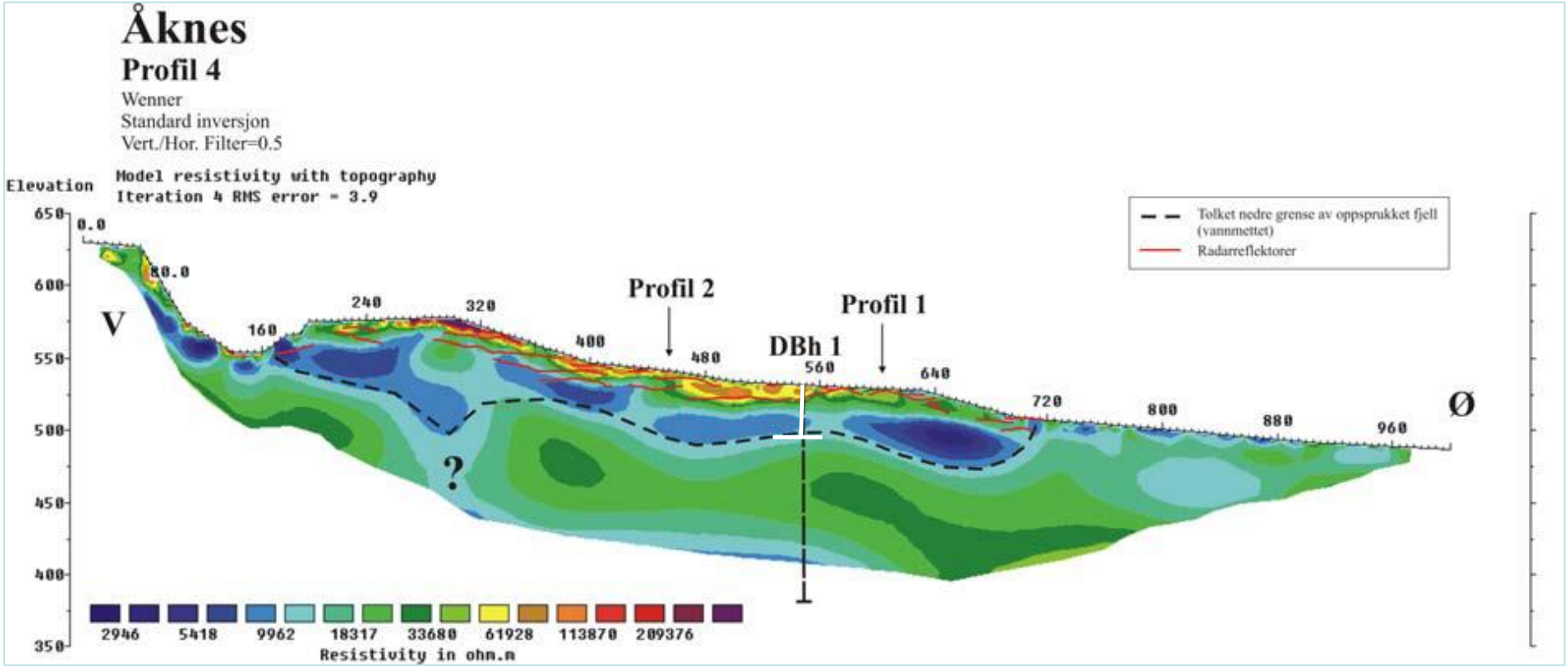


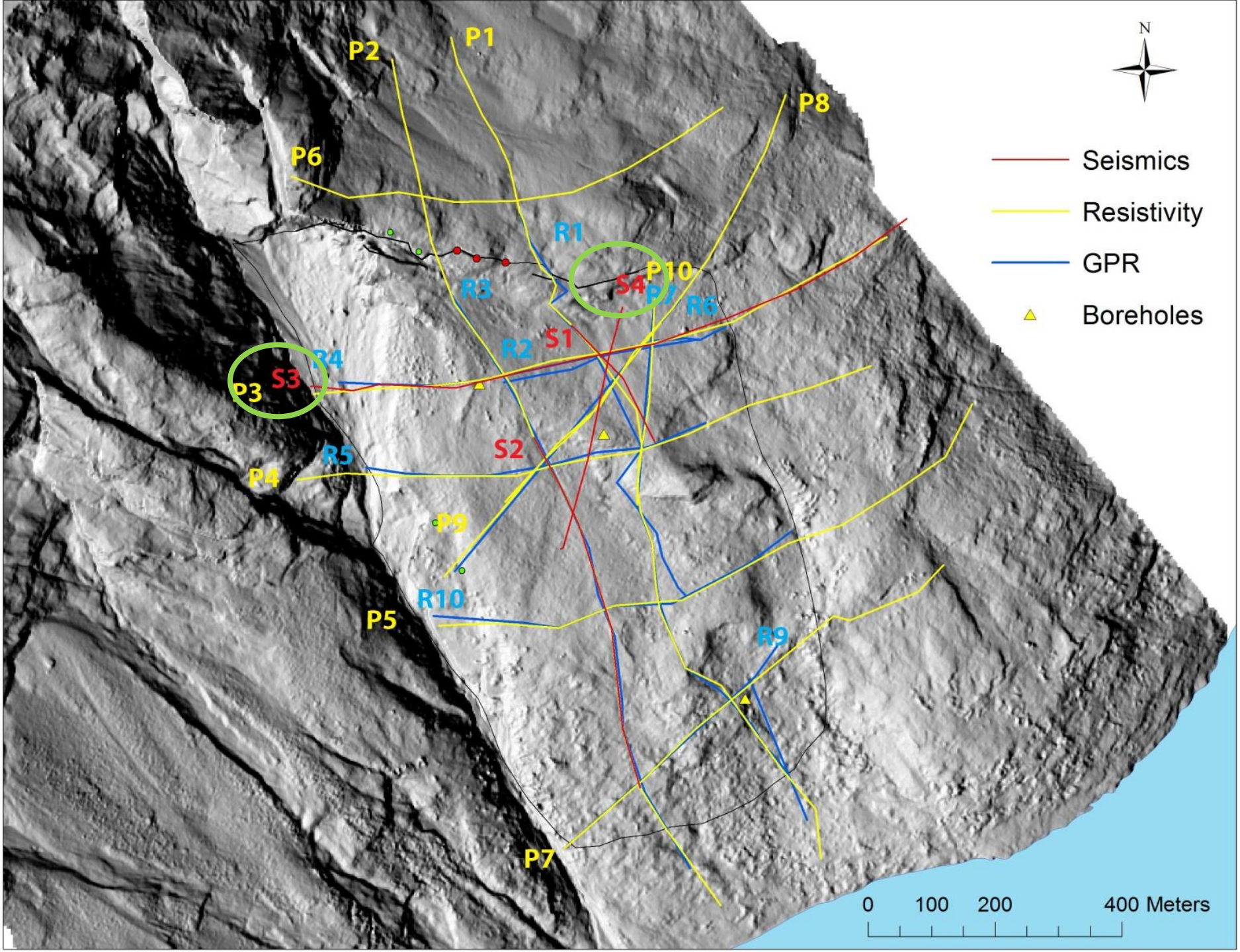
Rønning et al. NGU reports 2006.02 & 2007.026

DC resistivity

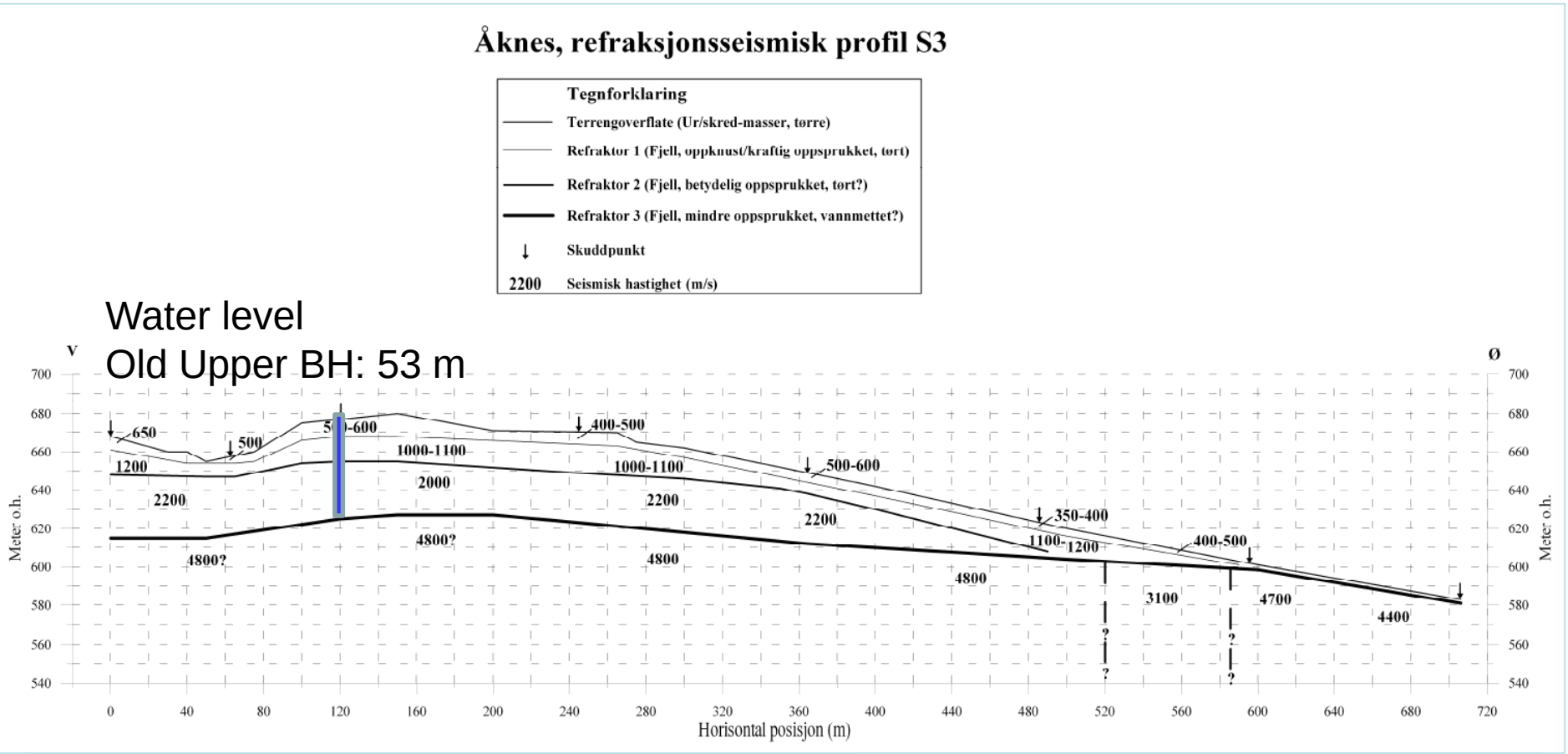


DC resistivity

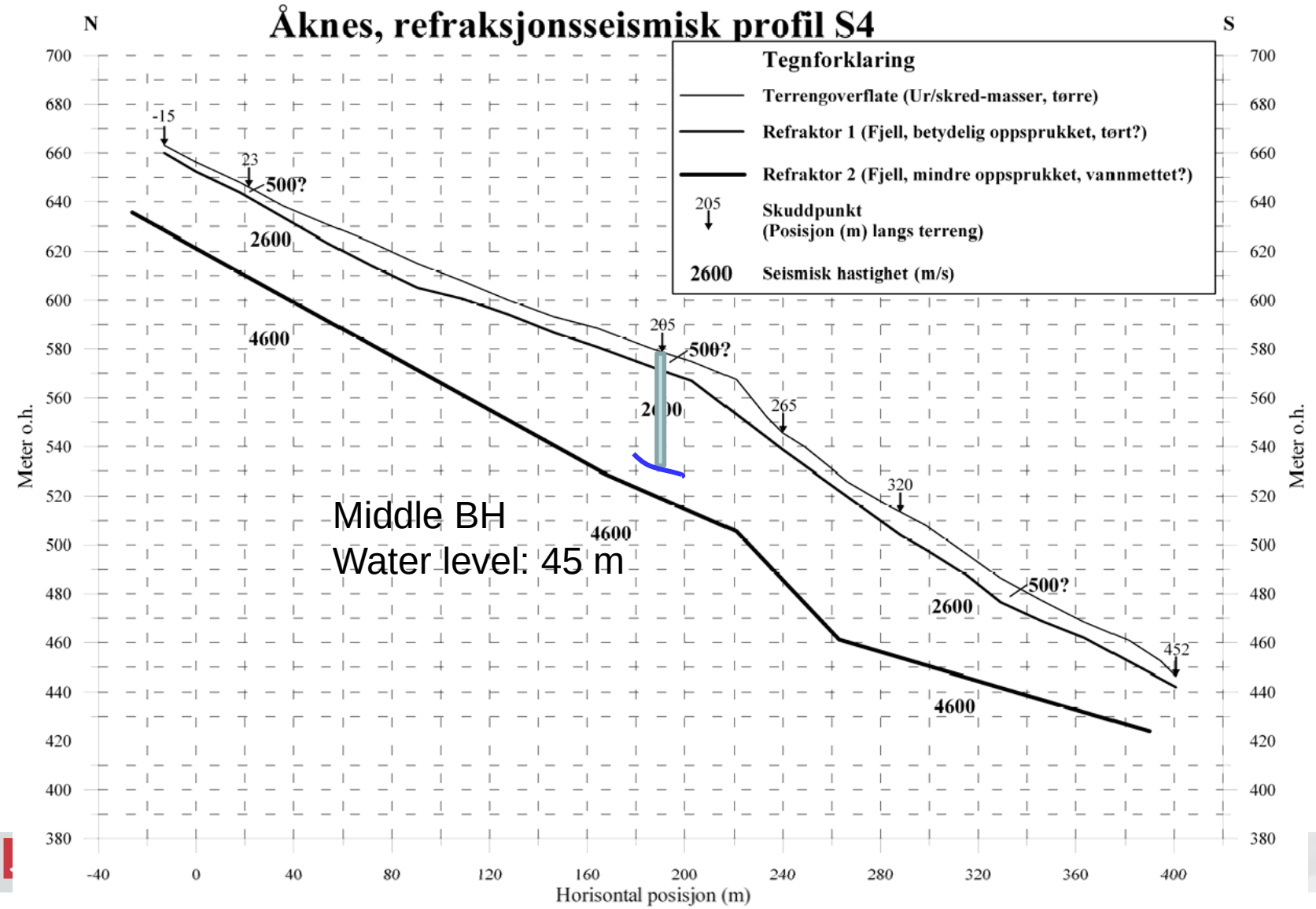



N
Seismics
Resistivity
GPR
Boreholes
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
R1
R2
R3
R4
R5
R6
R9
R10
S1
S2
S3
S4
0
100
200
400 Meters

Refraction seismics

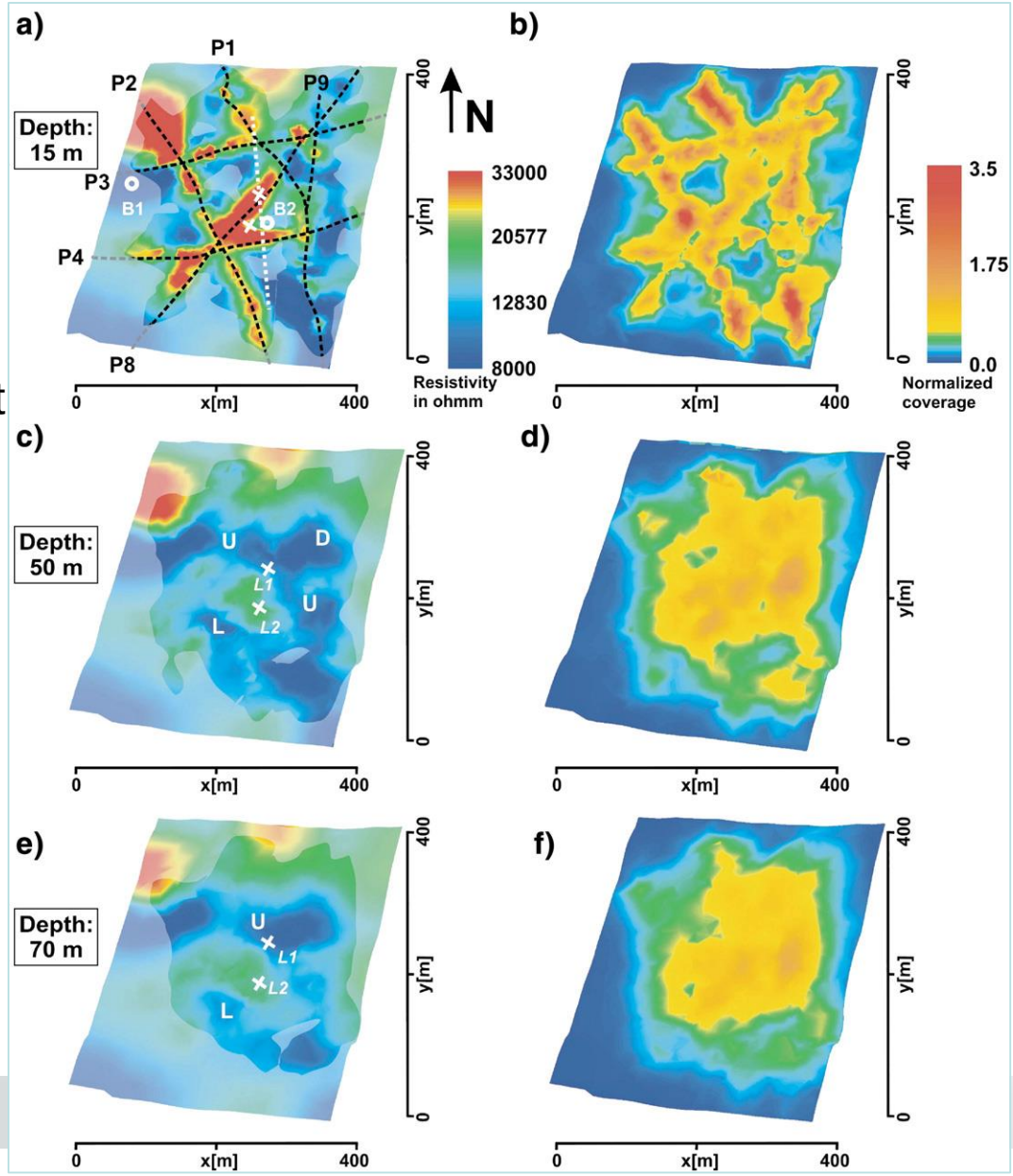


Refraction seismics



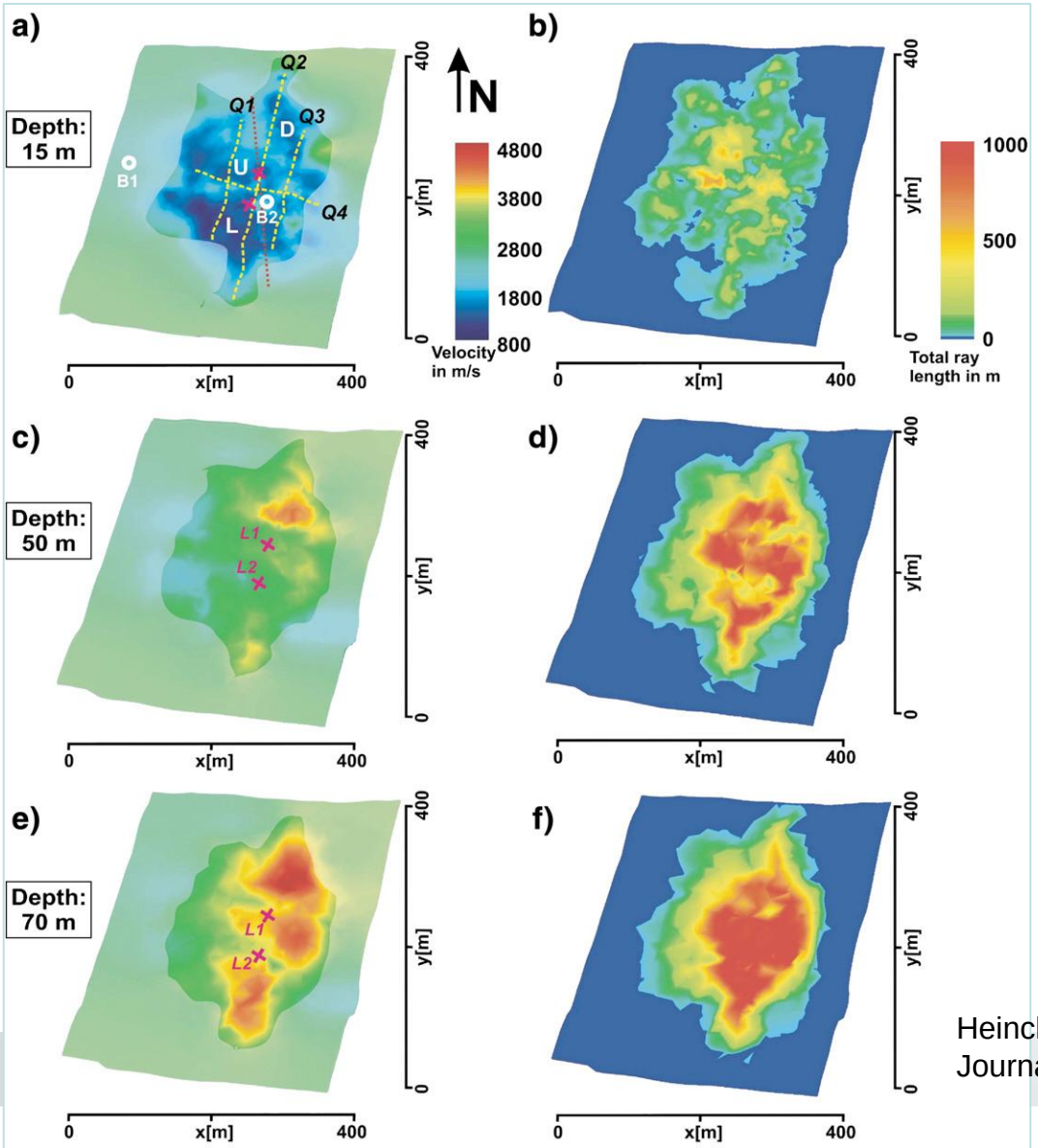
3D processing of resistivity

Resistivity at different dephs

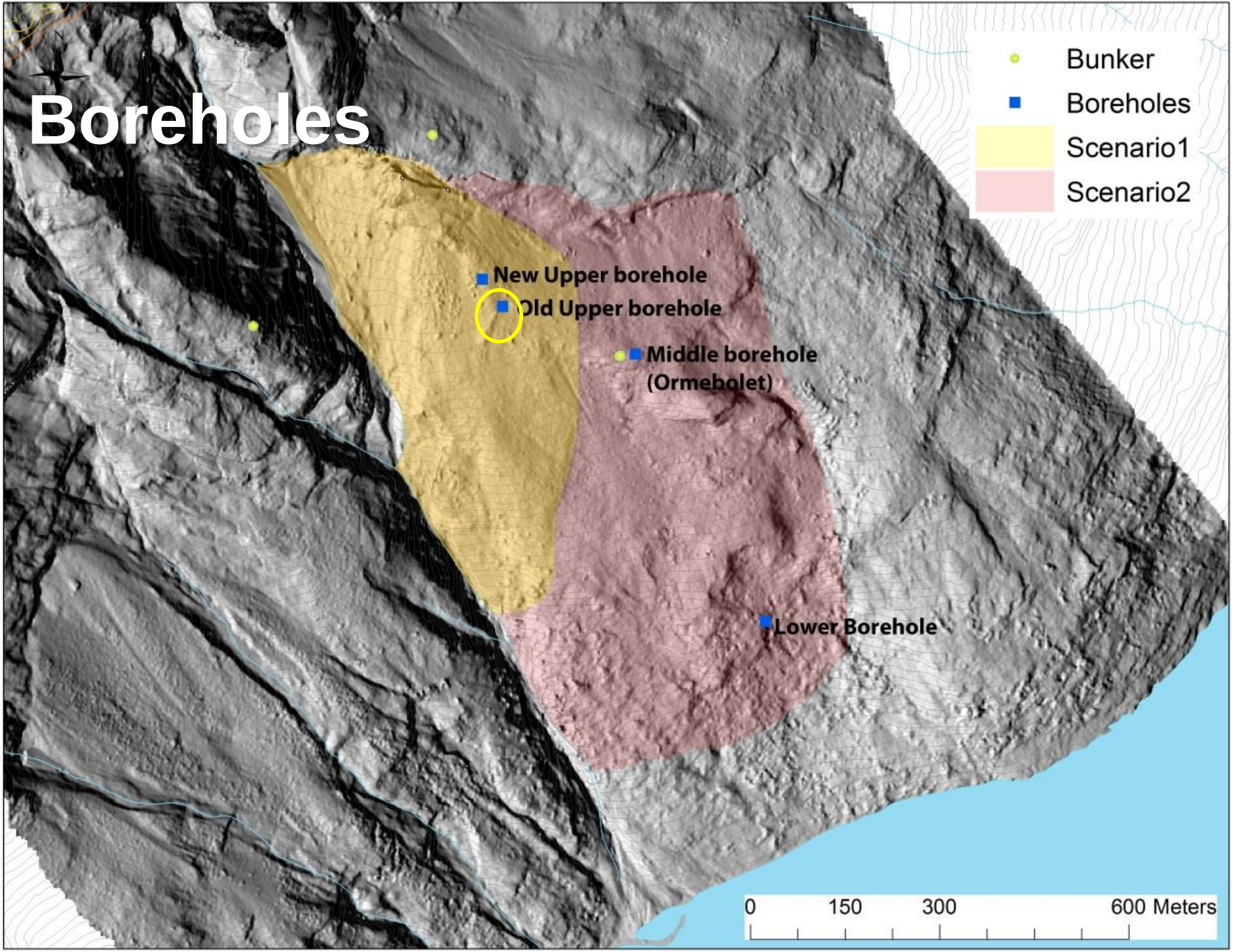


Data coverage at different dephs

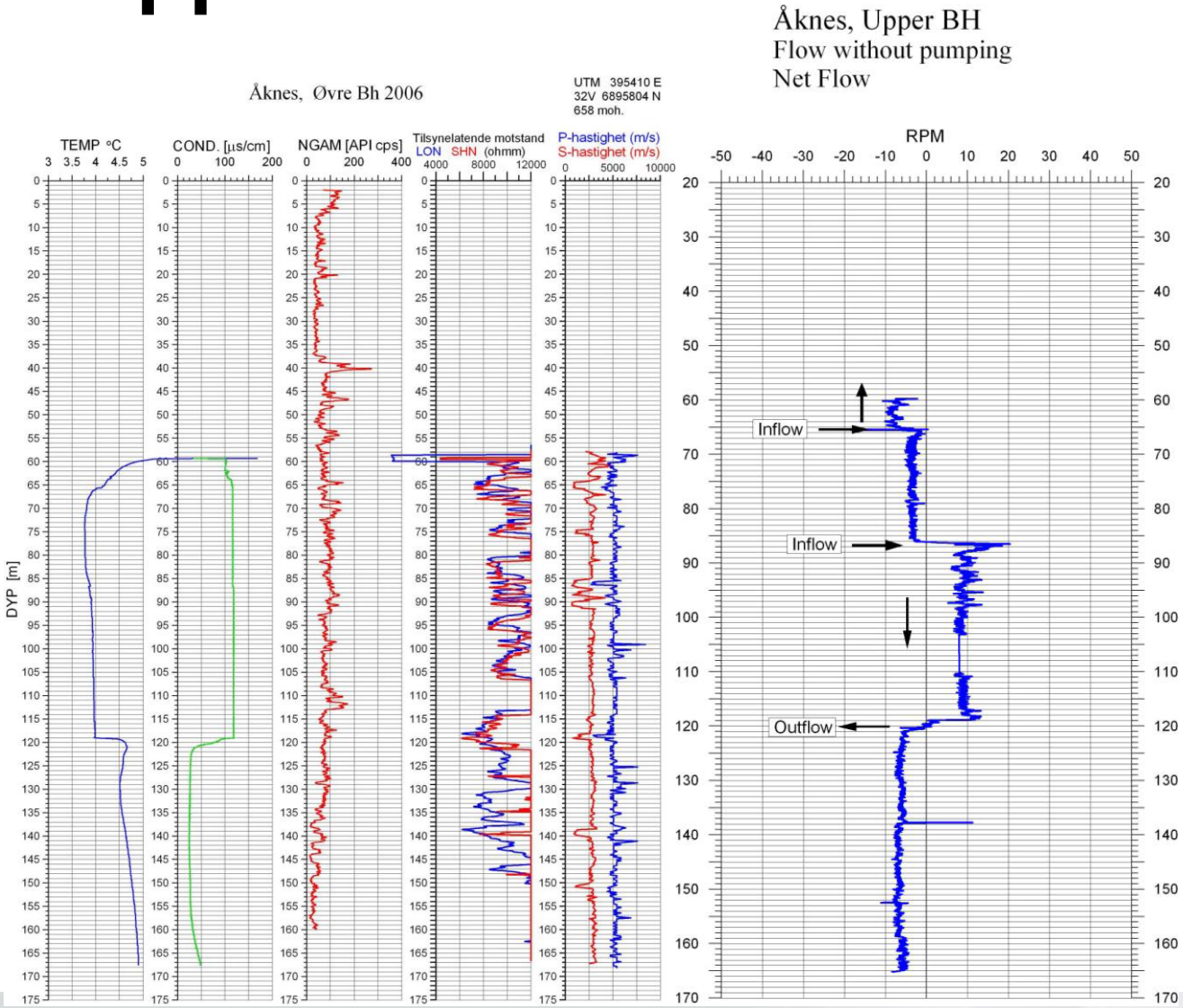
3D processing of refraction seismics



Heincke et al. 2010
Journal of Applied Geophysics, 70.

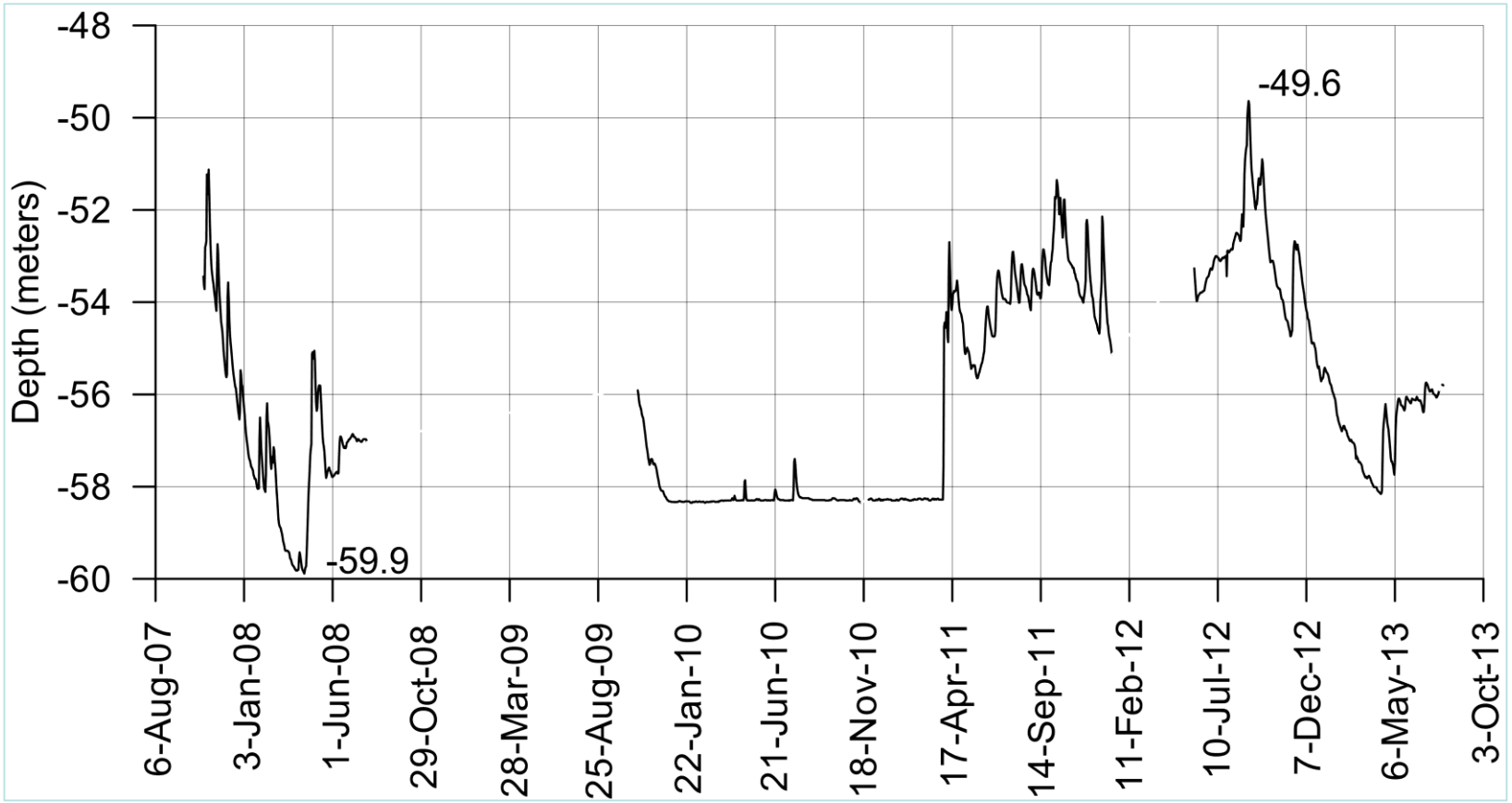

Boreholes
Bunker
Boreholes
Scenario1
Scenario2
New Upper borehole
Old Upper borehole
Middle borehole
(Ormebolet)
Lower Borehole
0
150
300
600 Meters

Old Upper borehole



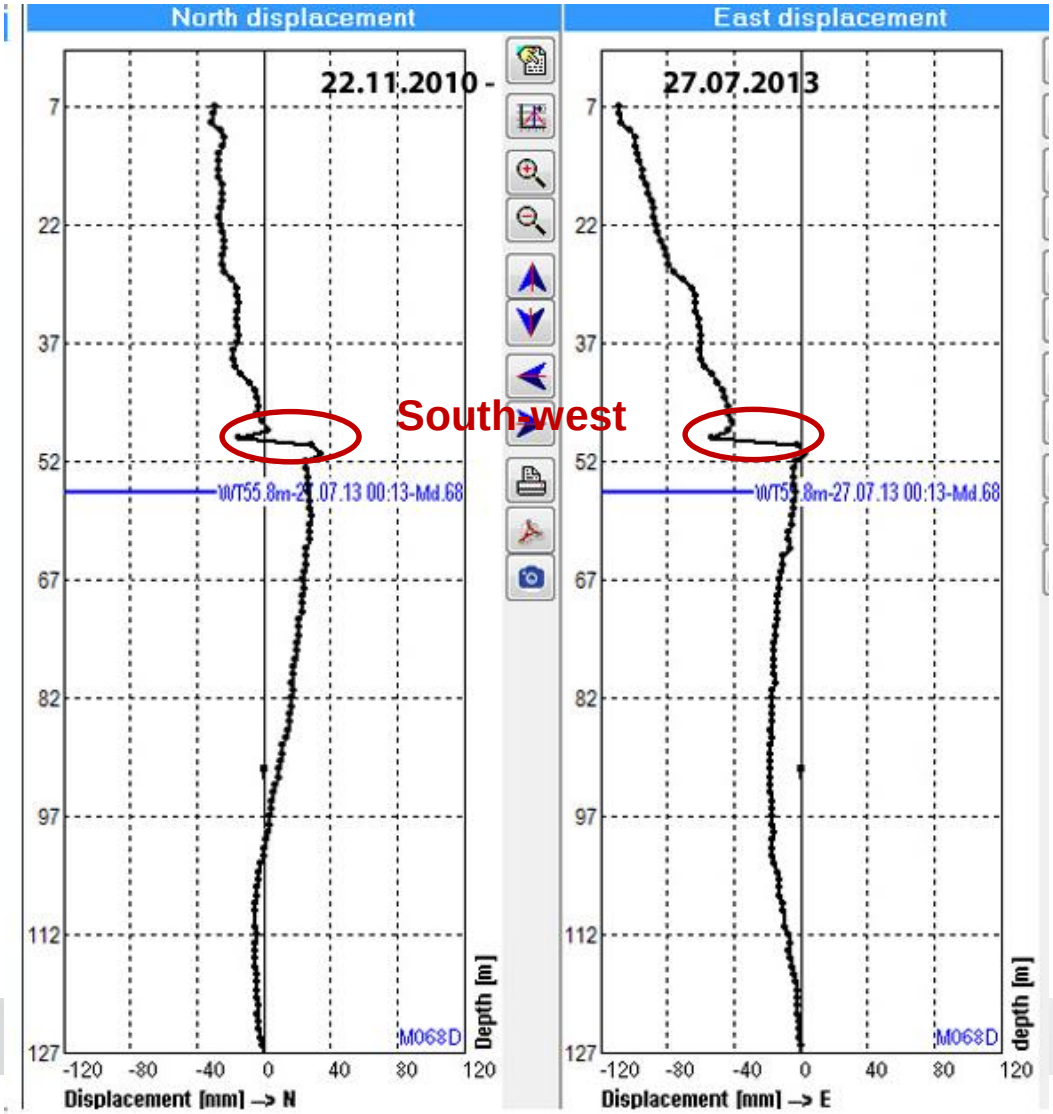
Elvebakk,
NGU report 2008.030

Old Upper Borehole – Water table



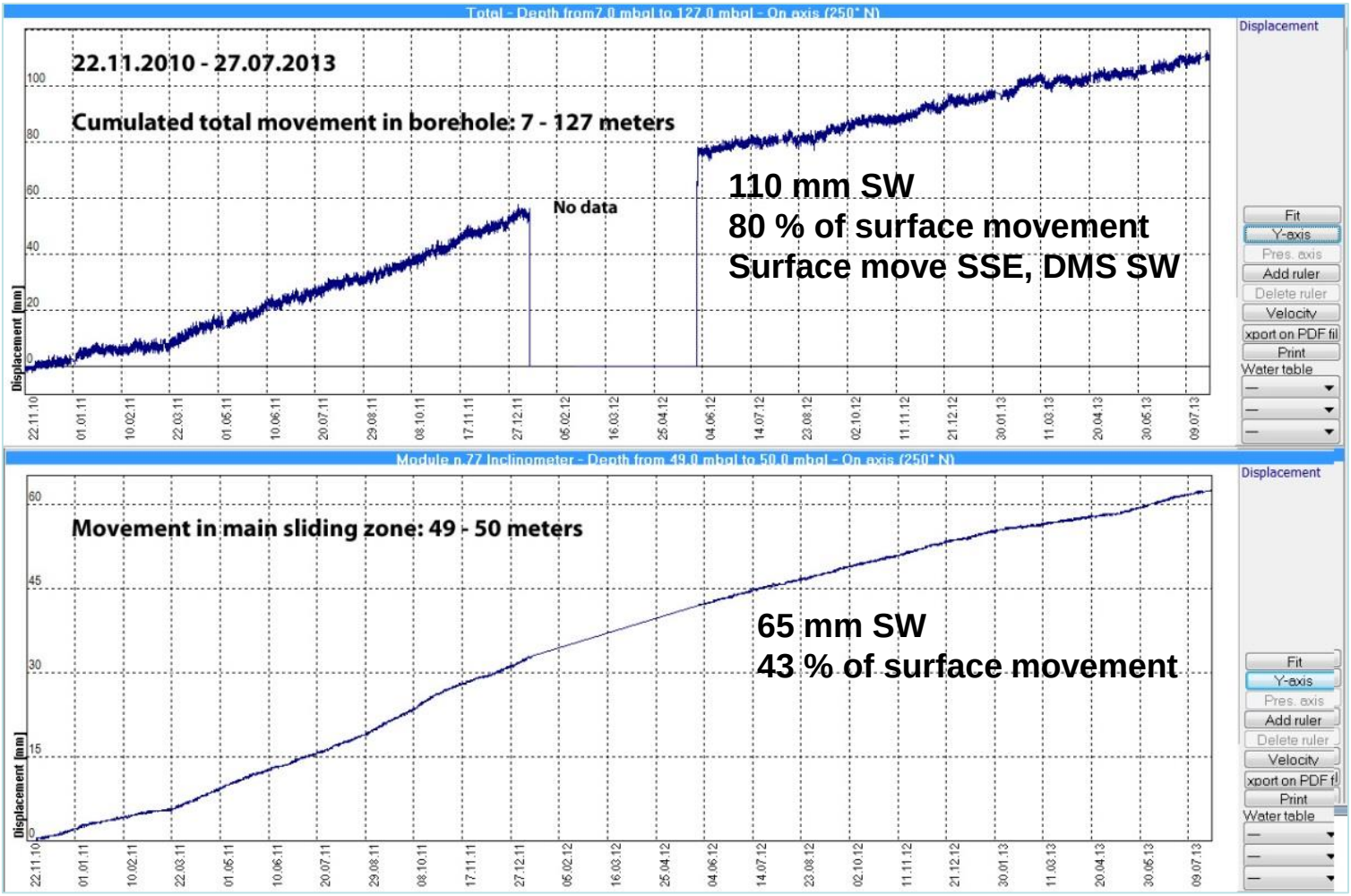
From DMS, CSG

Old Upper Borehole - movement



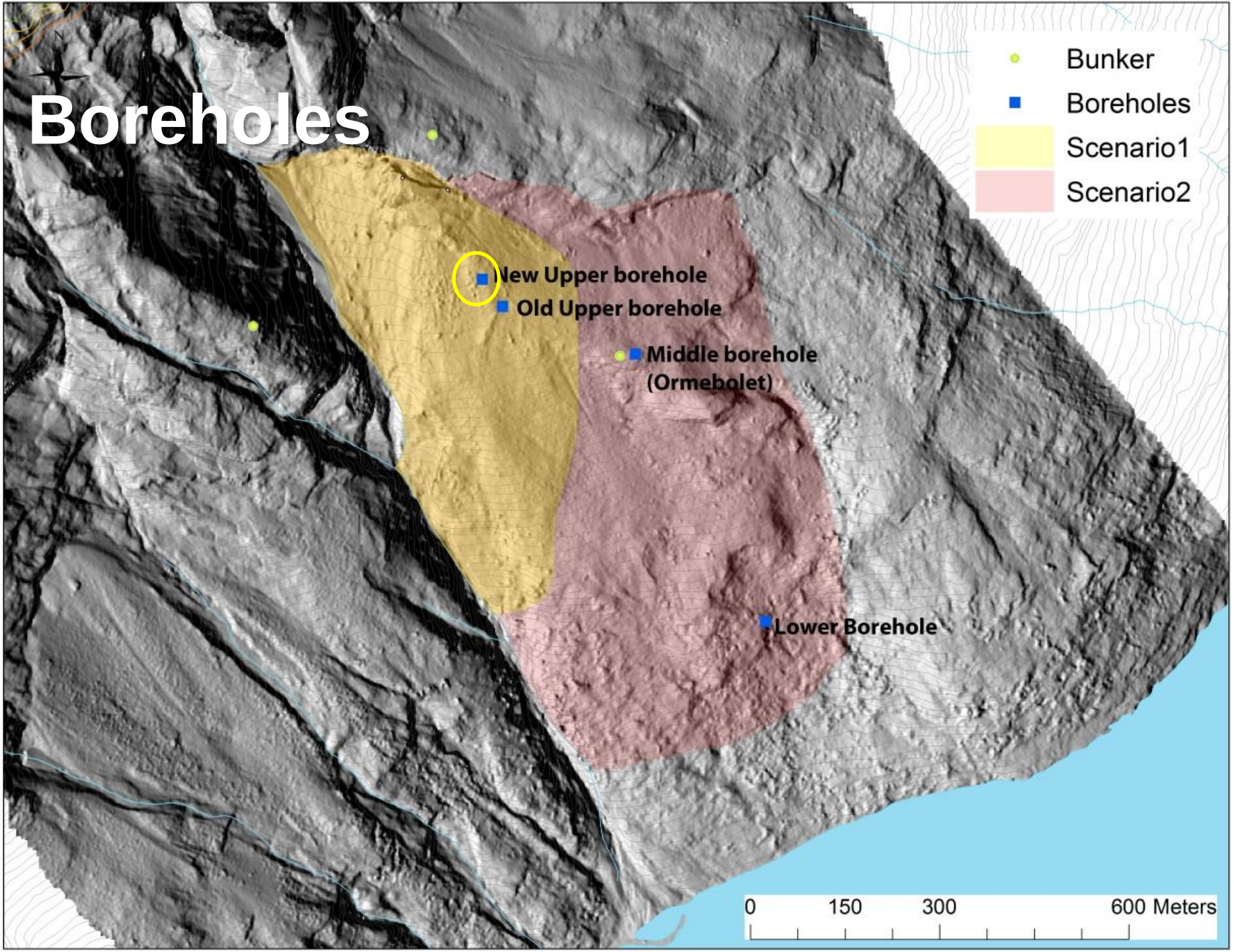
From DMS, CSG

Movement in sliding zone



From DMS, CSG


10:17:02 AM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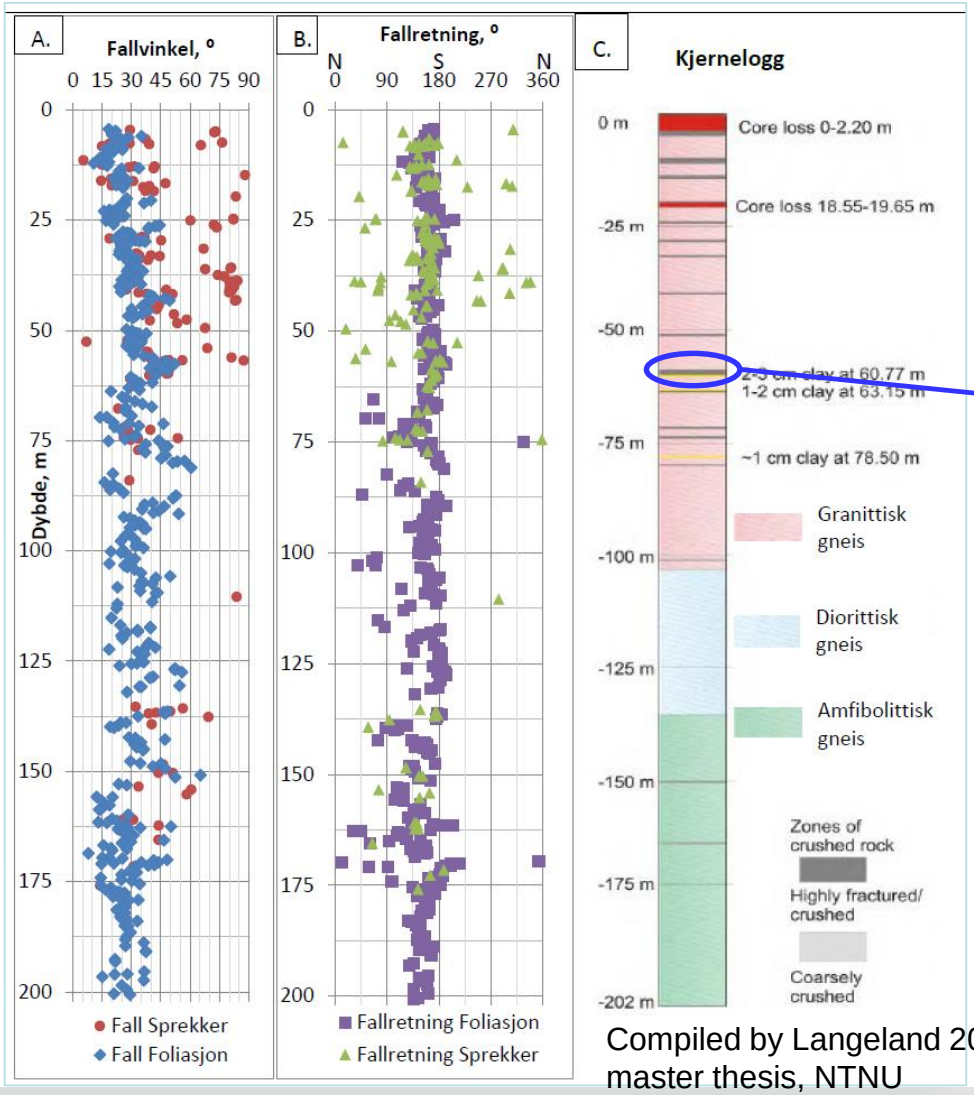
Old Upper borehole
Middle borehole
(Ormebolet)
Lower Borehole
0
150
300
600 Meters

Fractures and foliation



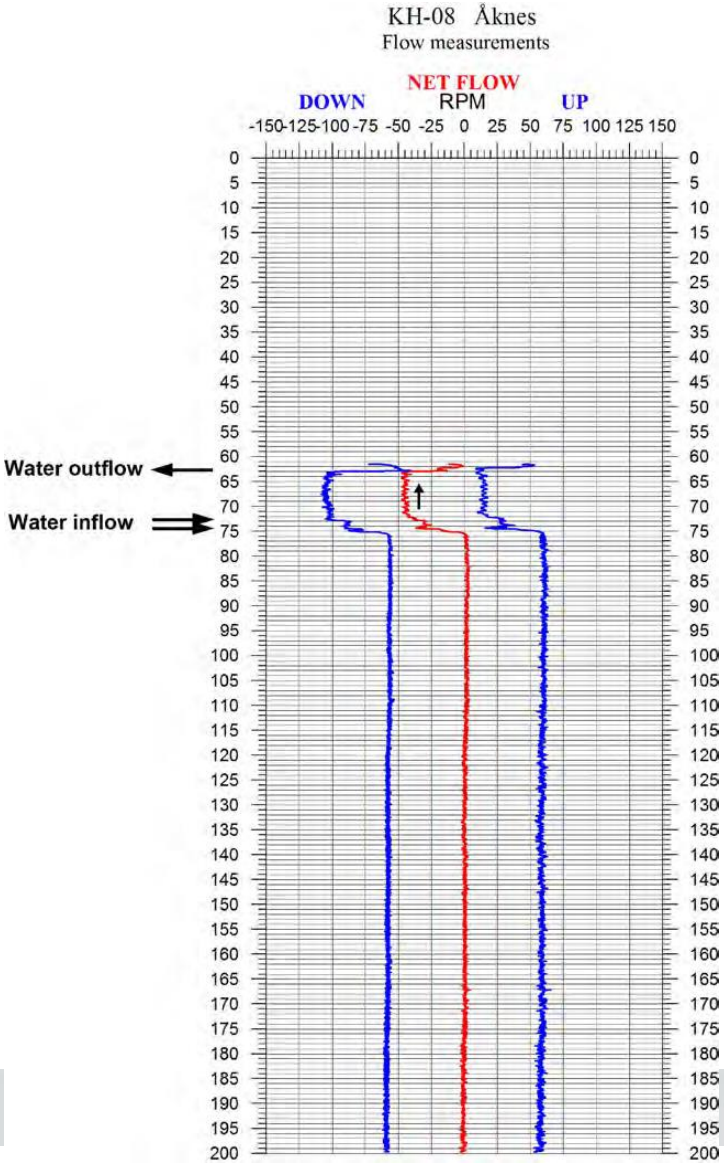
Compiled by Langeland 2014, master thesis, NTNU

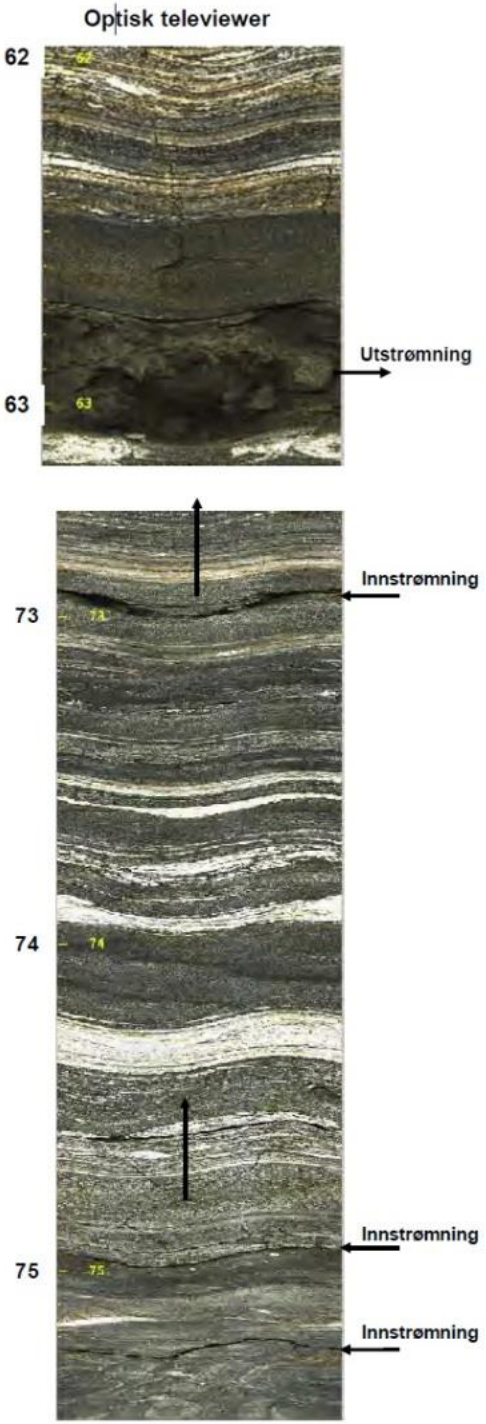
Zone of crushed roWell developed


-0061 .6M

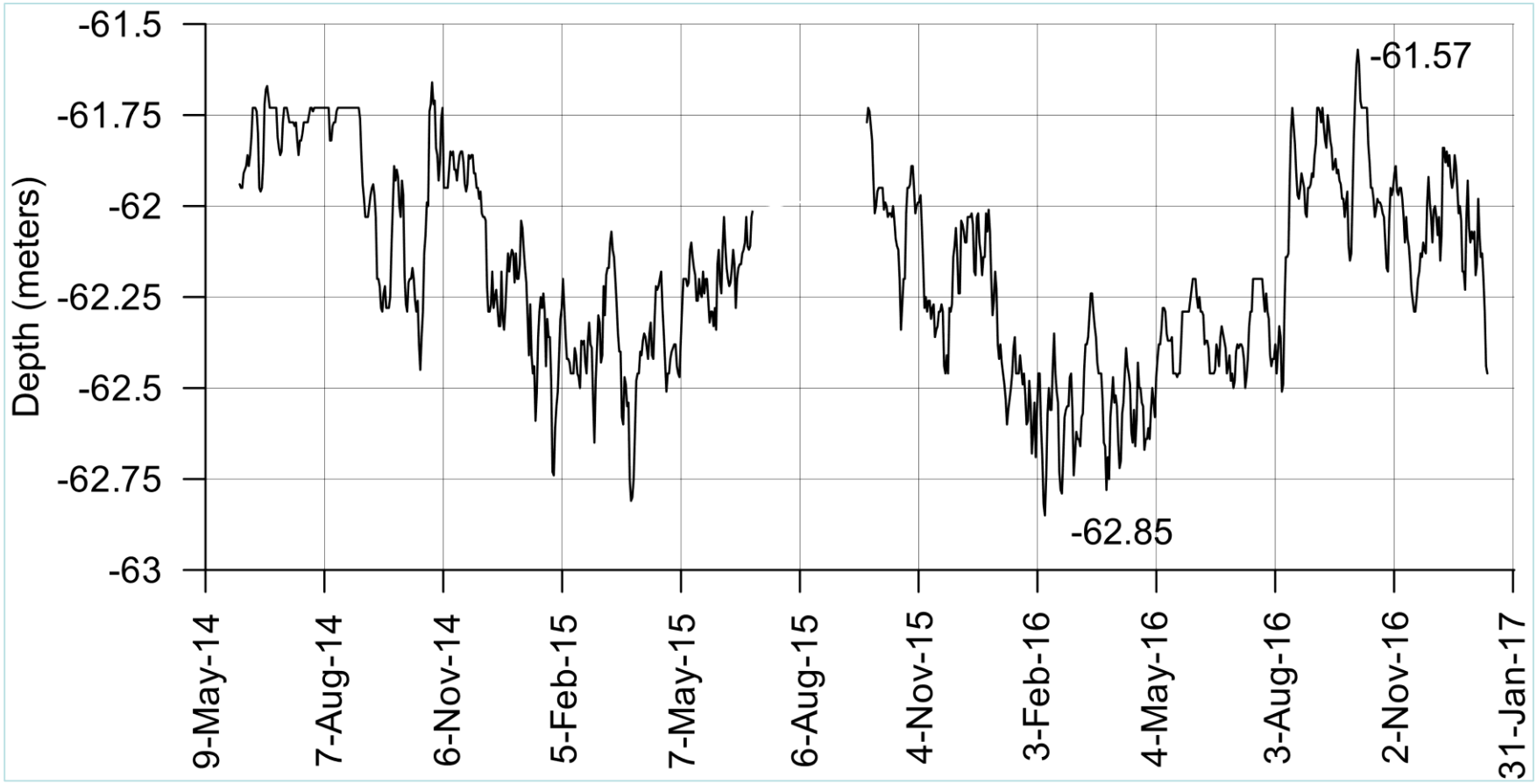

-0074 .2M

Water flow in the borehole

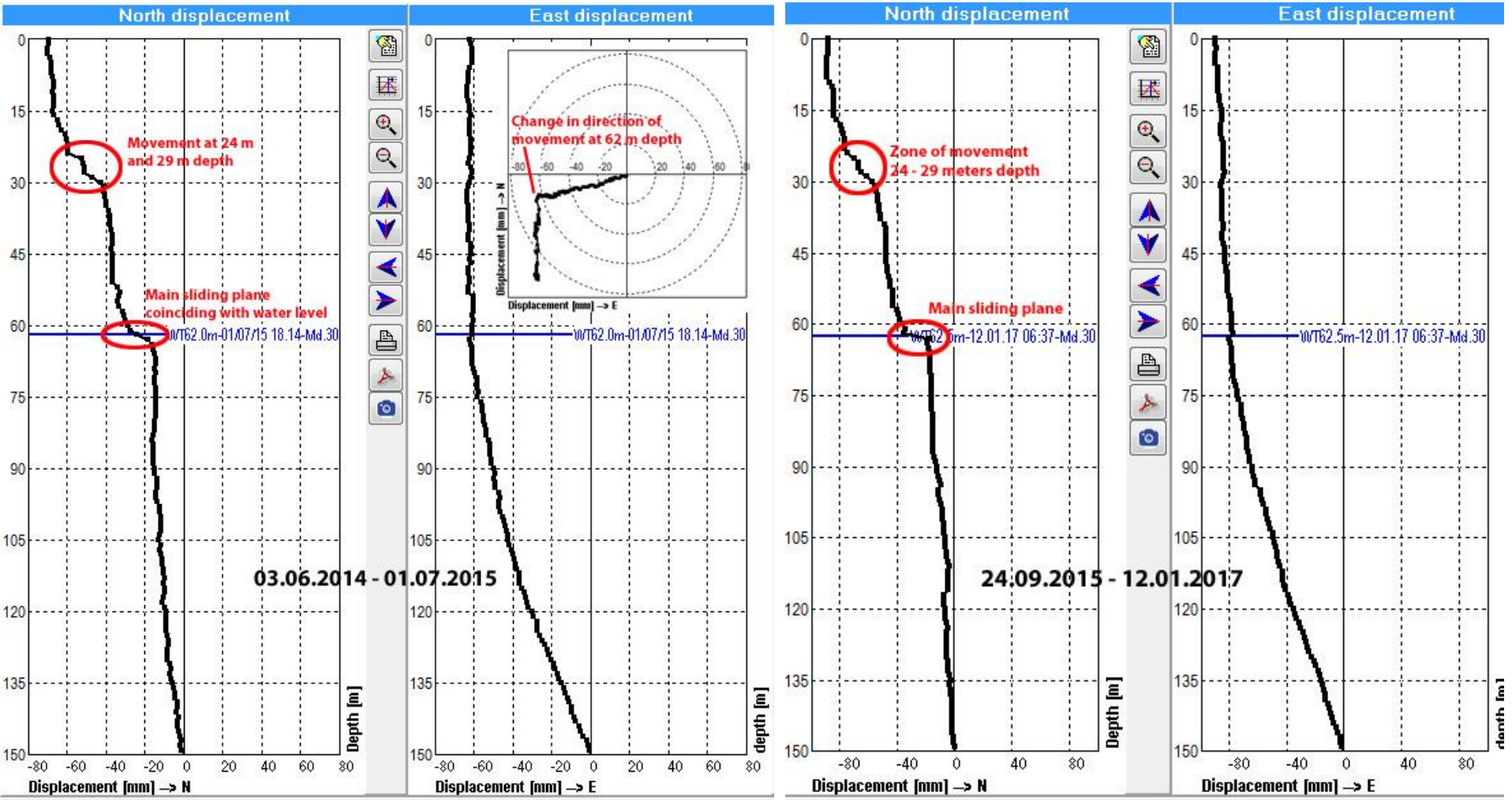




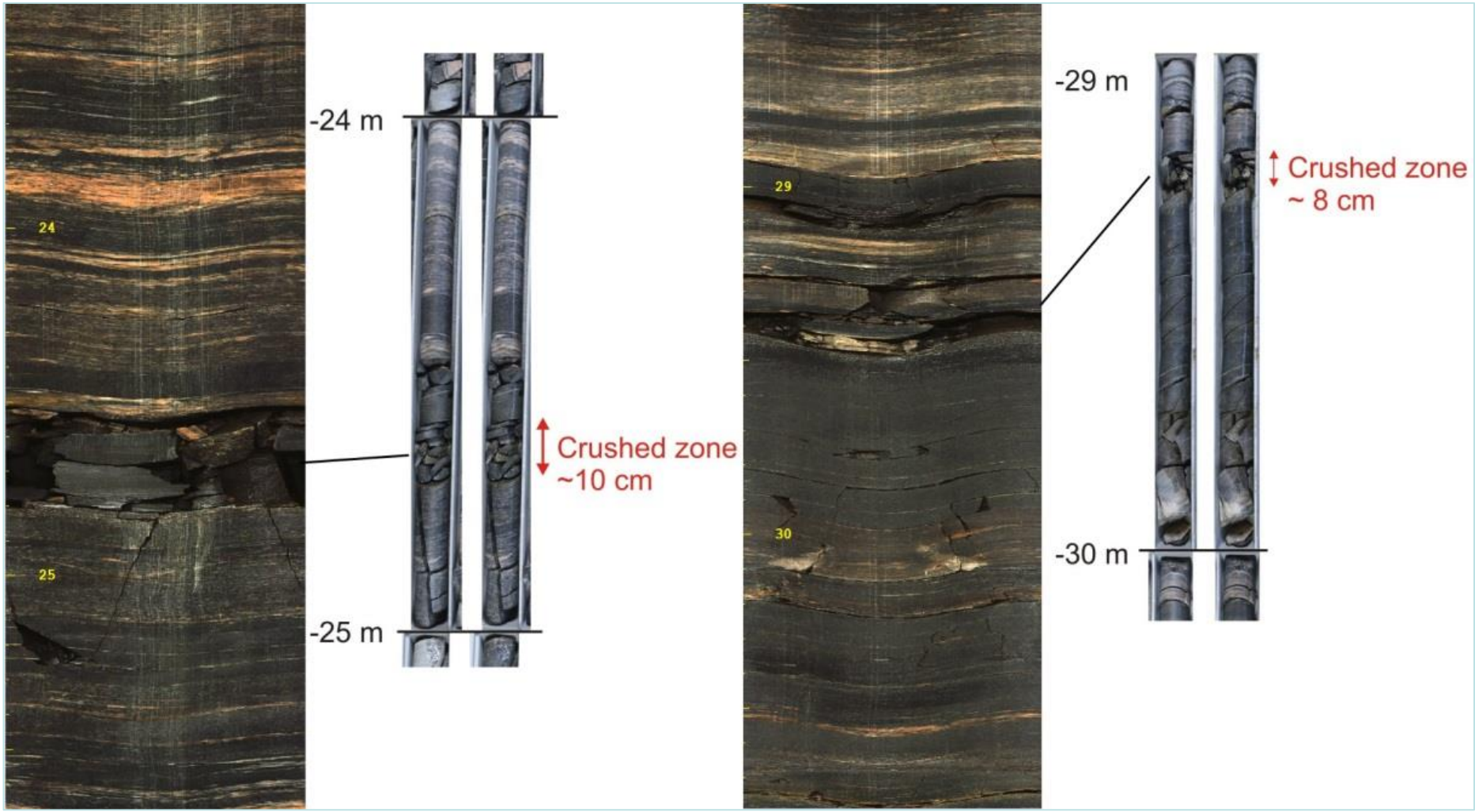
Water level in the borehole



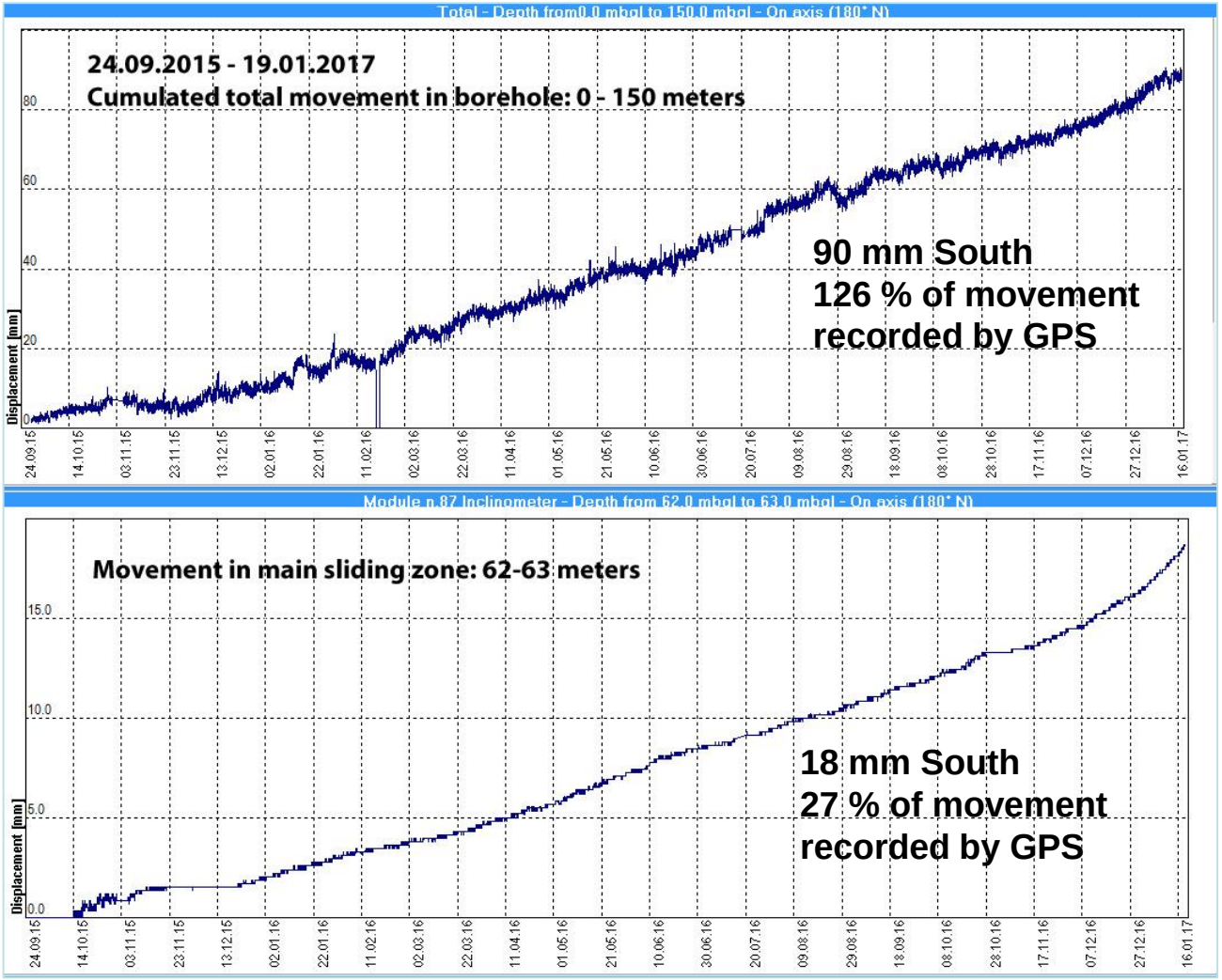
Movement in the borehole

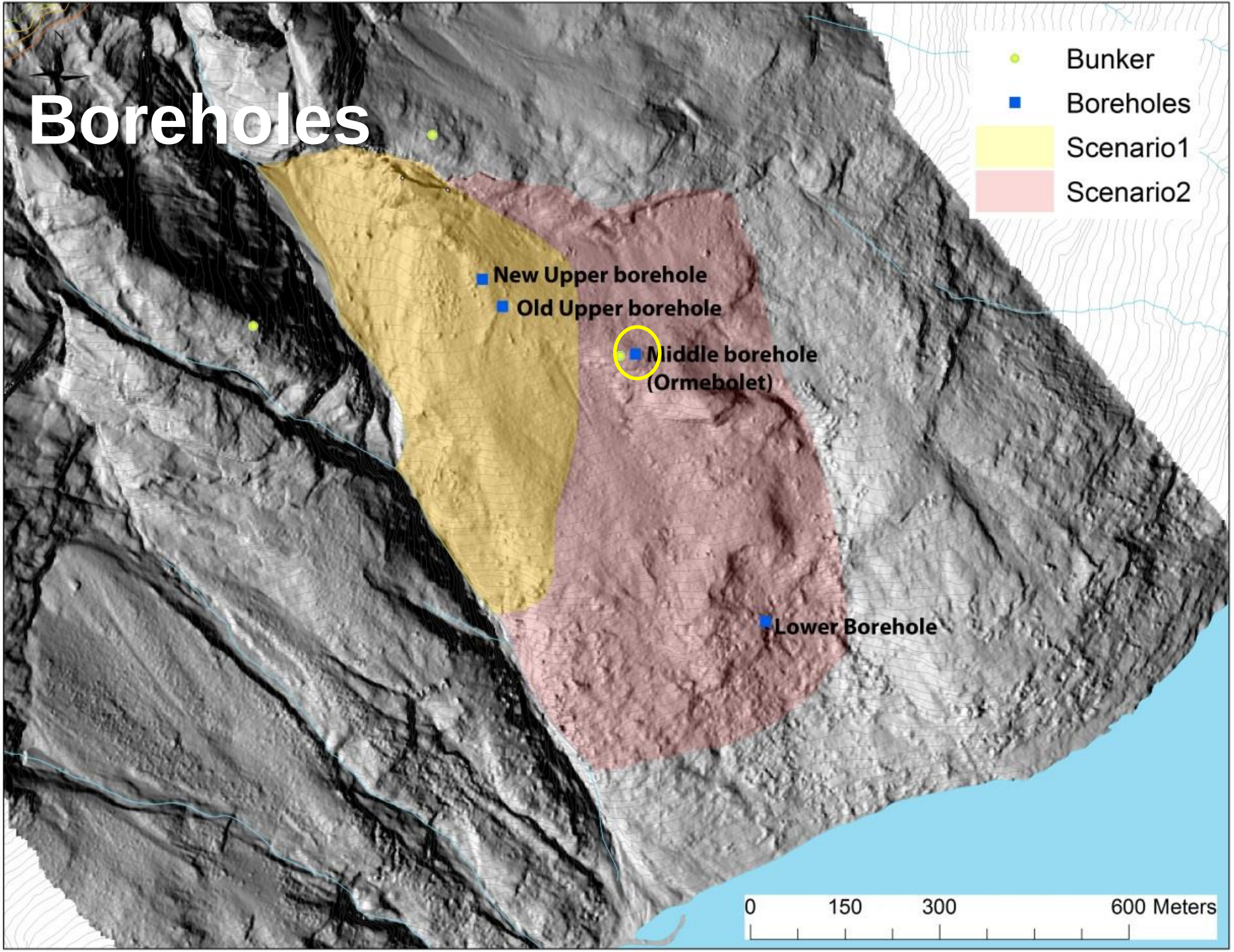


Movement at 24 – 29 m



Movement in the borehole




Boreholes
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(Ormebolet)
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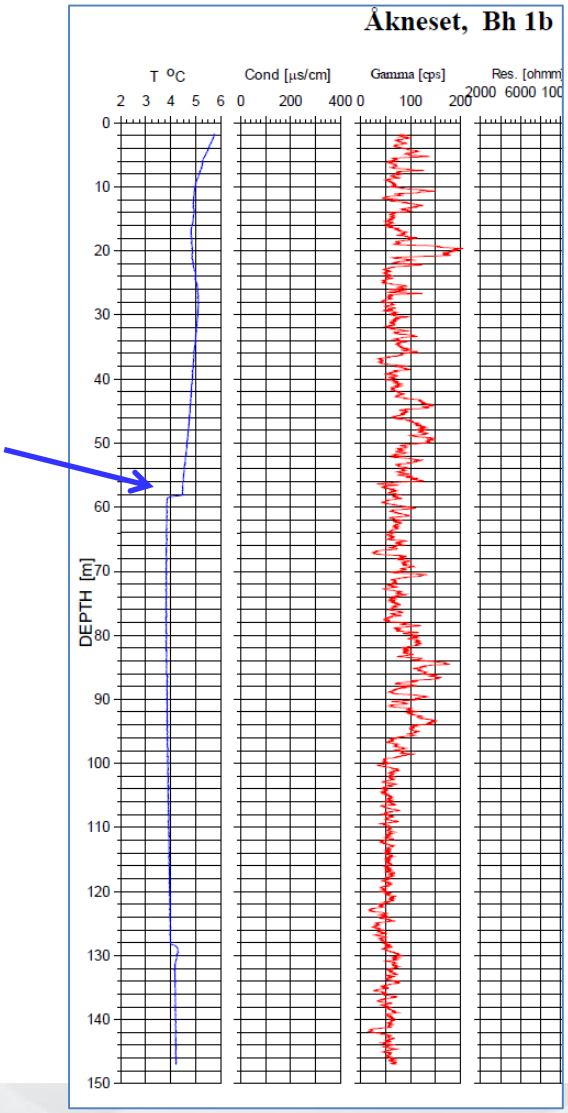
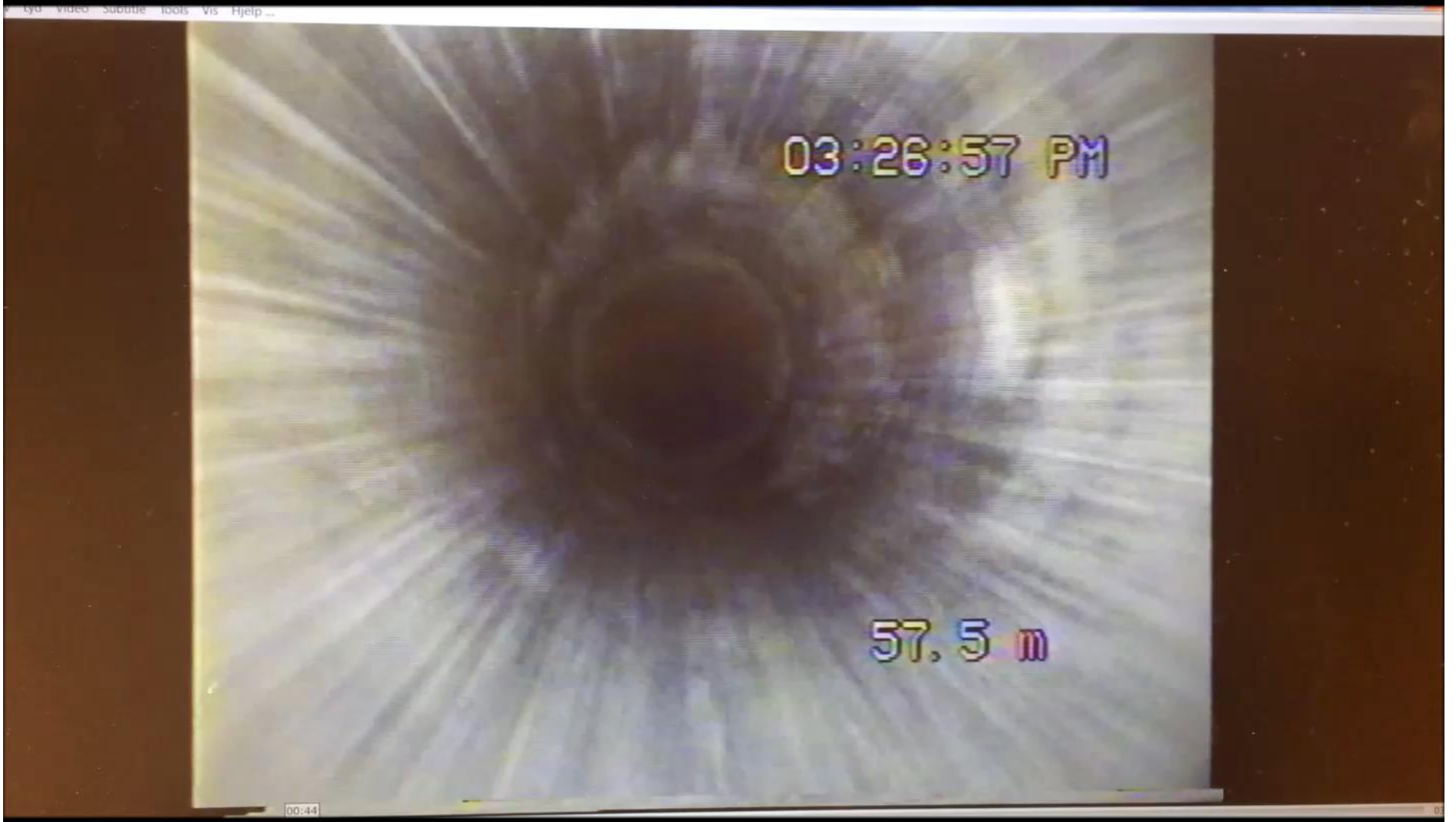
0
150
300
600 Meters

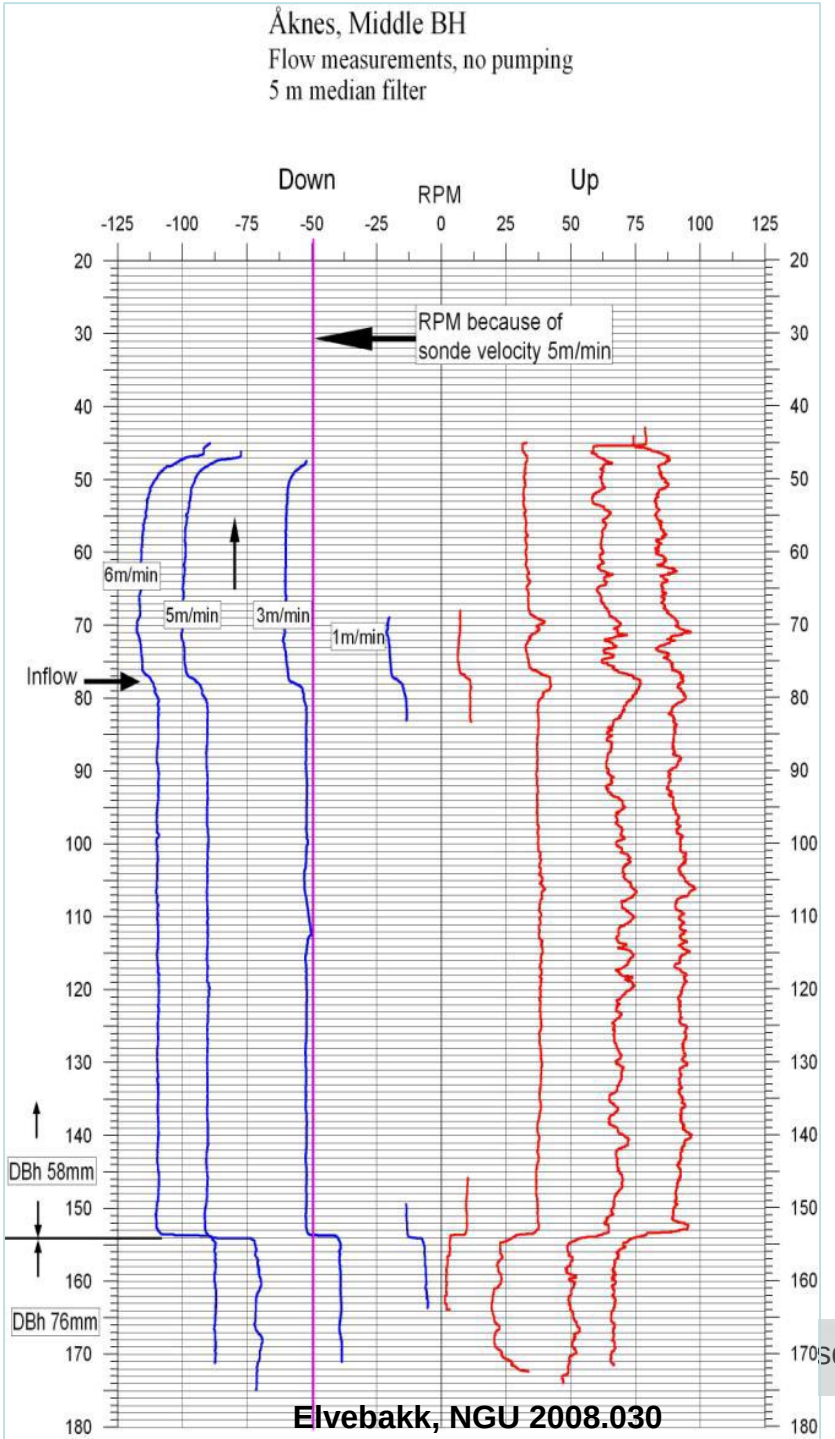
Middle borehole (Ormebolet)

- 2 holes to 150 m drilled in 2005
  - 1 vertical, 1 inclined 30°
  - Water level in vertical: 41.5 m
  - Inclined drained completely near bottom – probably still dry
- 1 vertical to 200 m in 2006 (DMS)
  - Drained completely at 194 m creating a vacuum
  - Was sealed at bottom by concrete
  - Water level about 45 m

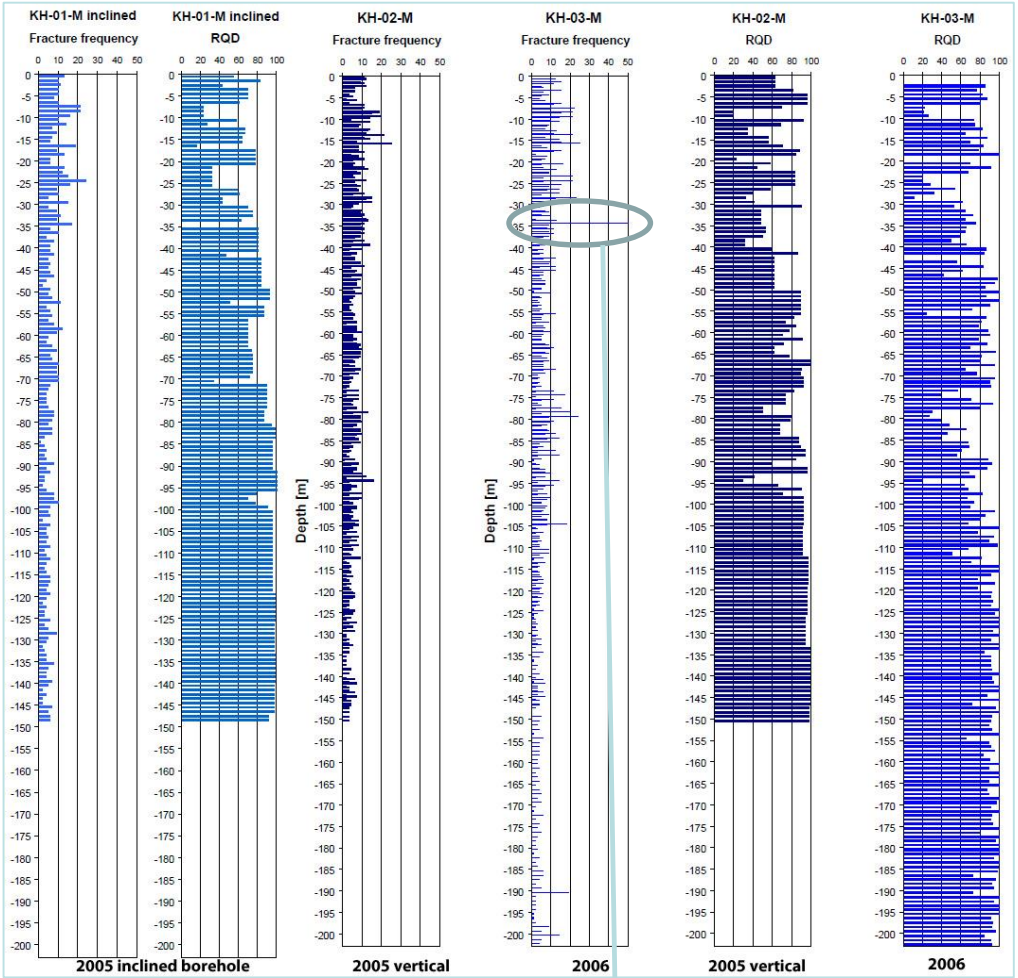


Temperature and gamma log from Inclined borehole. Rønningen, NGU report 002.2006


03:26:57 PM
57.5 m



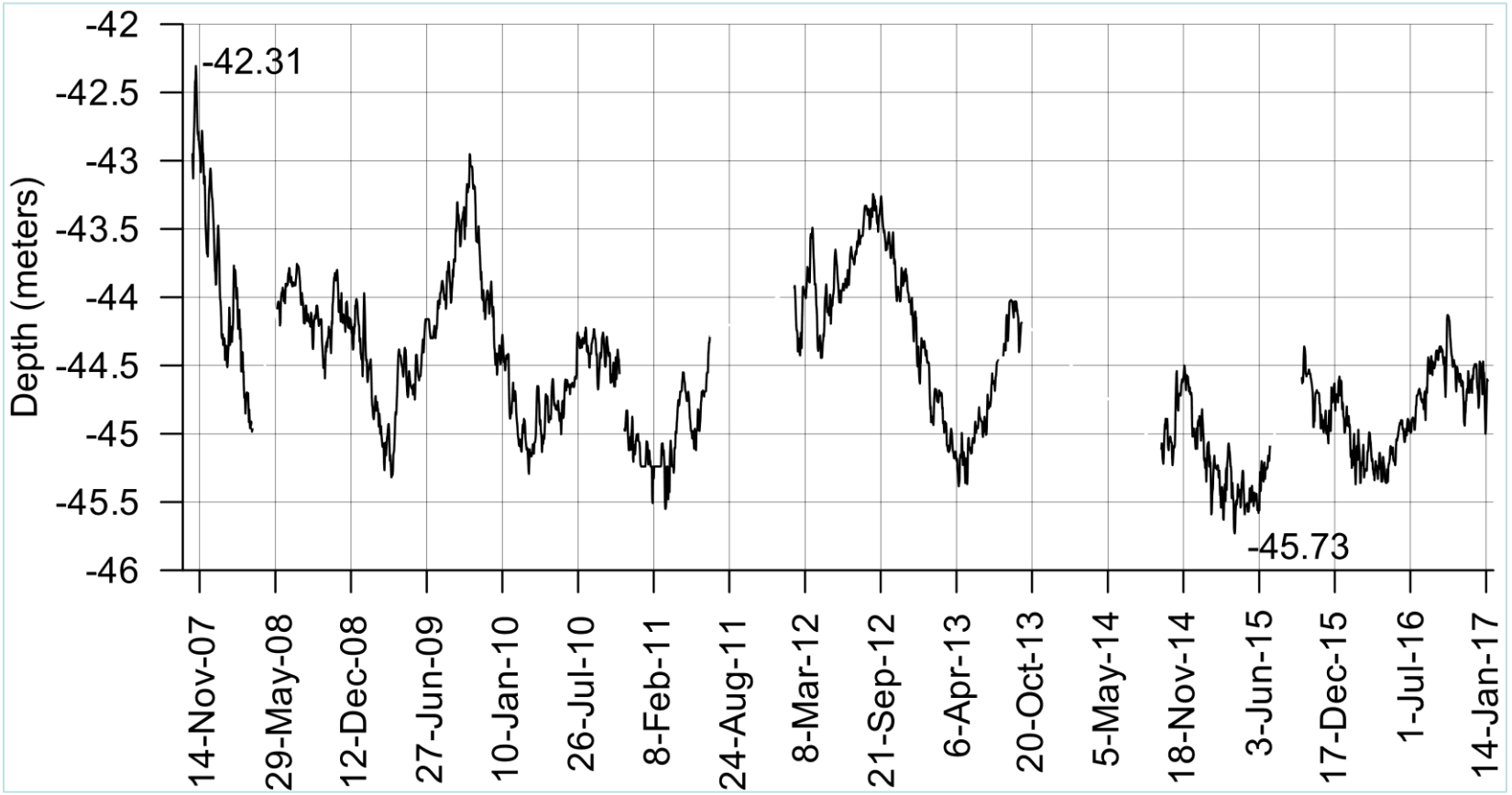
Elvebakk, NGU 2008.030



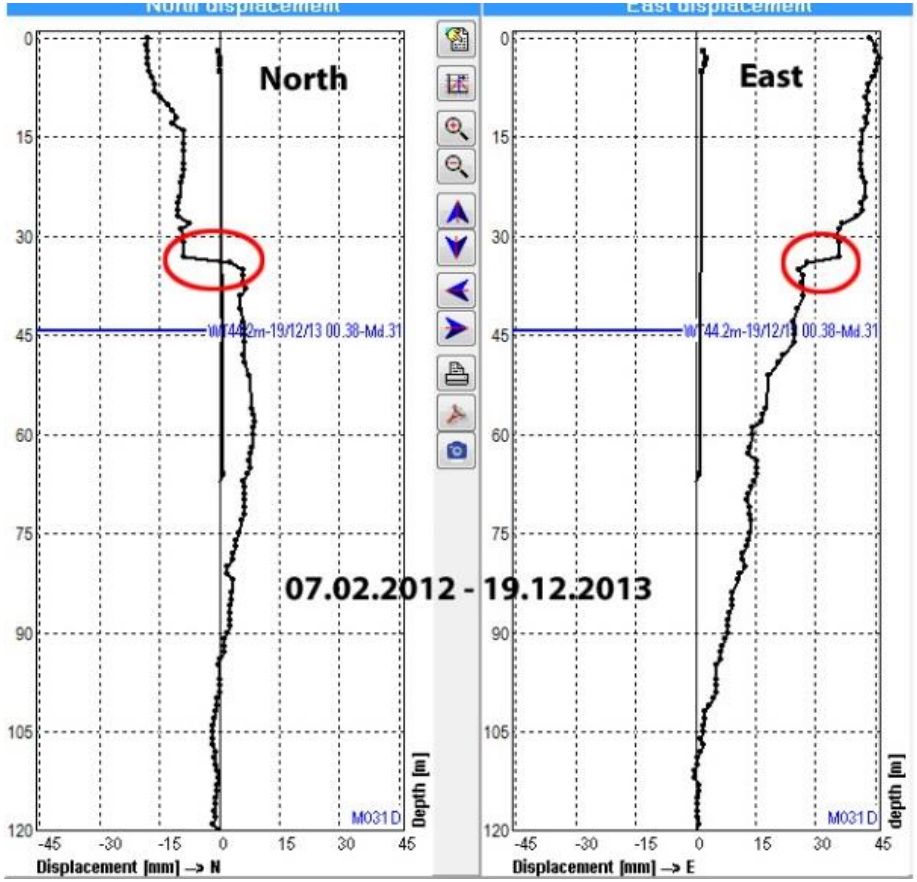
Ganerød, NGU 2007.020

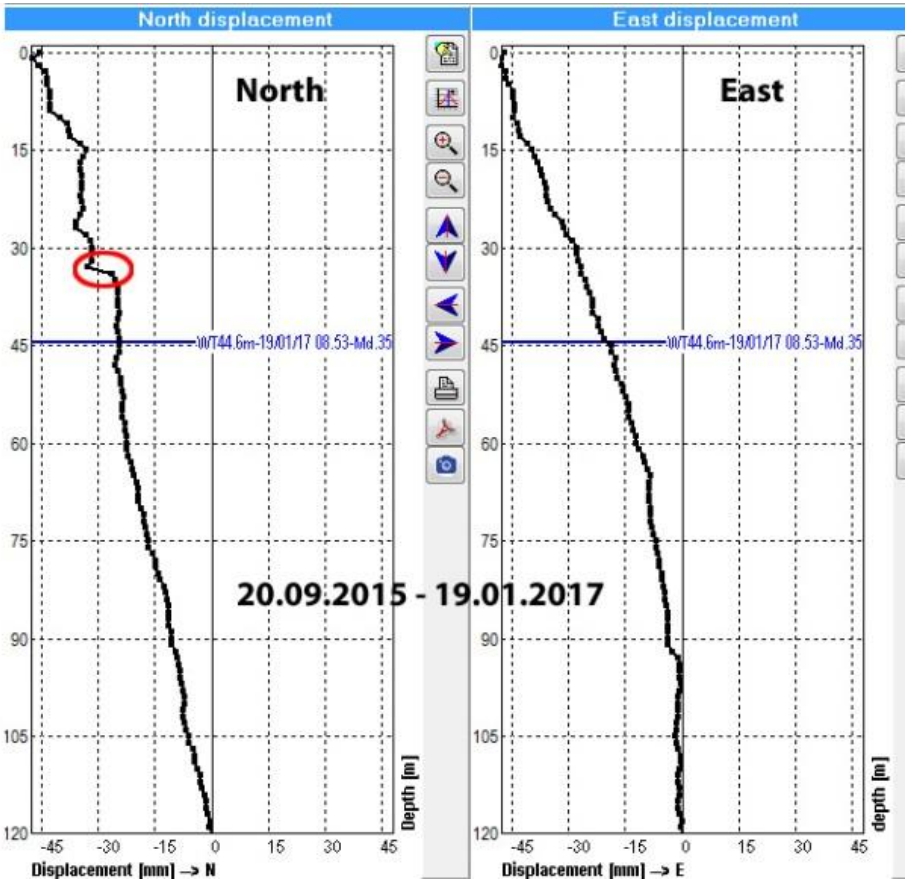
Sliding plane

Water level in Middle Borehole

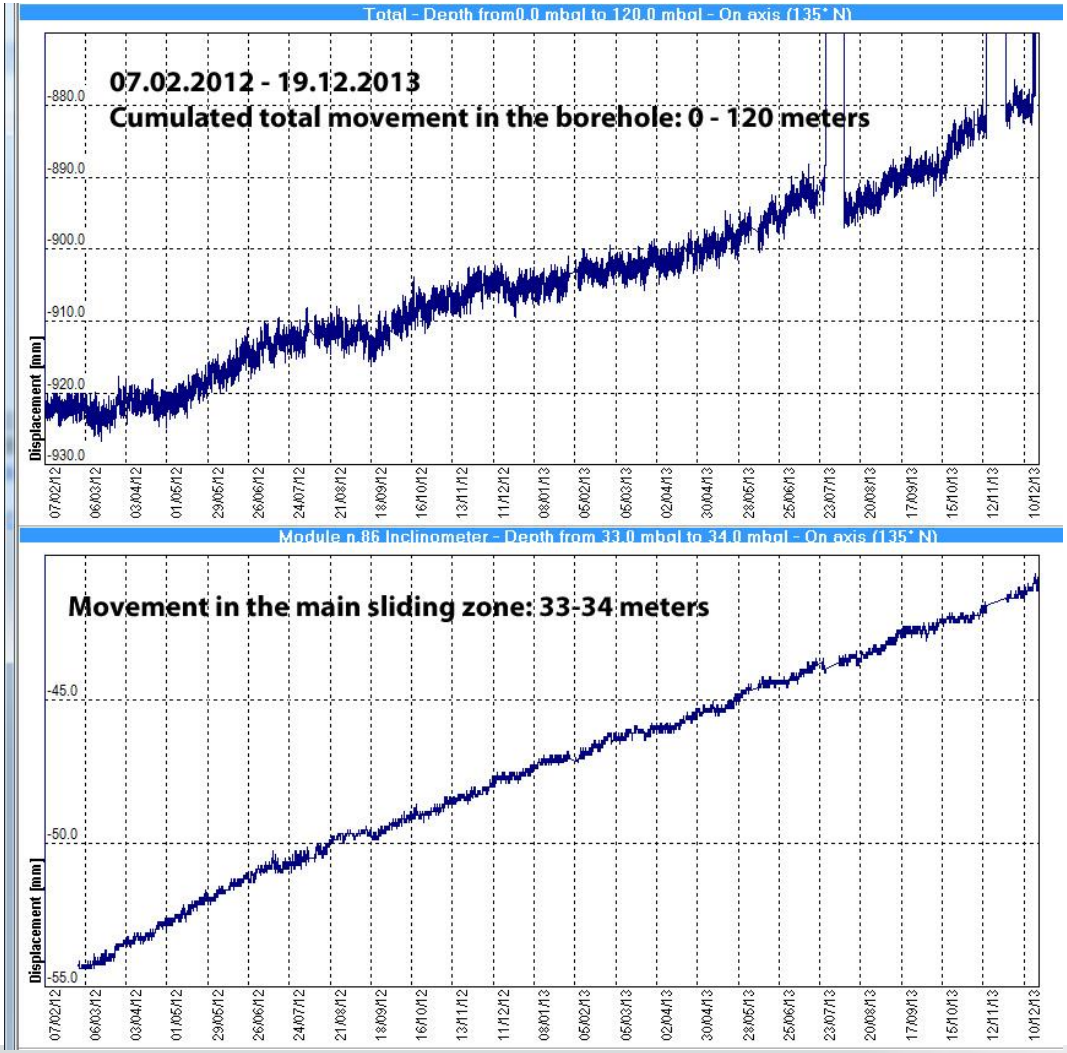


Movements in the Middle Borehole



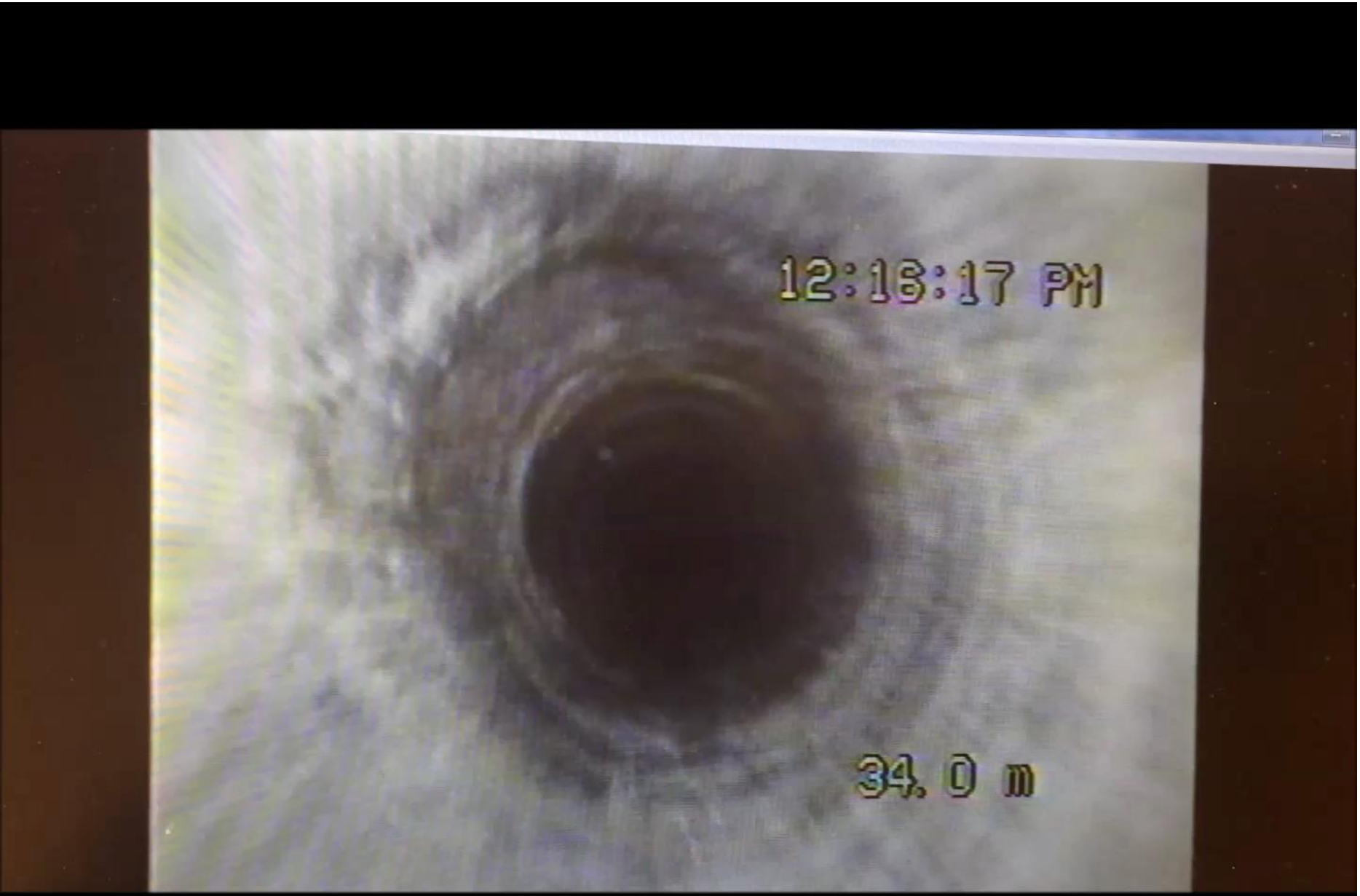


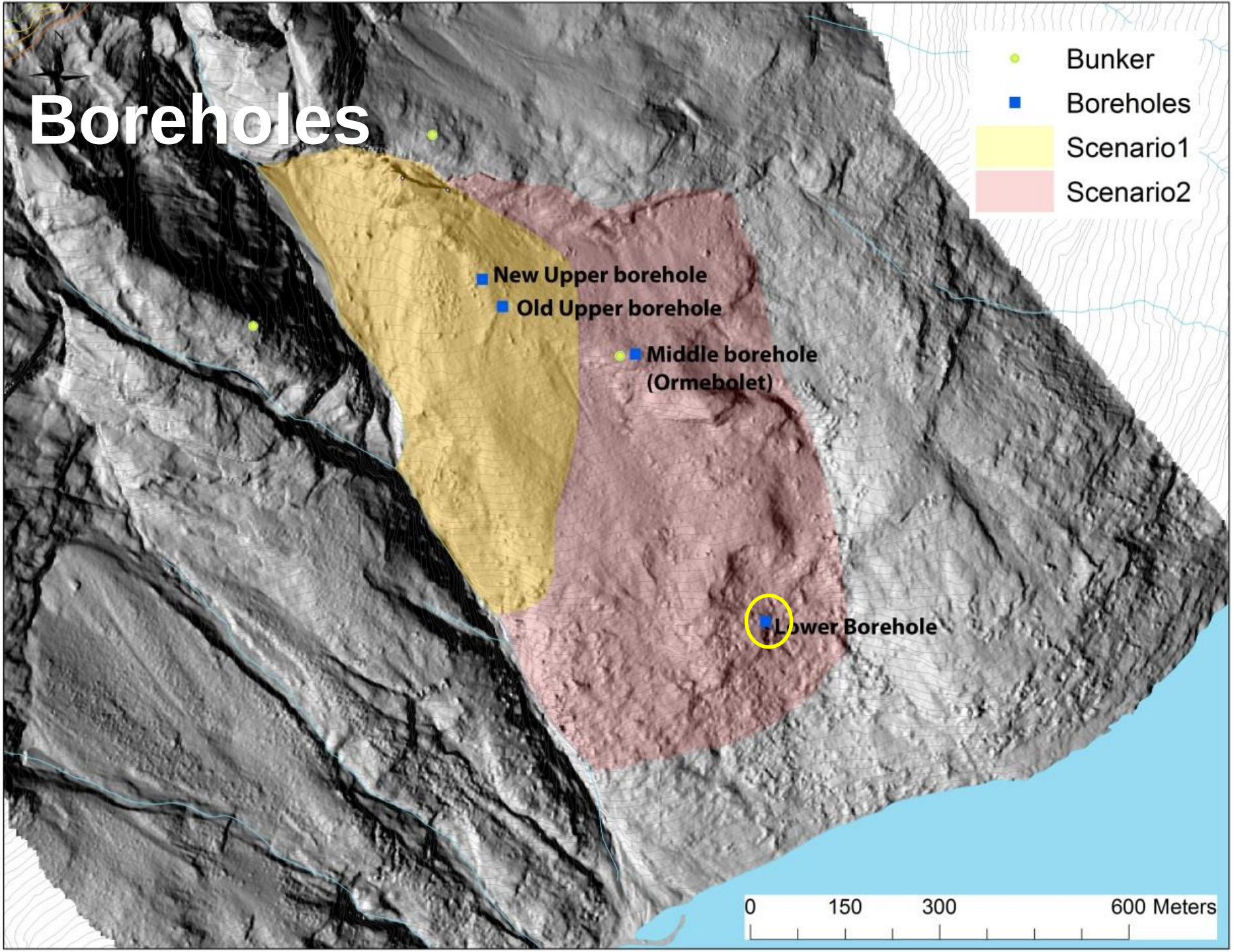
Movements in the Middle Borehole



Total movement SE:
100 % of surface GPS
New DMS has
direction SW

Sliding zone:
33 % of surface GPS


12:18:17 PM
34.0 m


Boreholes
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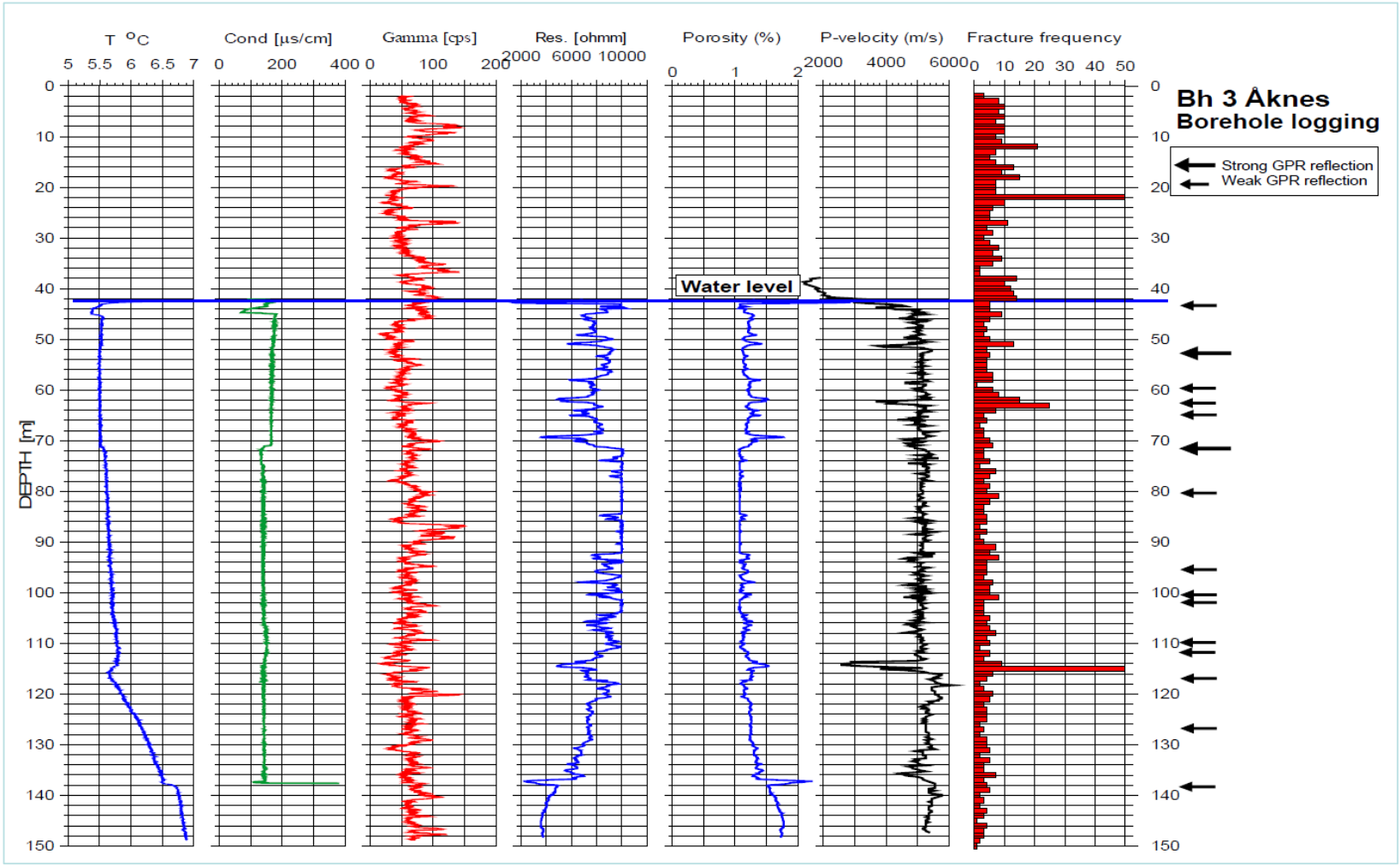
Scenario2
New Upper borehole
Old Upper borehole
Middle borehole
(Ormebolet)
Lower Borehole
0
150
300
600 Meters

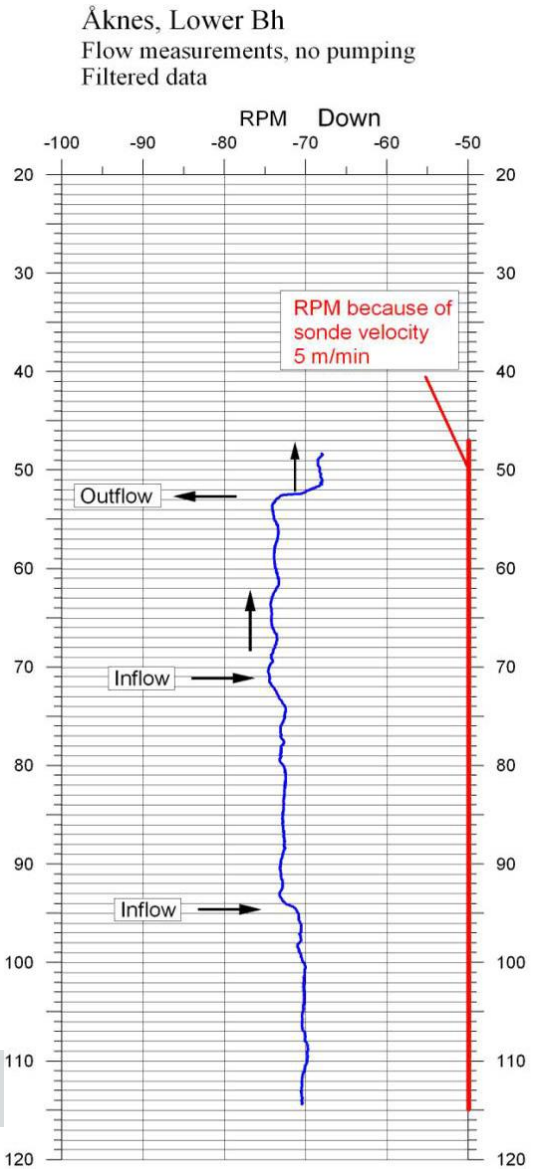
Lower borehole - logs

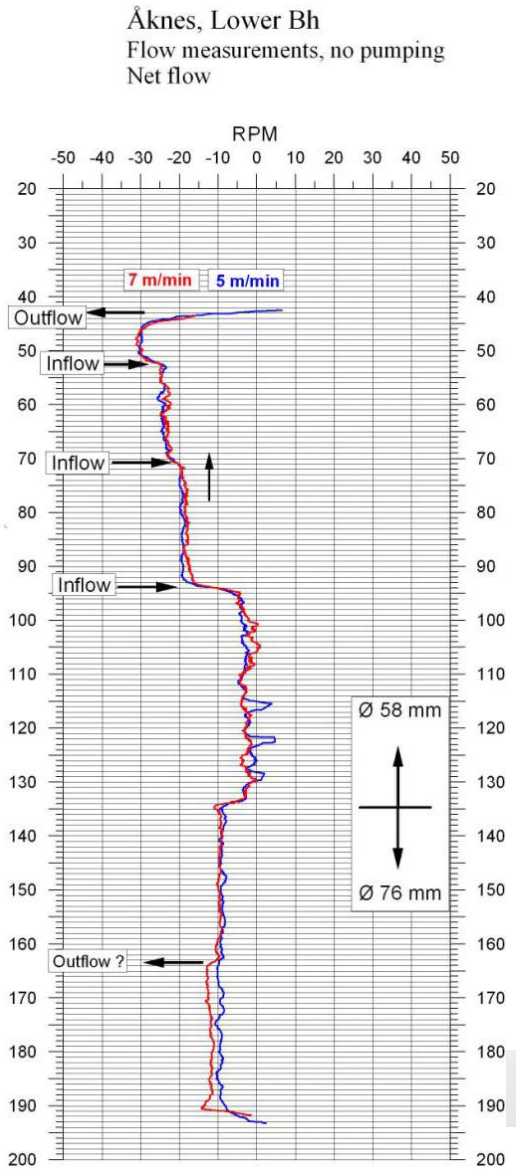


Rønningen, NGU report 002.2006

Lower Borehole: Flow measurements

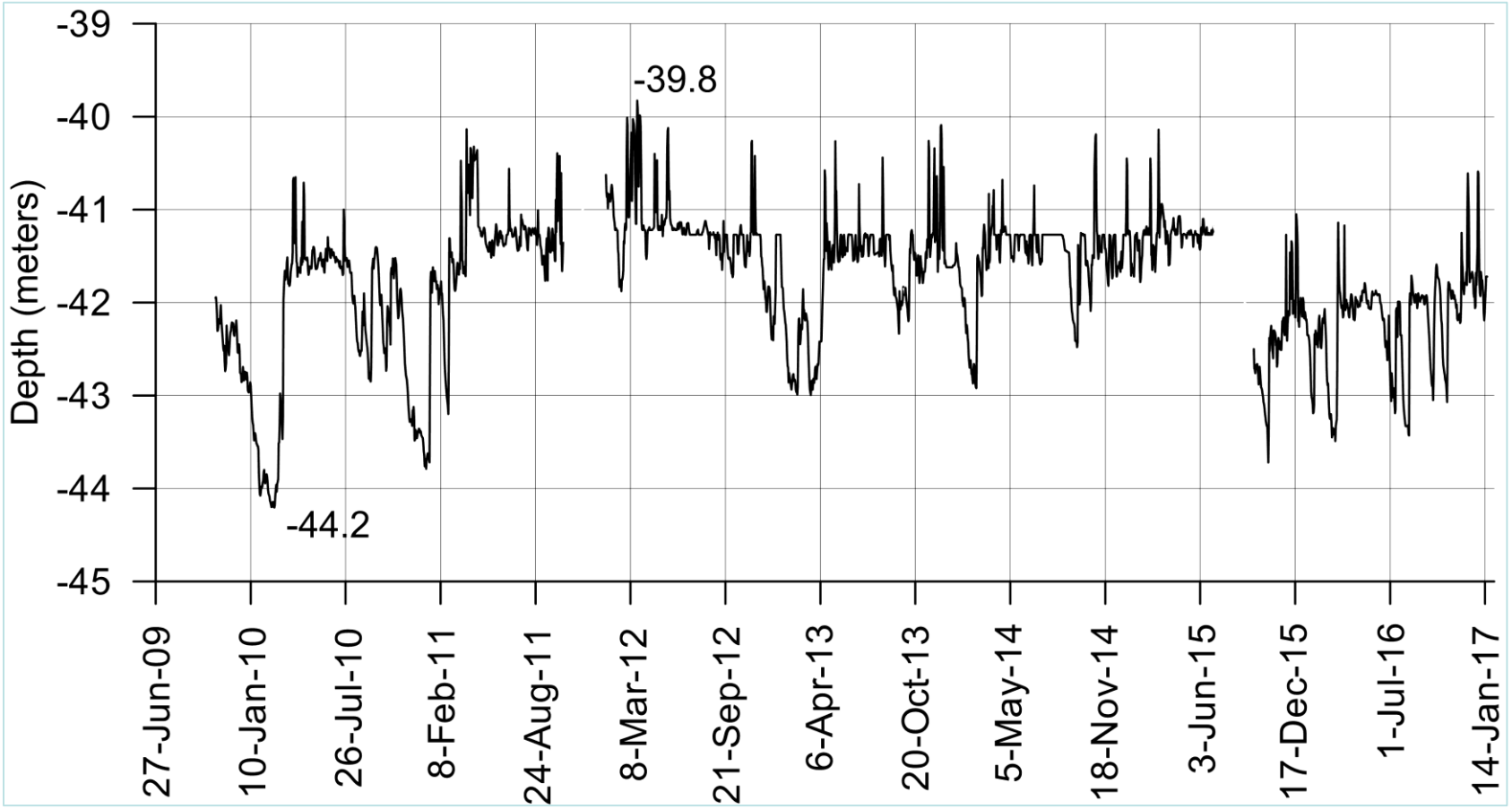
Left: Before casing was installed





With casing to 134 m

Water level (DMS) in Lower Borehole




10:40:18 AM

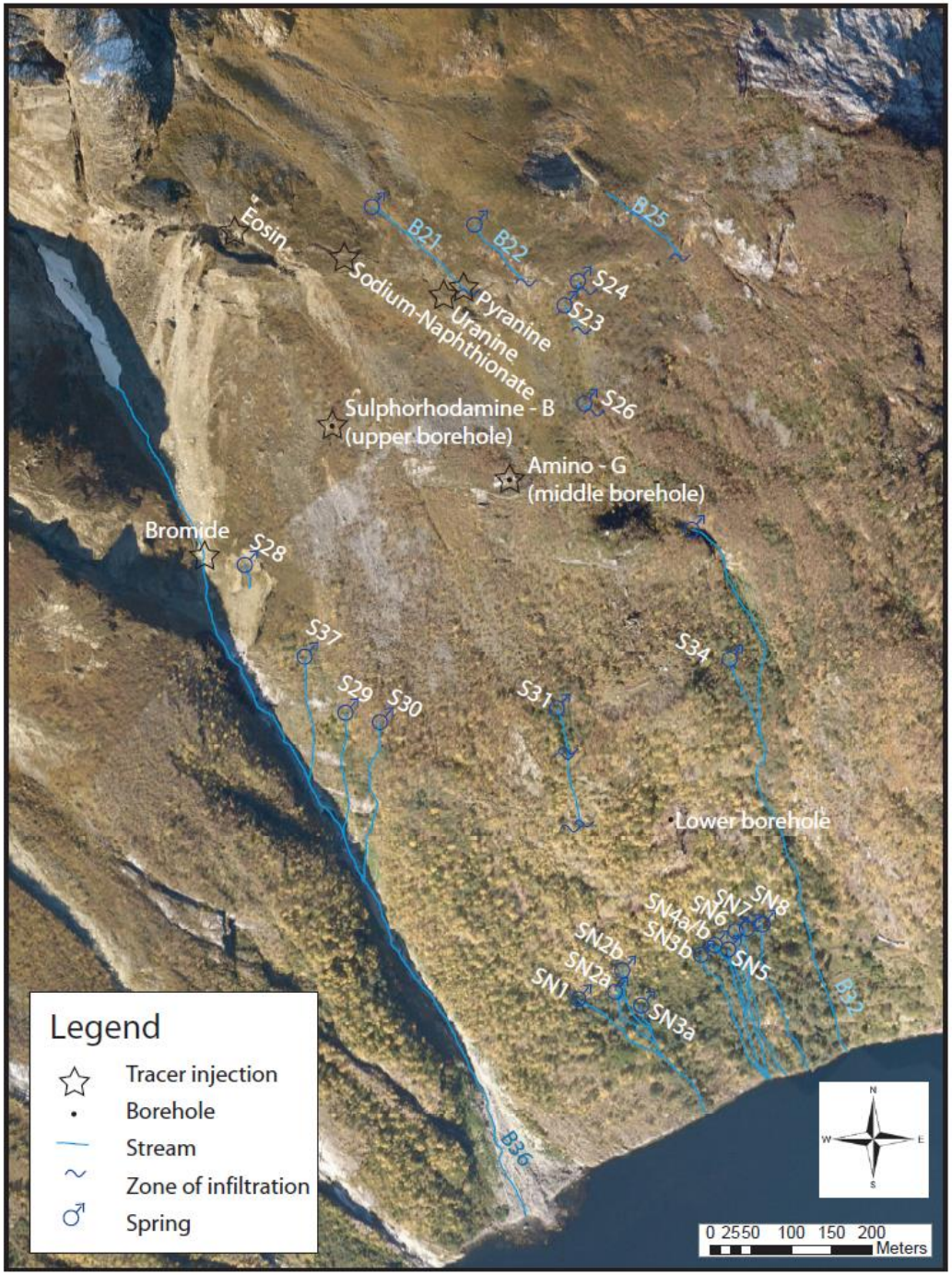
Ground water investigations

- 2 master theses from ETH, supervisor Simon Löw
  - Frei – Multi tracer and water balance
  - Thoeny – Electric conductivity logging

- 1 master thesis NTNU: Tracer for flow velocity

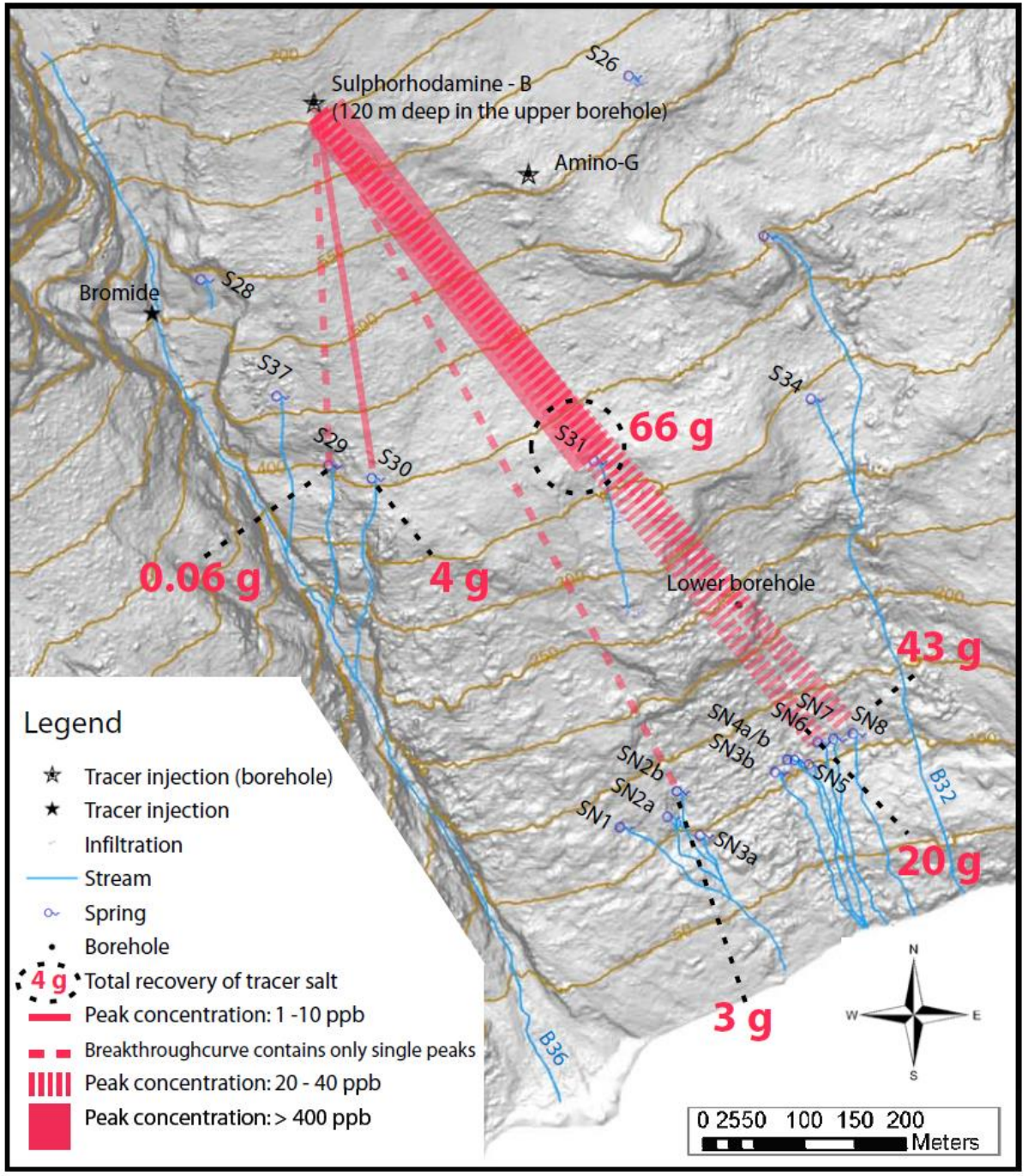
Multi-tracer experiment

Hydro-geological features and tracer injection points

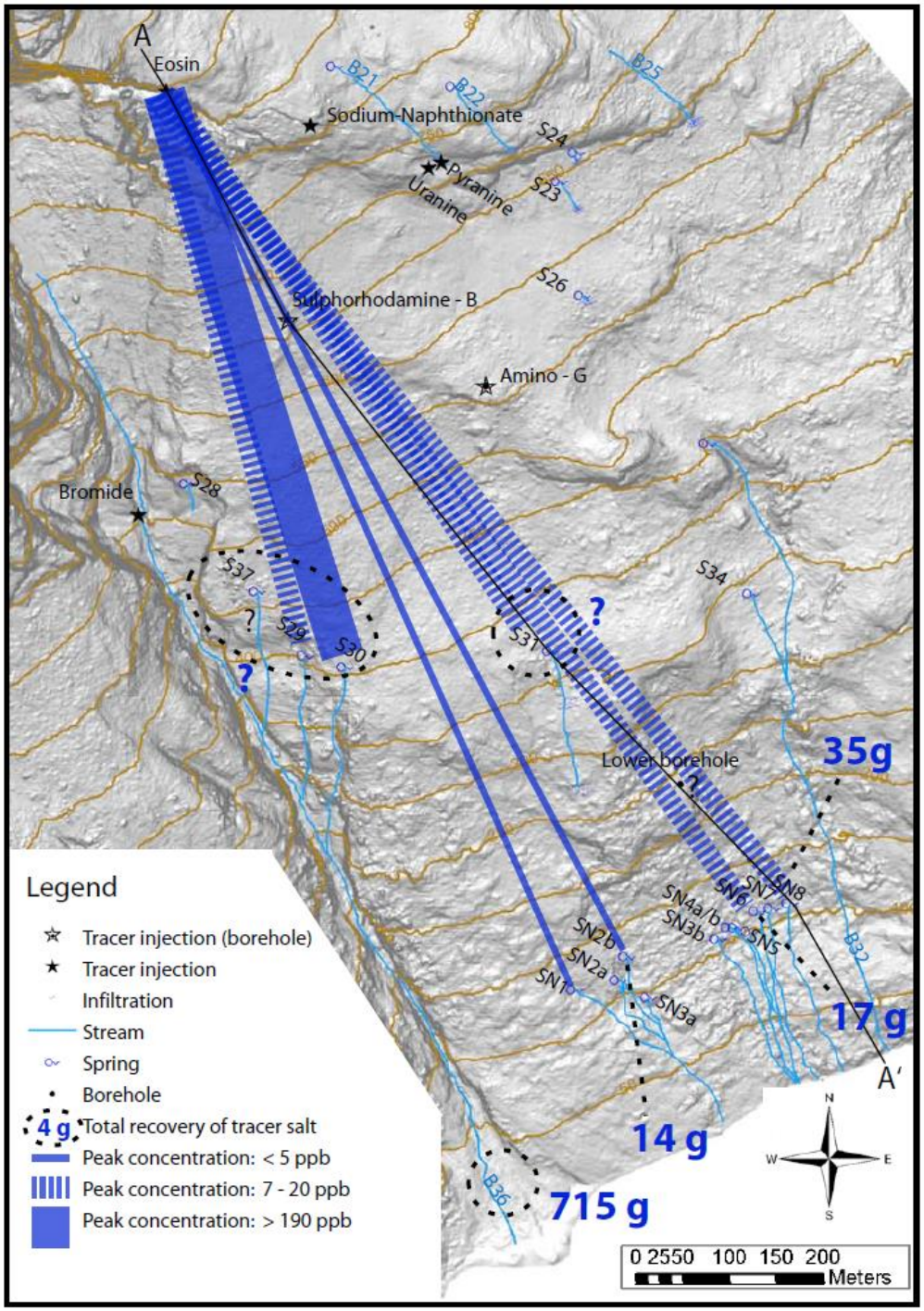


Frei, 2008, master thesis ETH

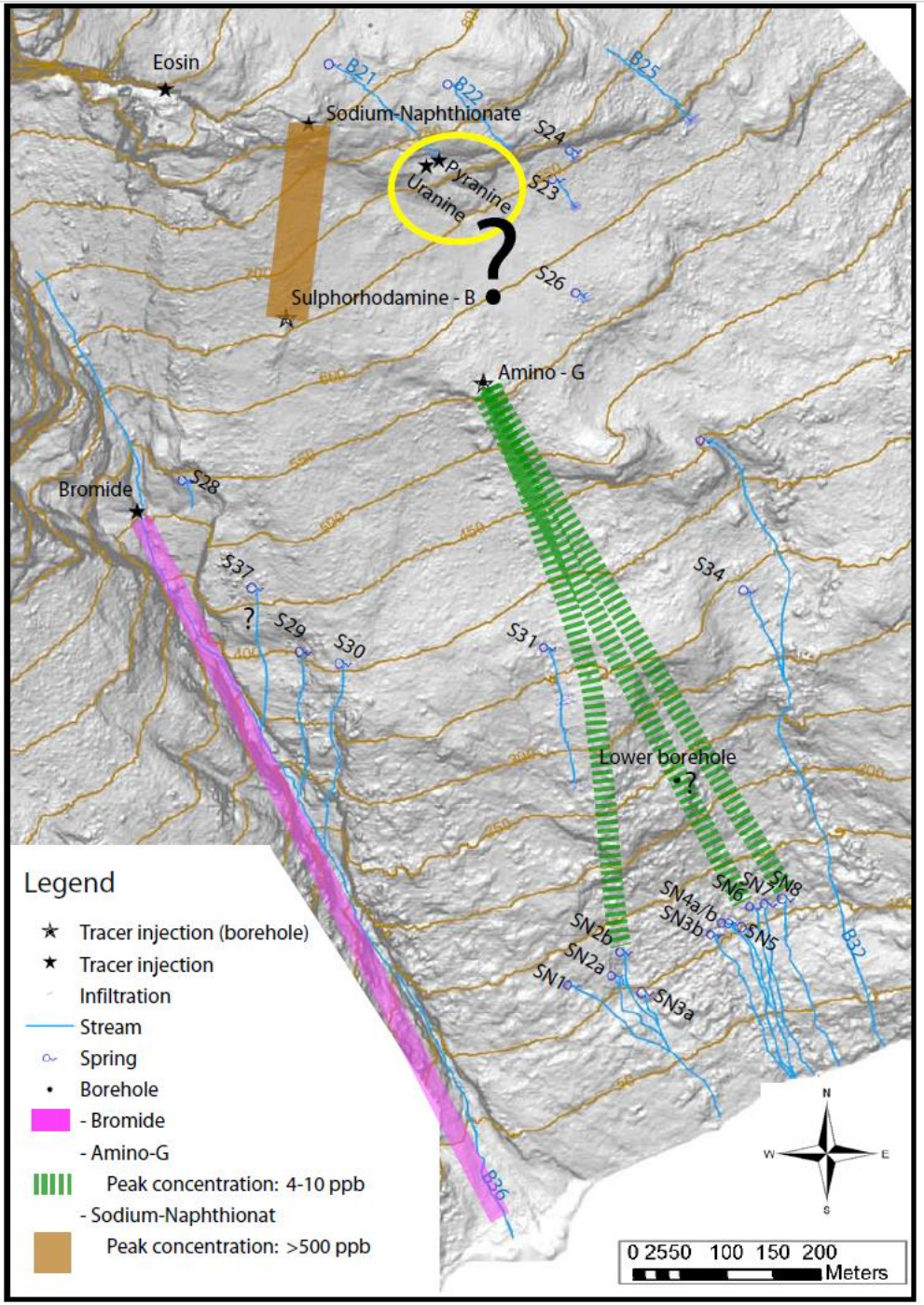
Flow direction of tracer injected in Upper Borehole



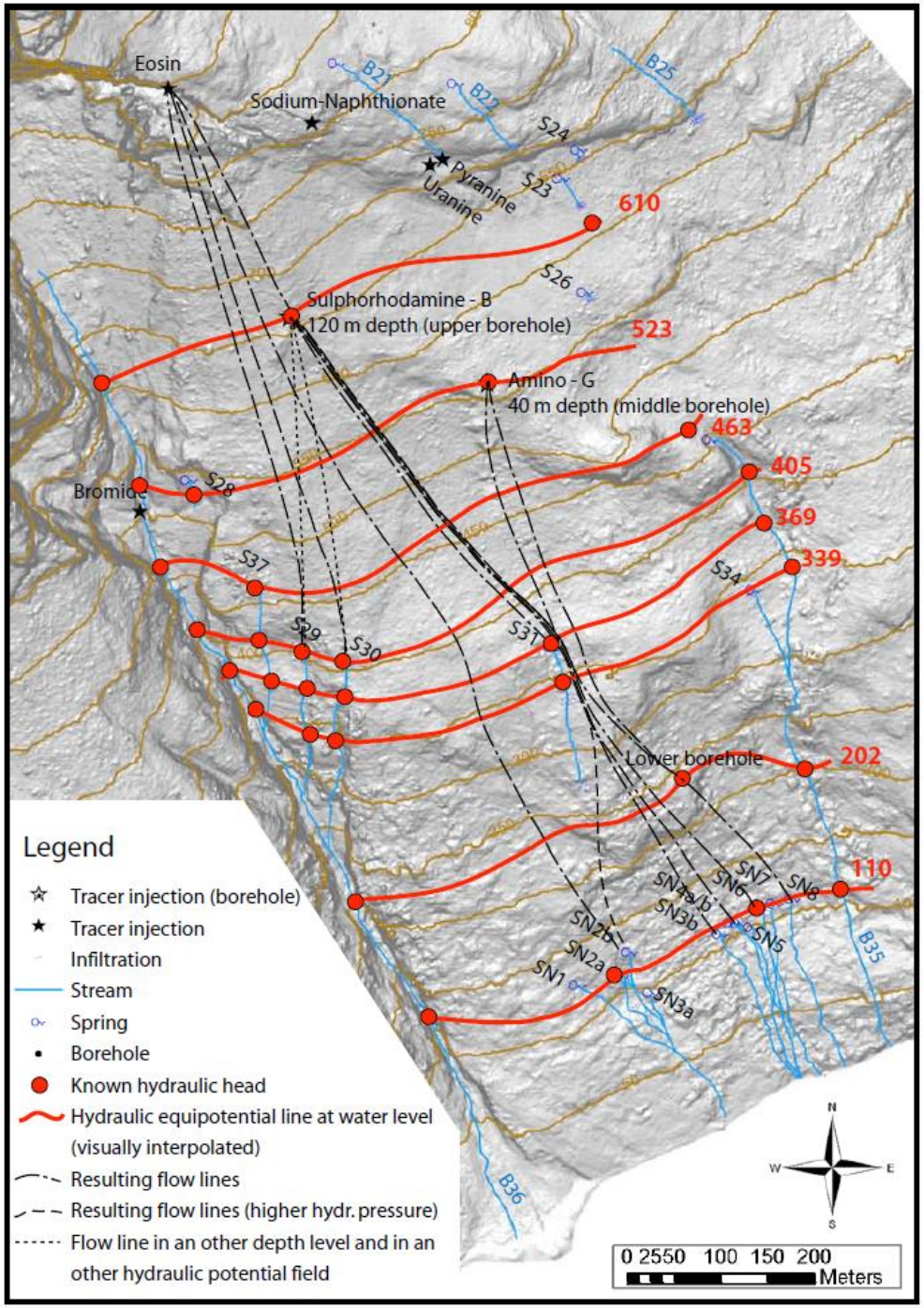
Flow direction of tracer injected into the graben



Flow direction of tracer injected into the Middle borehole and streams into back fracture

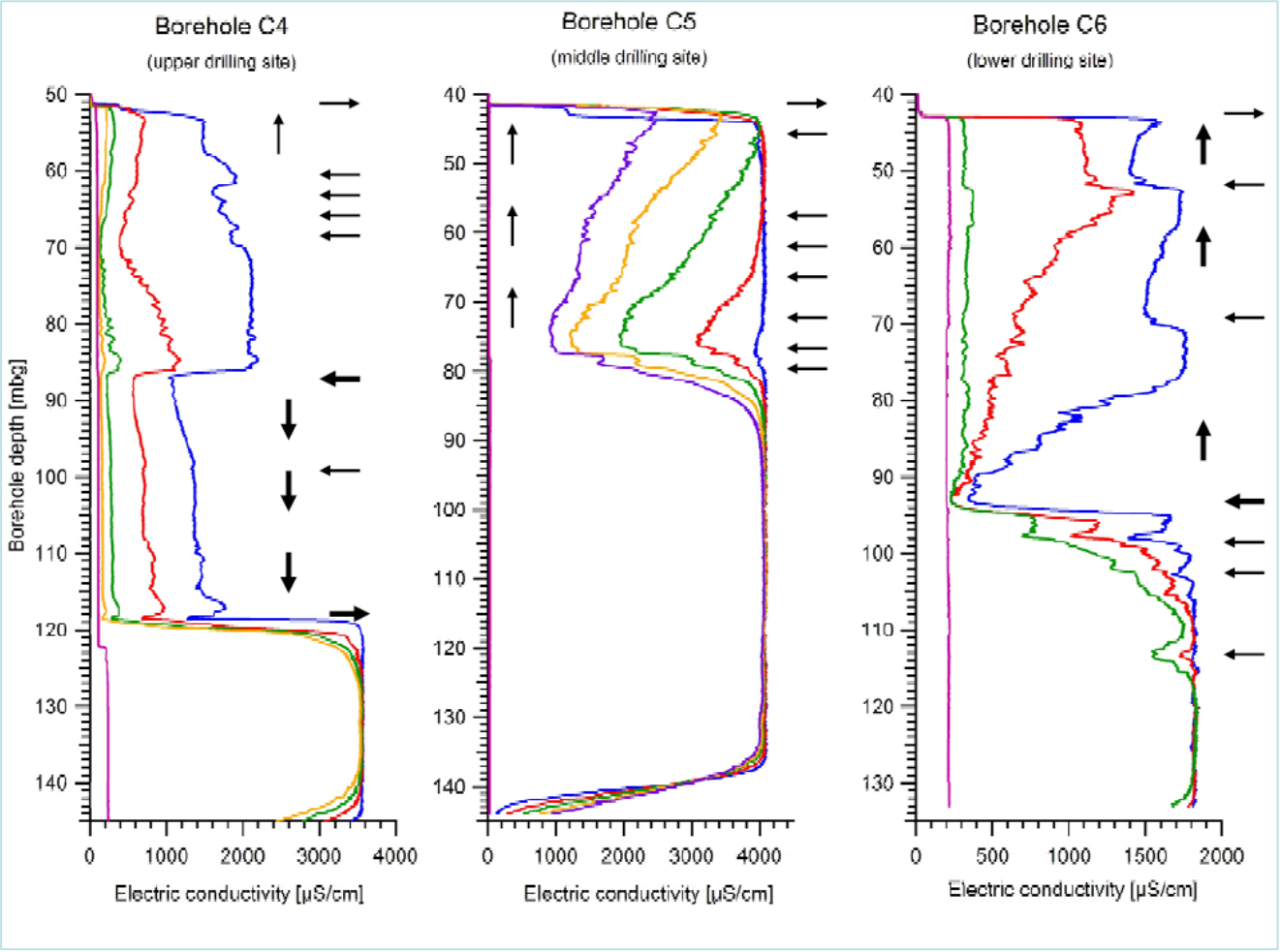


Known hydraulic heads, and equipotential lines and flow lines



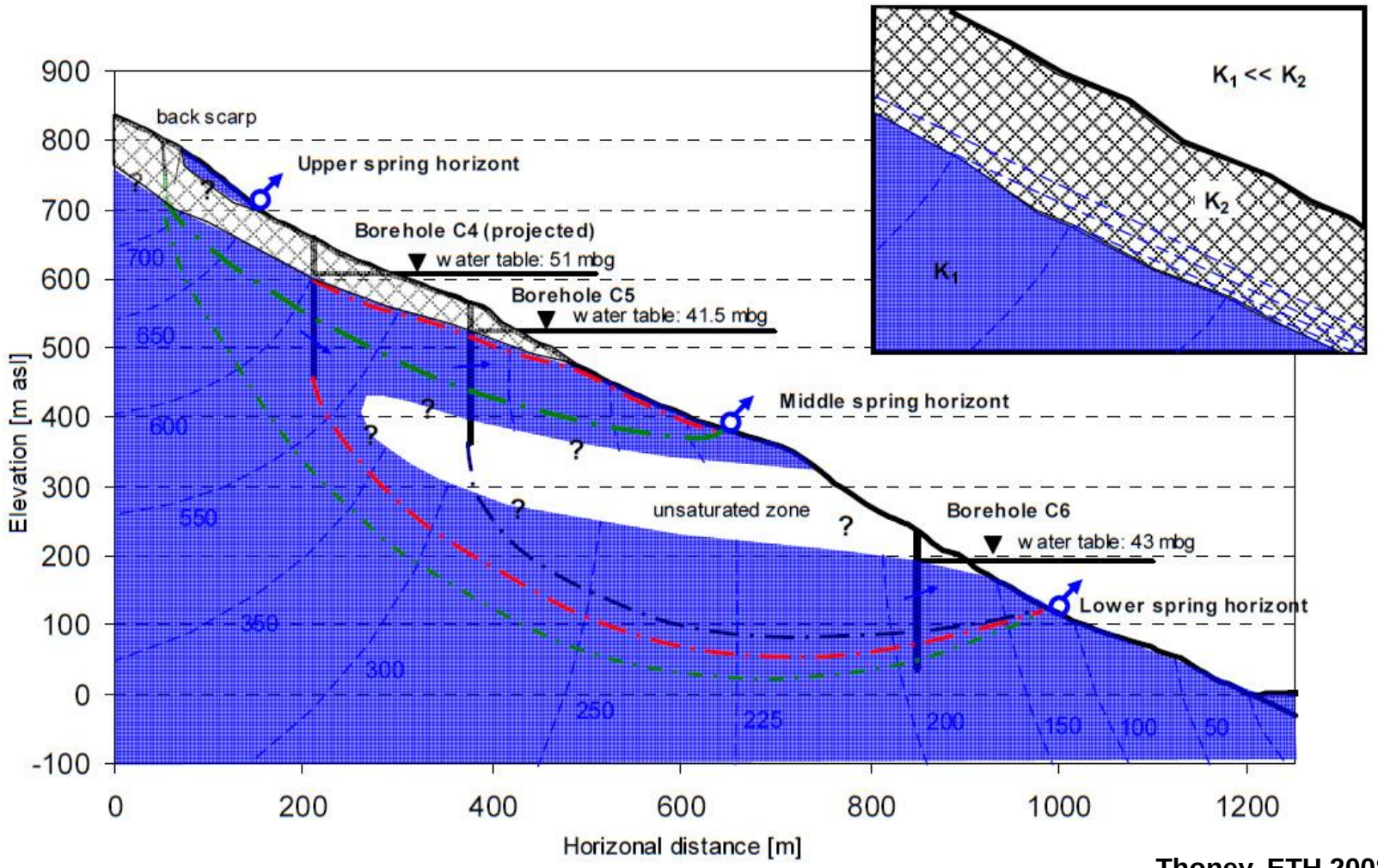
Frei, 2008, master thesis ETH

Dynamic fluid conductivity logging



Thoney, ETH 2008

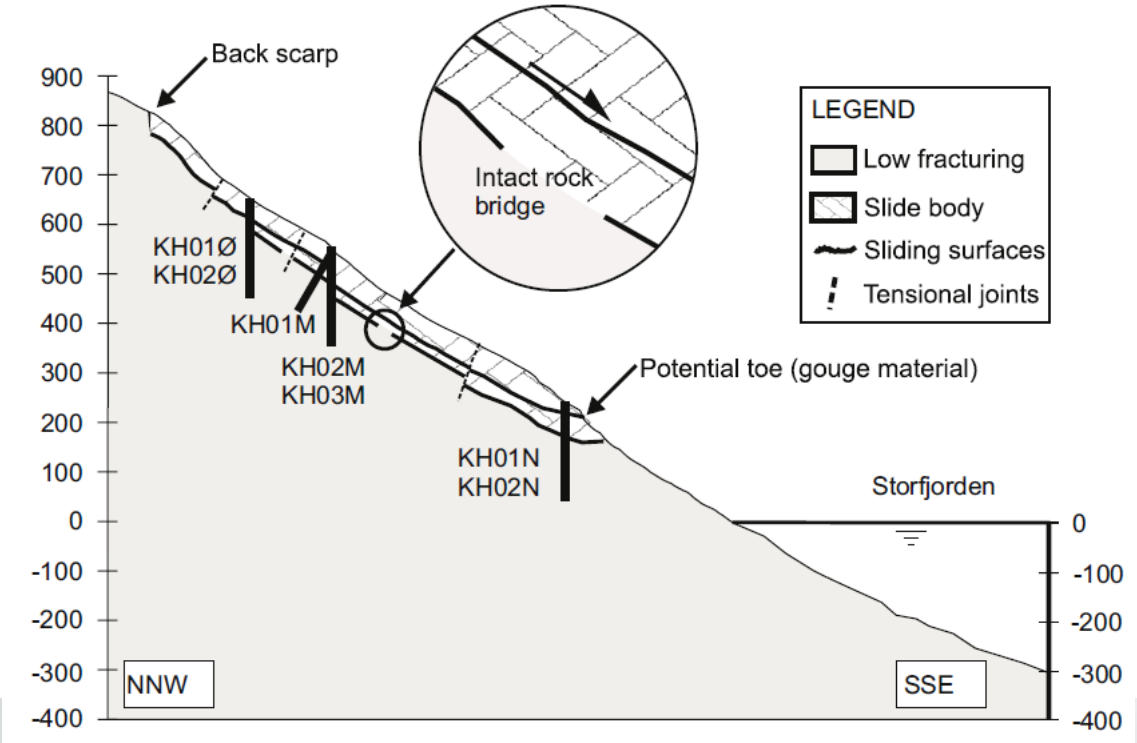
Conceptual ground water flow model



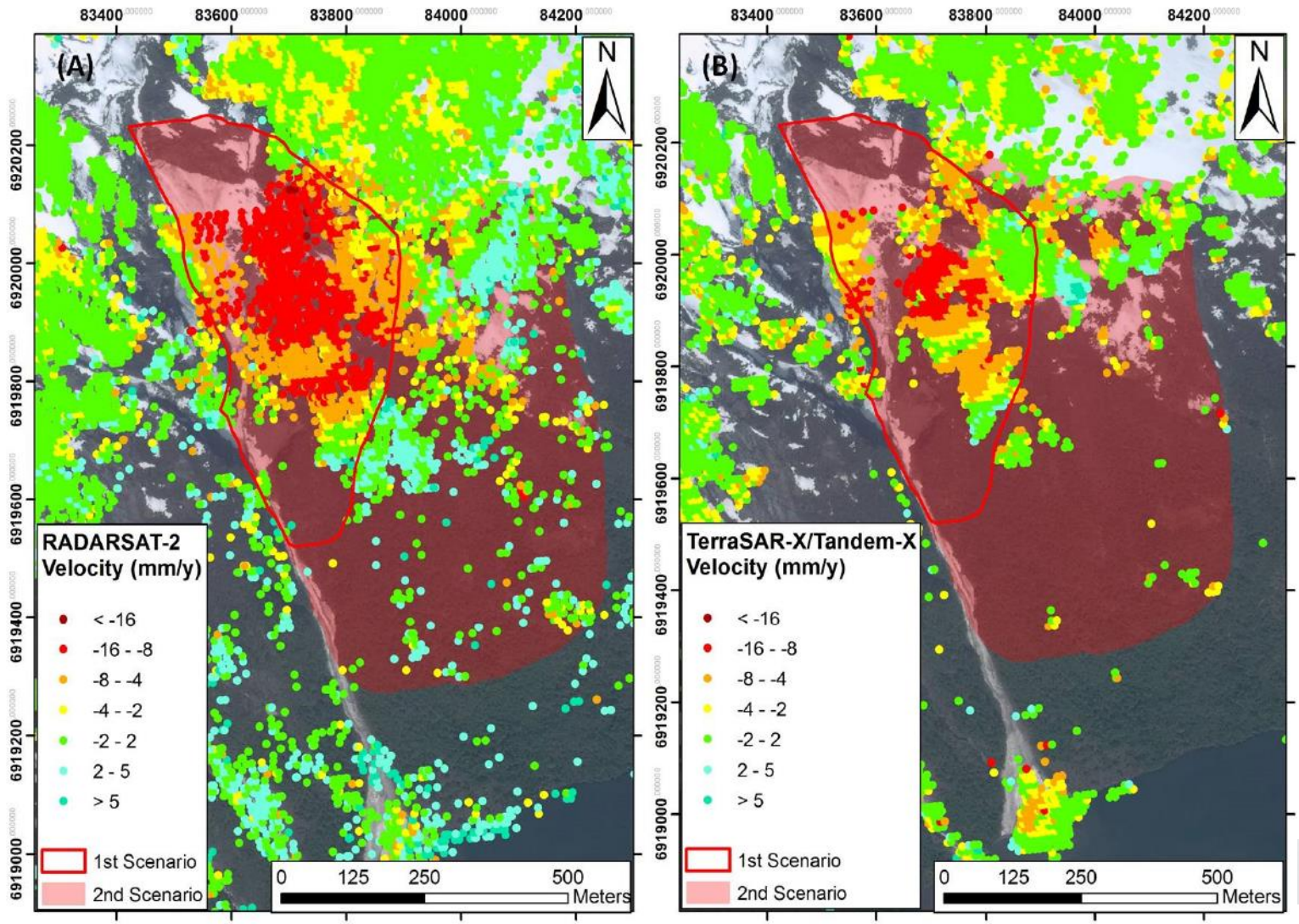
Thoney, ETH 2008

Stability modelling

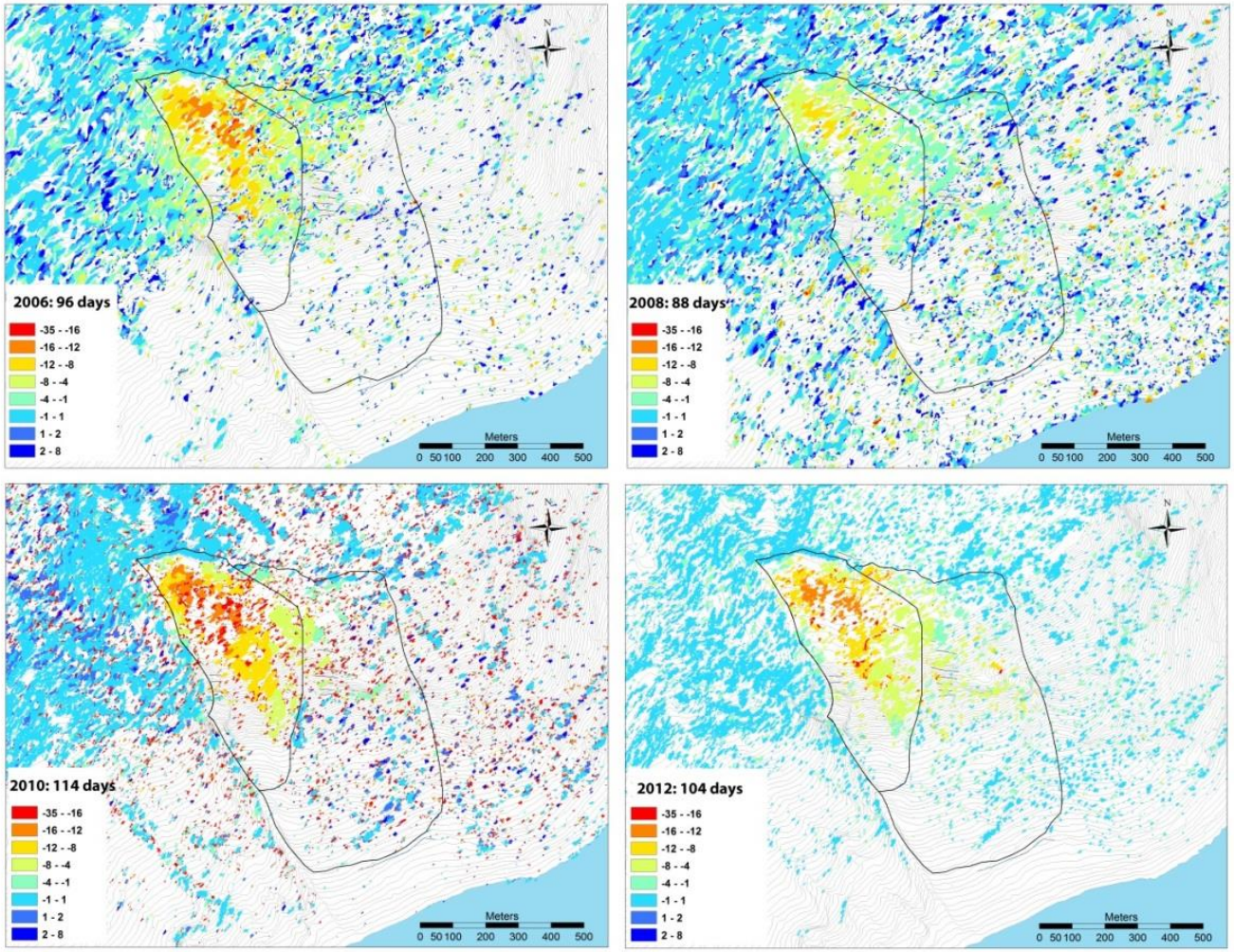
- Kveldsvik: UDEC, static and dynamic stability analysis
- Grøneng: Shear strength in sliding plane from physical measurements on material tests



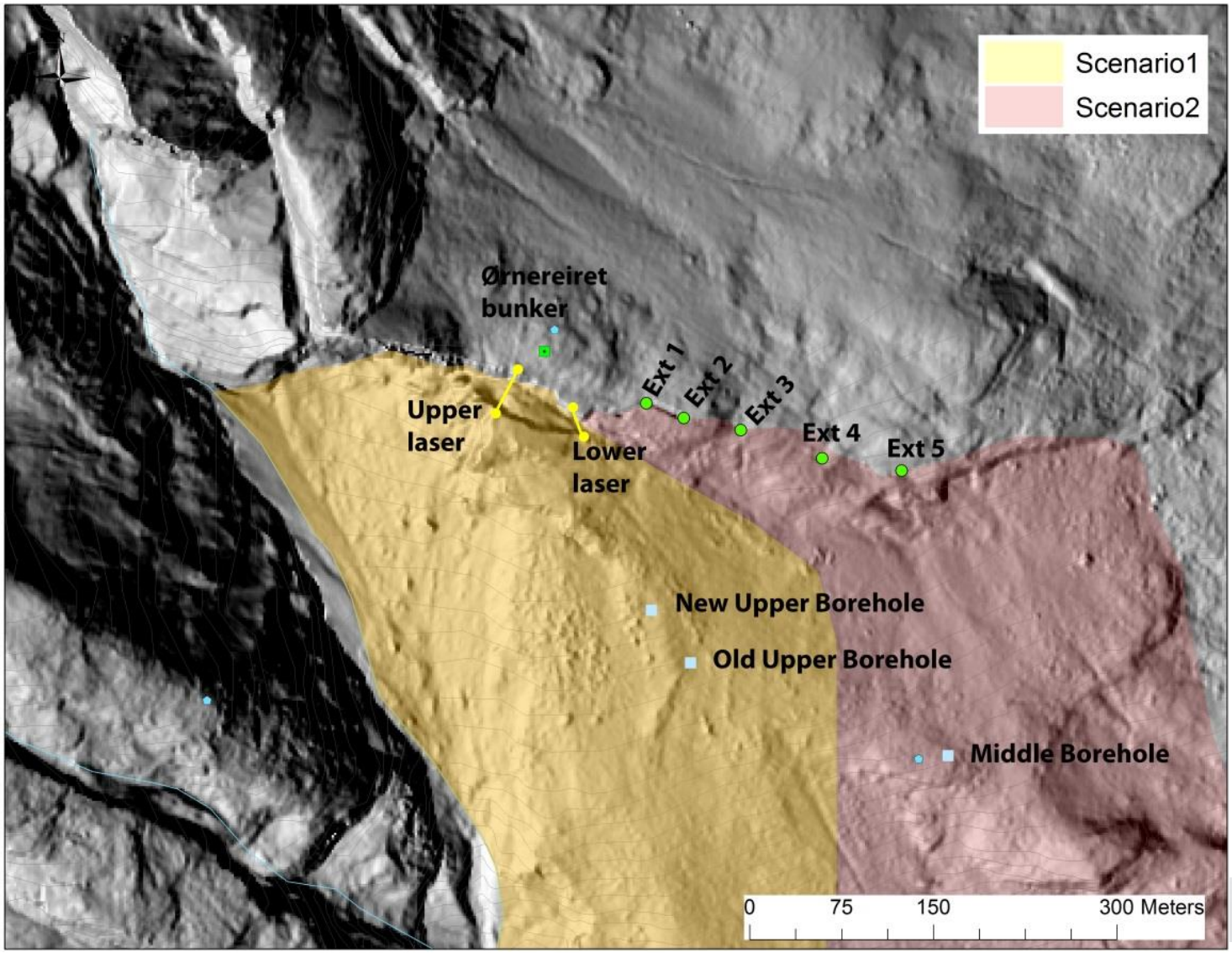
Surface movement: Satellite InSAR



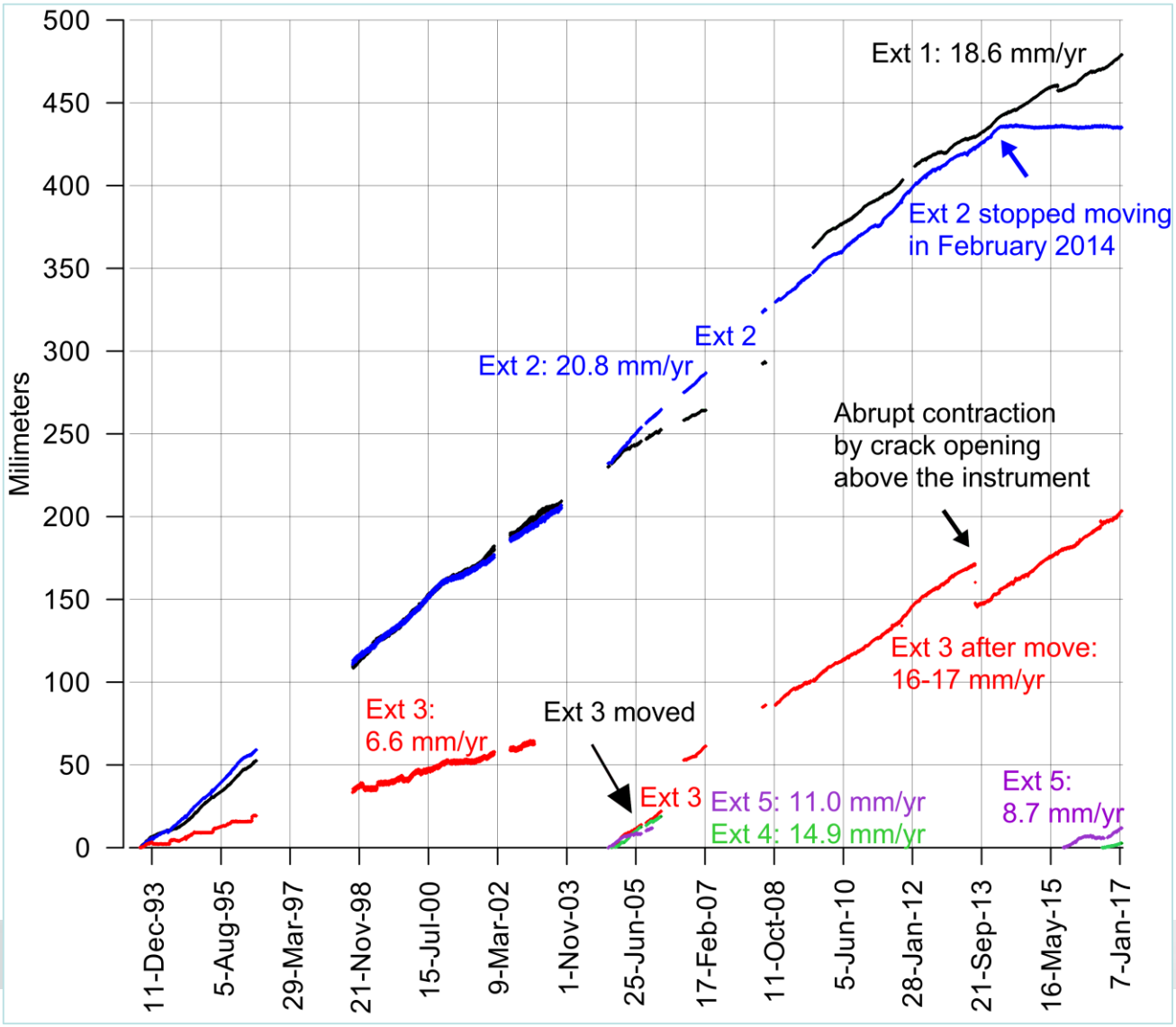
Surface movements: Ground based InSAR



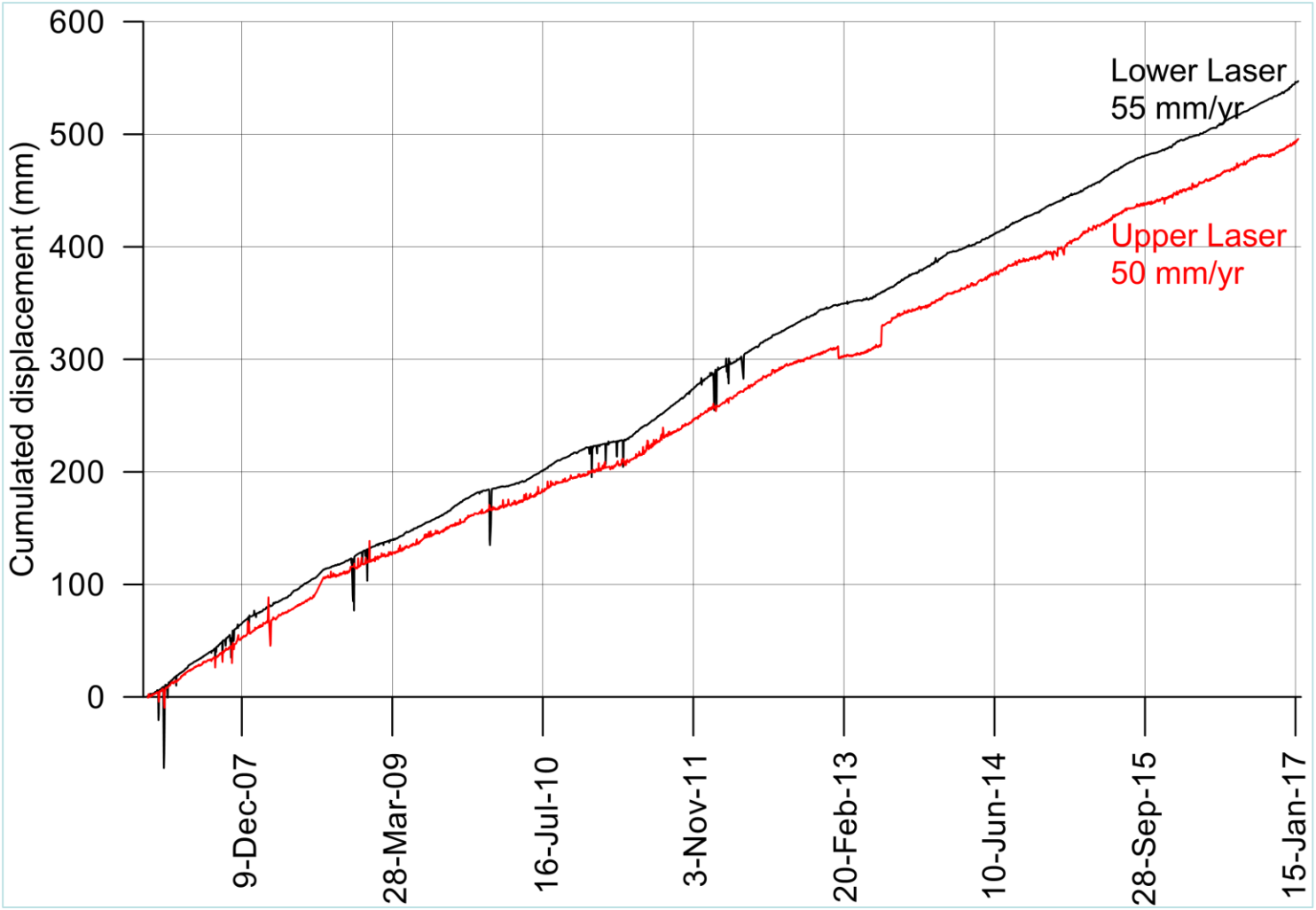
Instruments Upper area: Lasers and extensometers



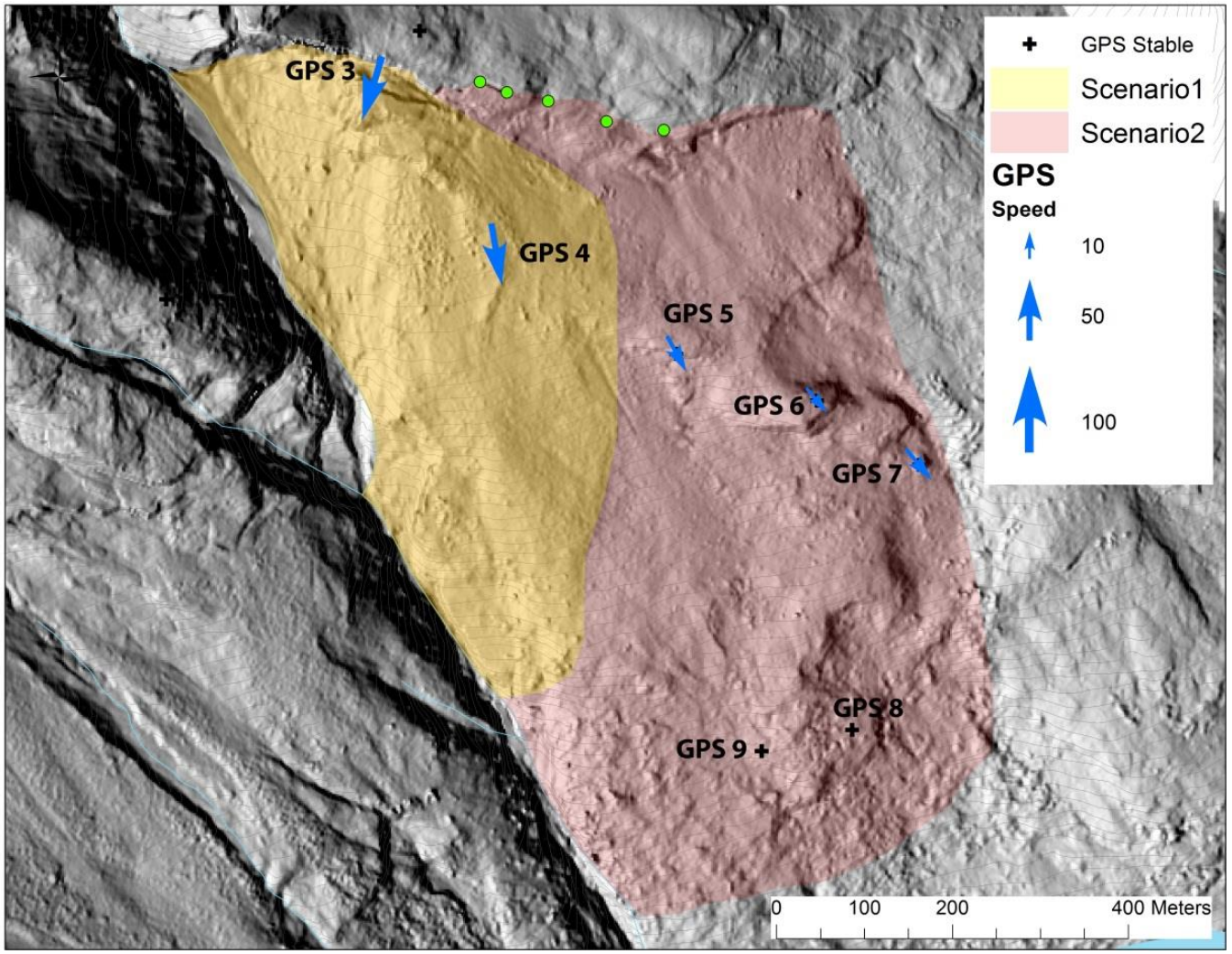
Extensometers – since 1993



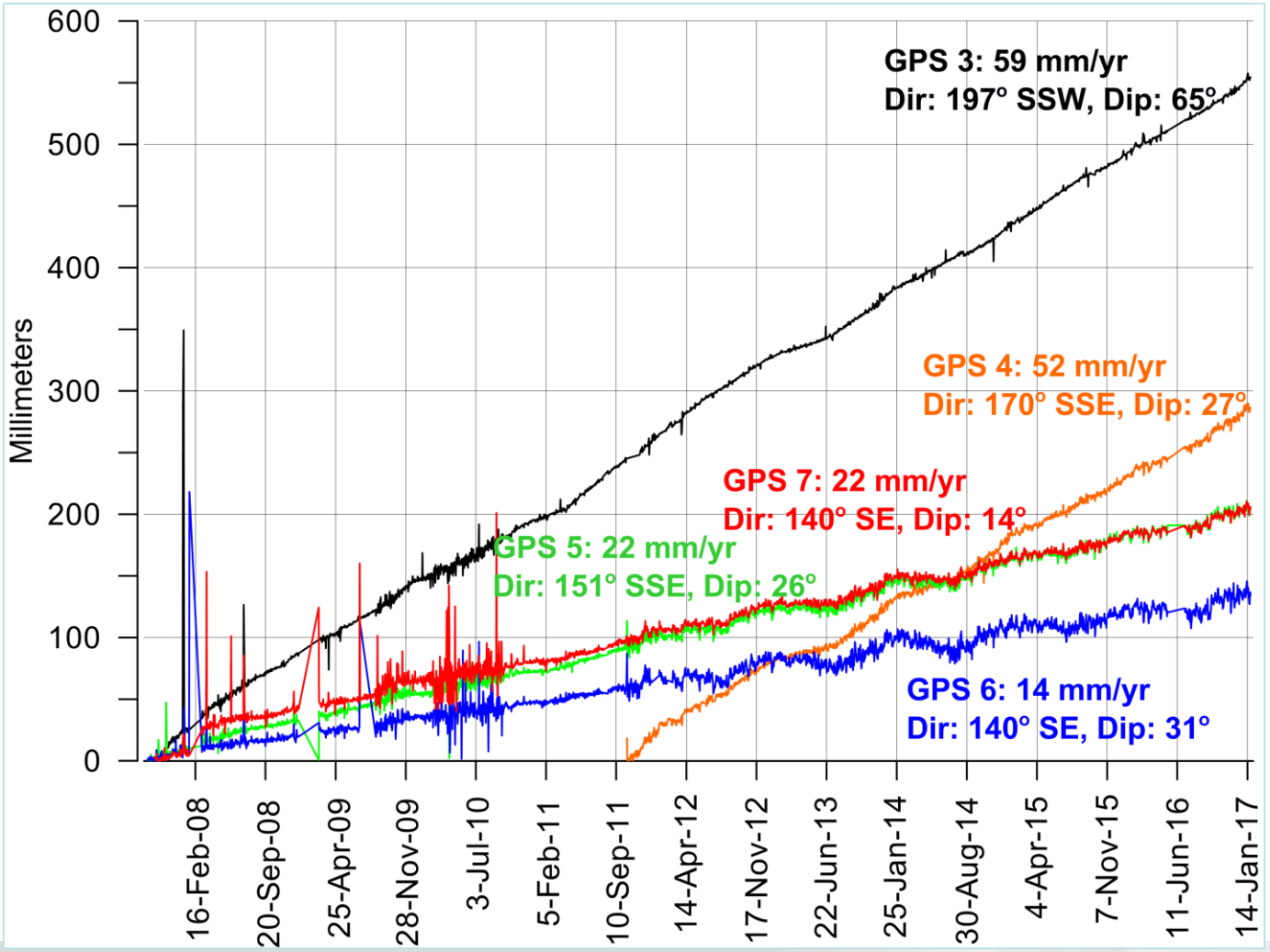
Lasers – Since 2007



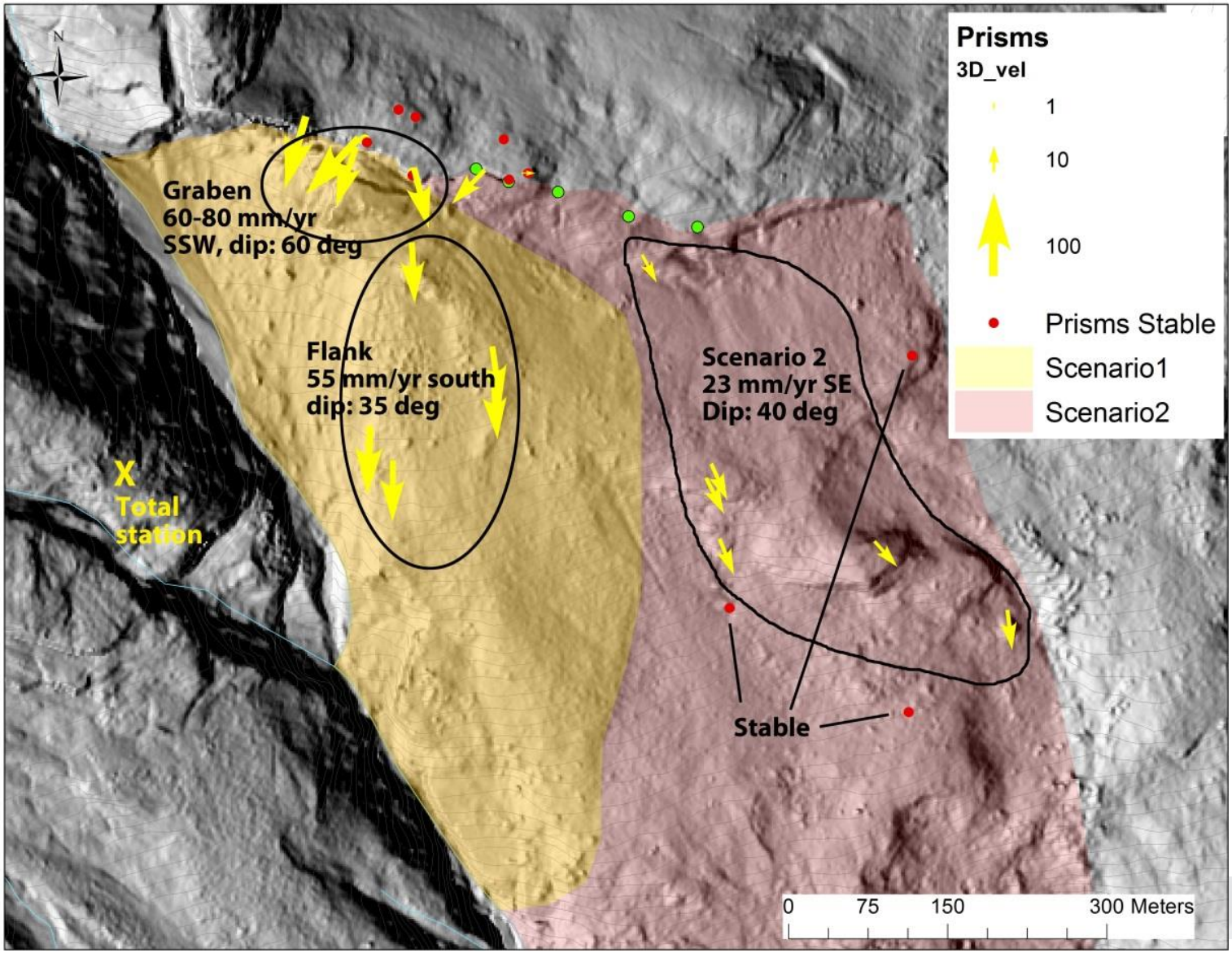
GPS network


GPS 3
GPS 4
GPS 5
GPS 6
GPS 7
GPS 8
GPS 9
GPS Stable
Scenario1
Scenario2
GPS
Speed
10
50
100
0
100
200
400 Meters

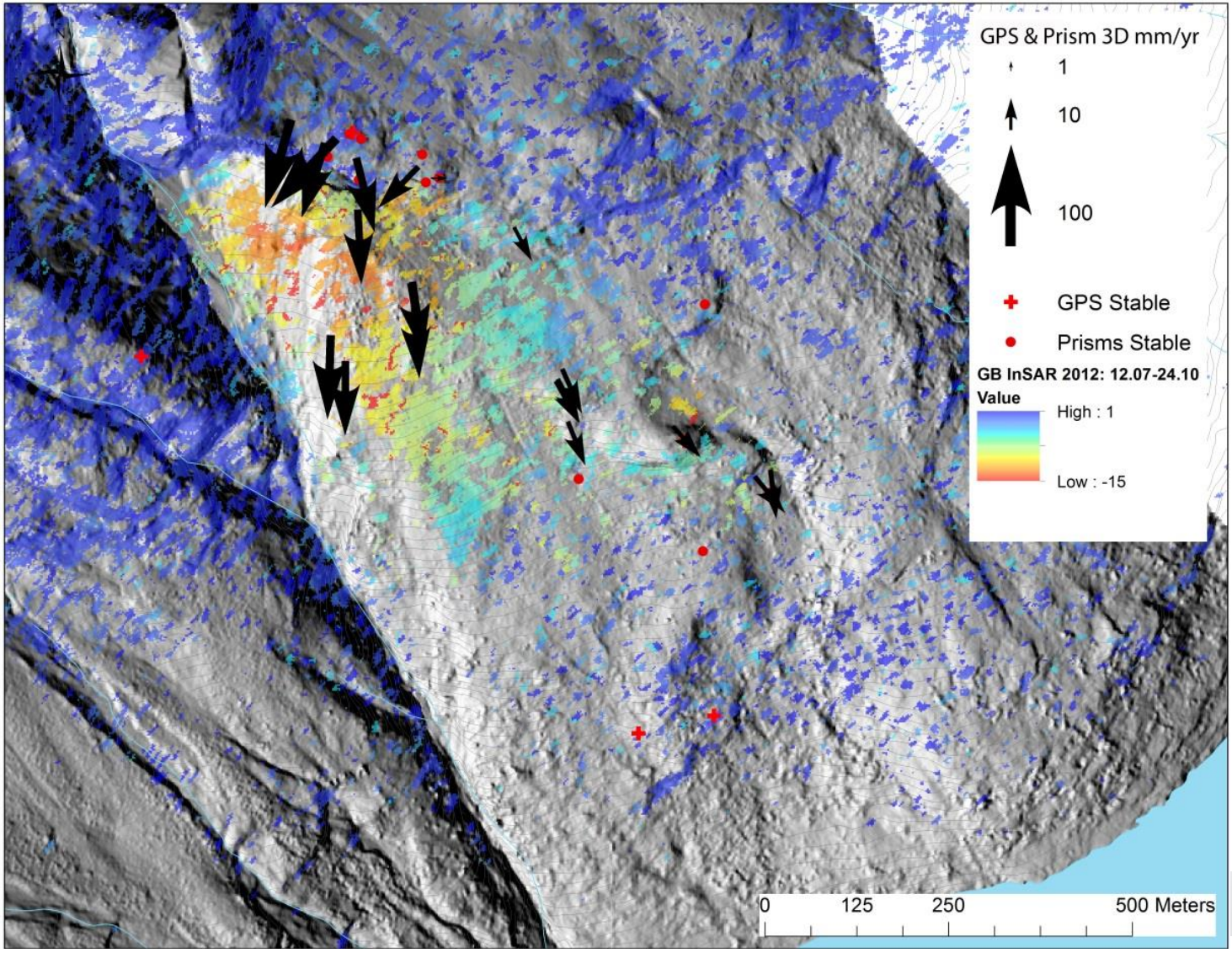
GPS time series – 3D direction



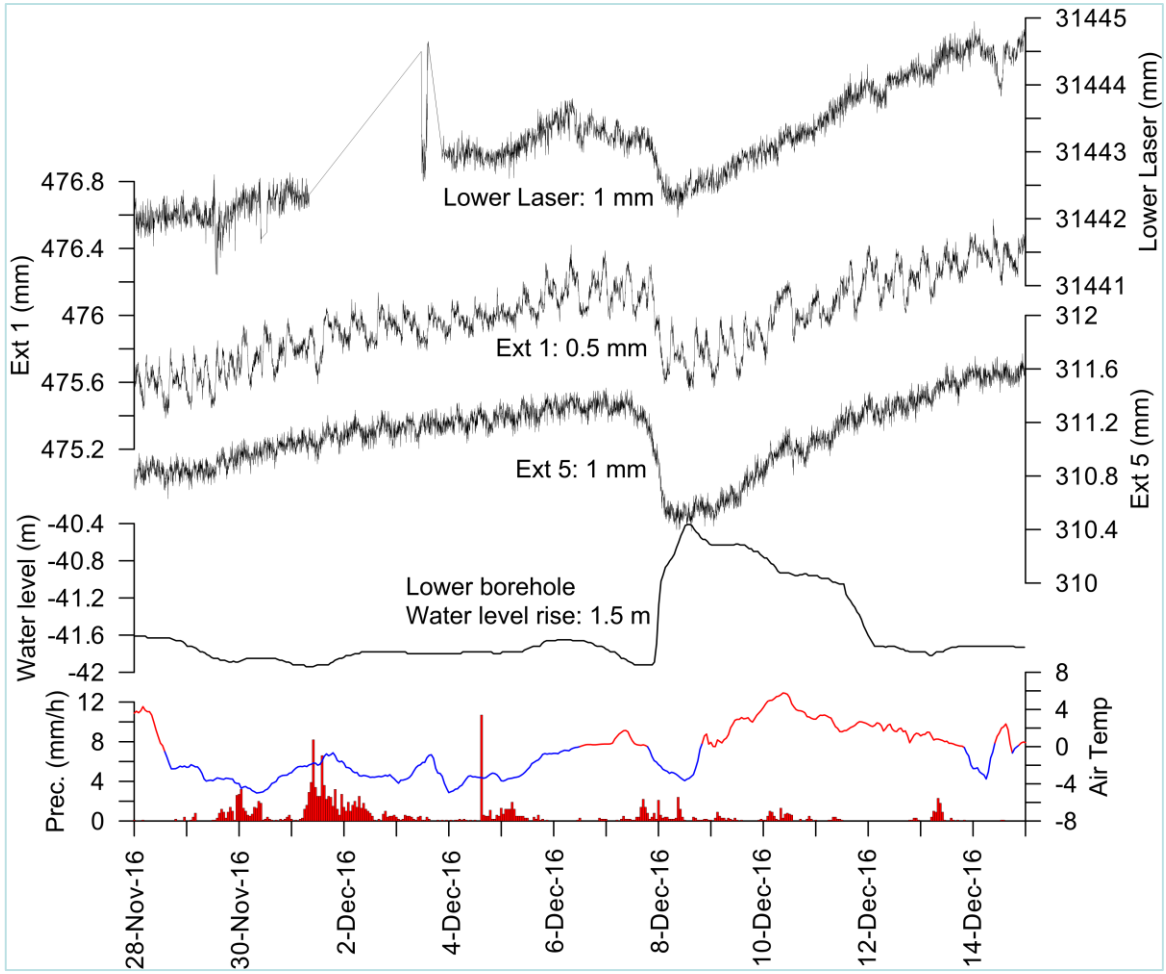
Total station and 28 prisms

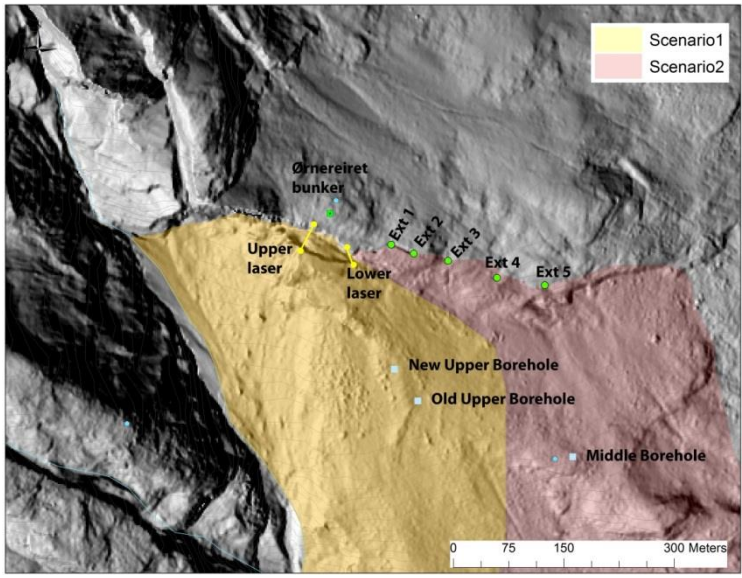


GB InSAR, totalstation and GPS

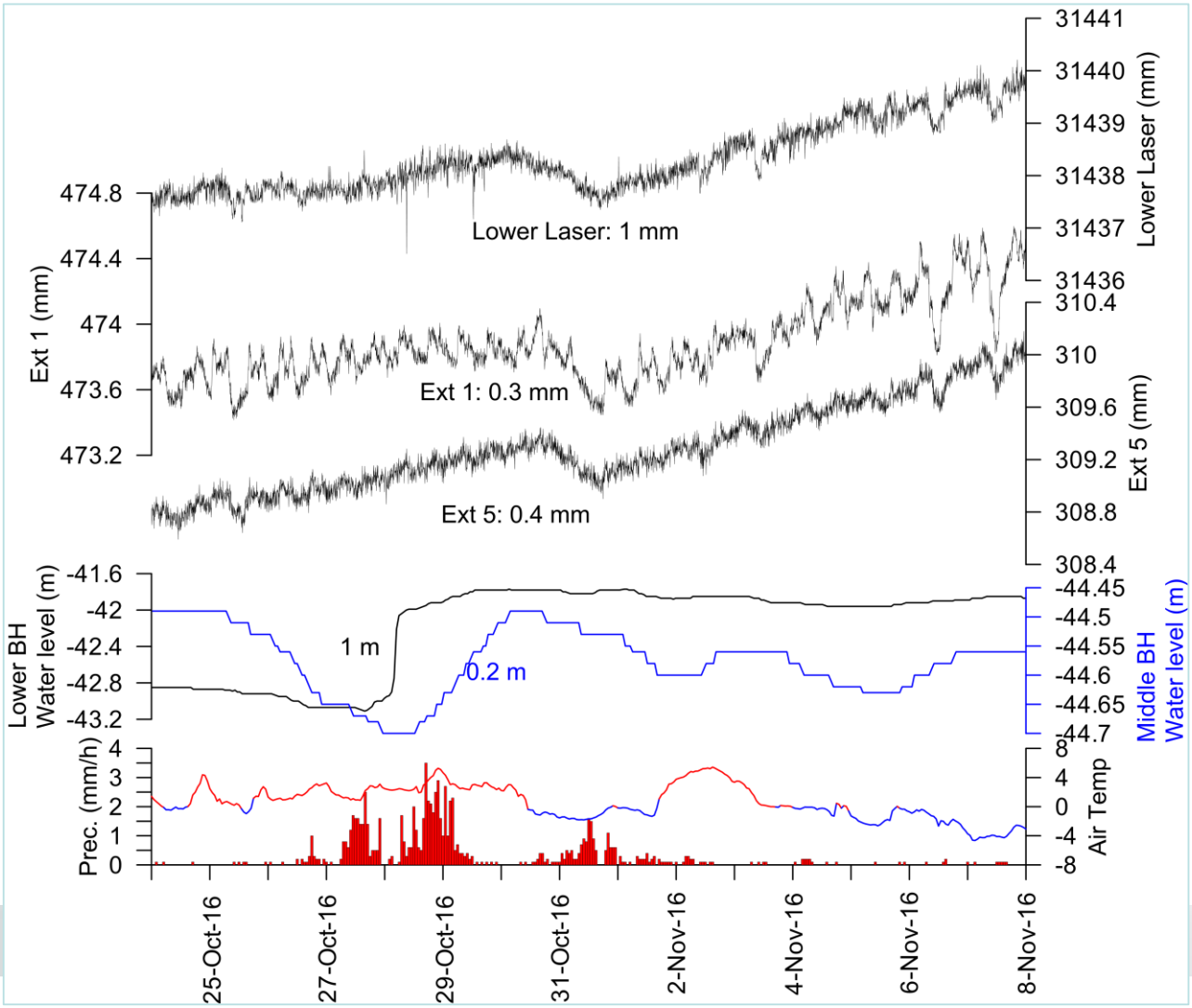


Meteorology, water level, movement

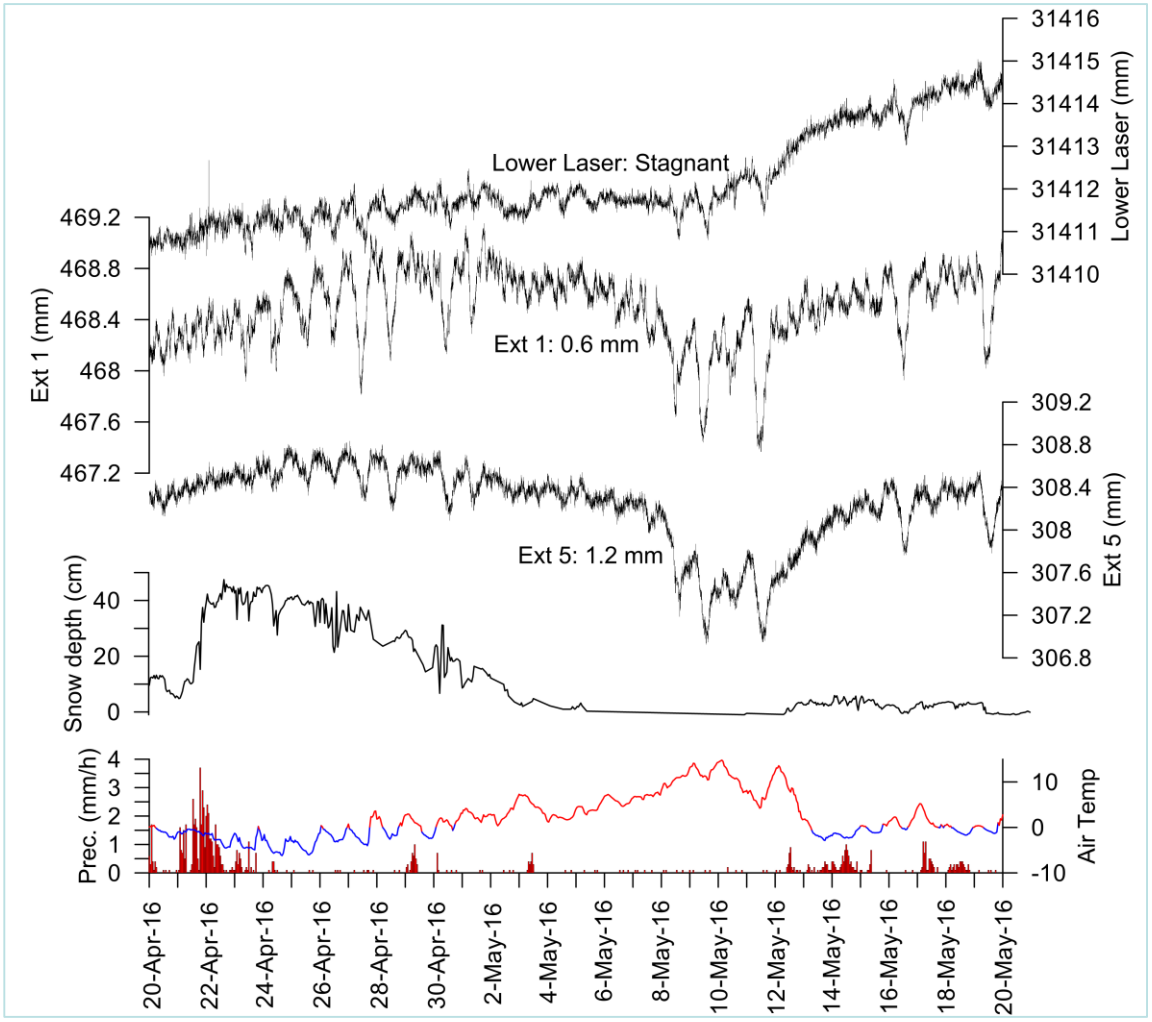




Meteorology, water level, movement

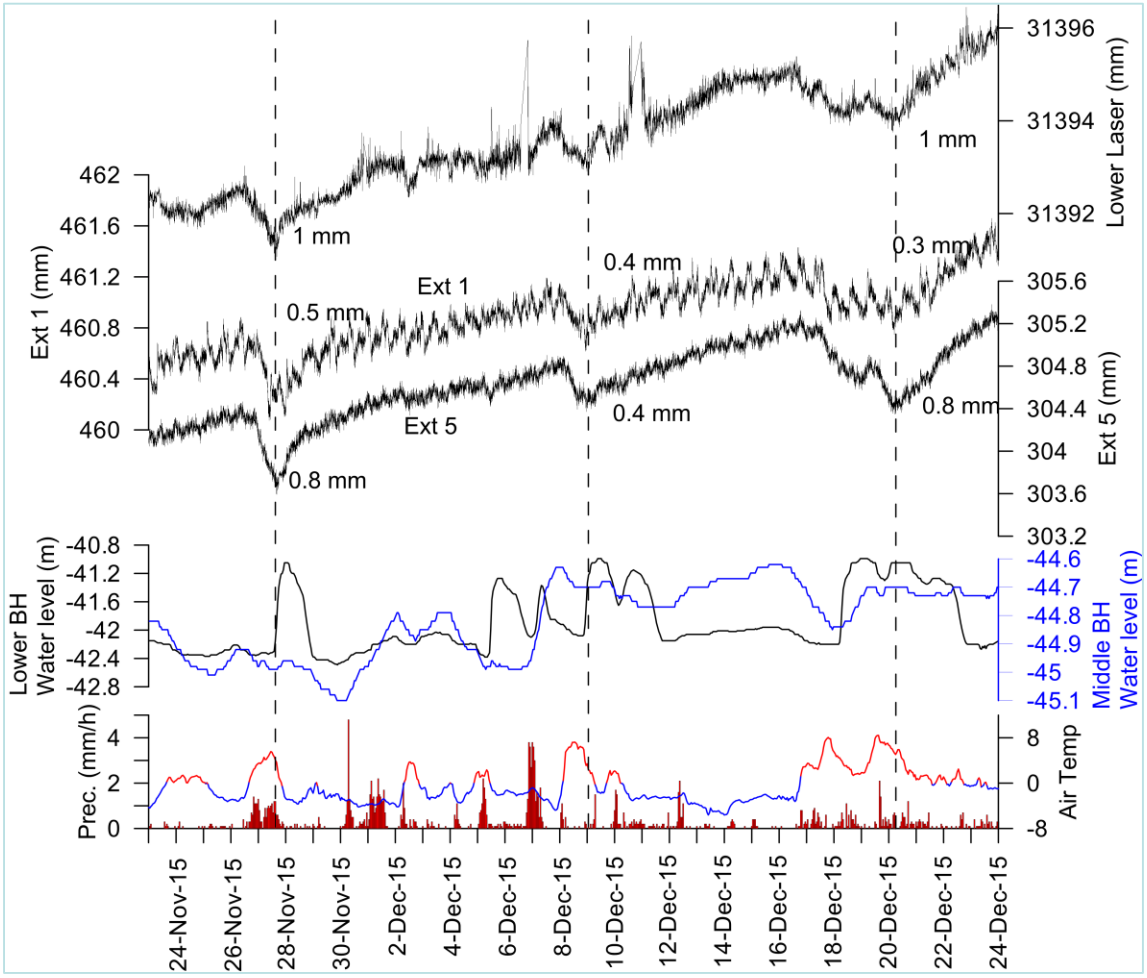


Meteorology, water level, movement



Snow melt 2016

Meteorology, water level, movement



Important points

- How is the water table related to the sliding plane?
  - Sliding plane above the water table at Old Upper and Middle Boreholes?
  - Water table at sliding plane at New Upper
- How is the movement influenced by the water table?
  - Higher water table in late summers do not consistently cause larger movement
- Mechanism for contraction along the back fracture with high water supply?
- How is the hydrology at Åknes connected to the area above - or lake above the mountain ridge?
- Better define water table with refraction seismics or other geophysics?
- More tracer studies defining flow paths?