Case study: The Åknes rock slope

Vidar Kveldsvik
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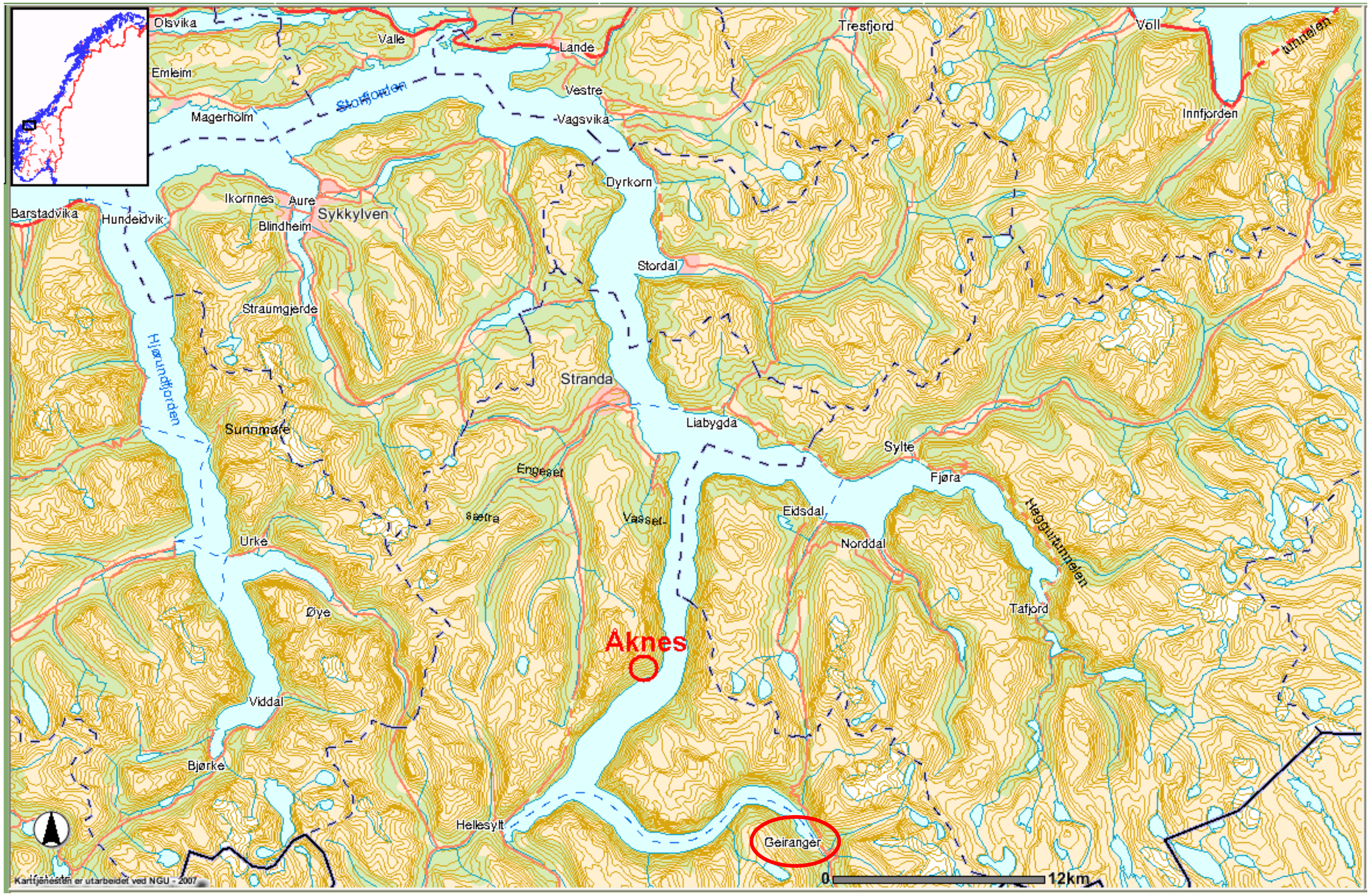
Content

- Overview of the situation
- Tsunami modelling: numerical and experimental
- Monitoring and early warning system
- Geological and geotechnical investigations
- Slide models

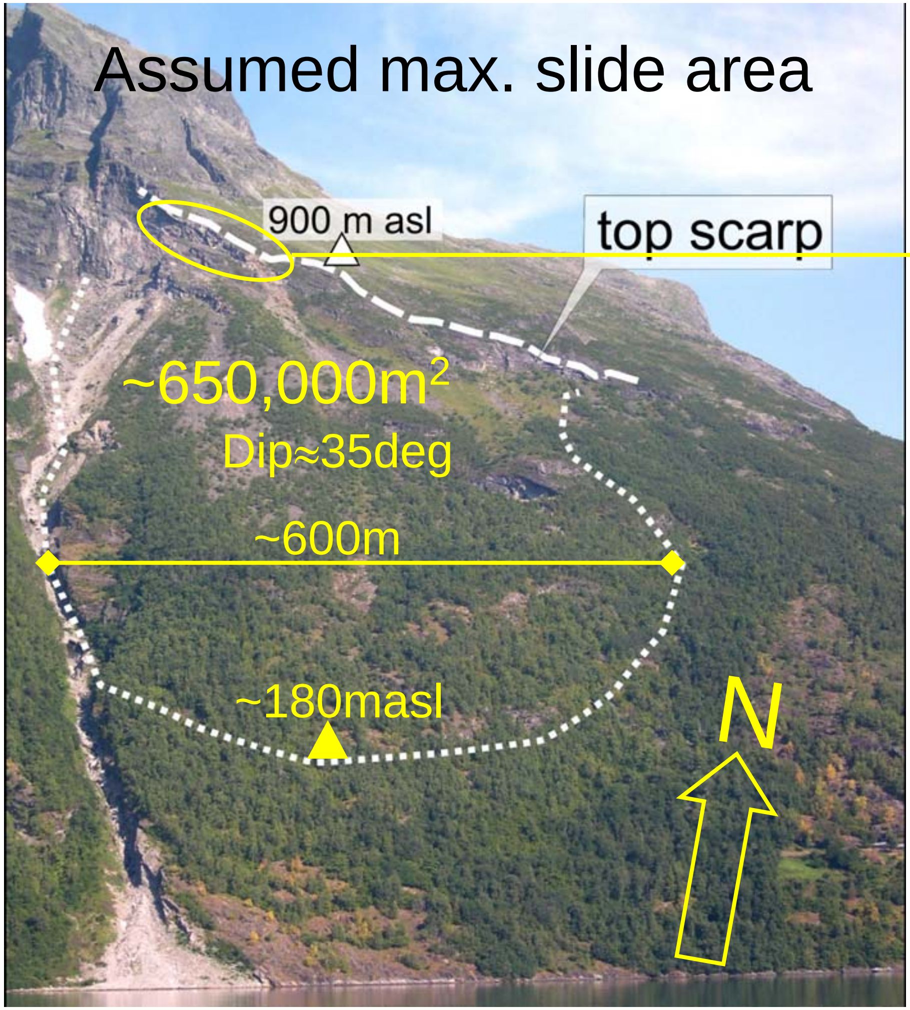
Several communitites along the fjord Geiranger is one of Norway's most visited tourist attractions, most arriving on cruise ships

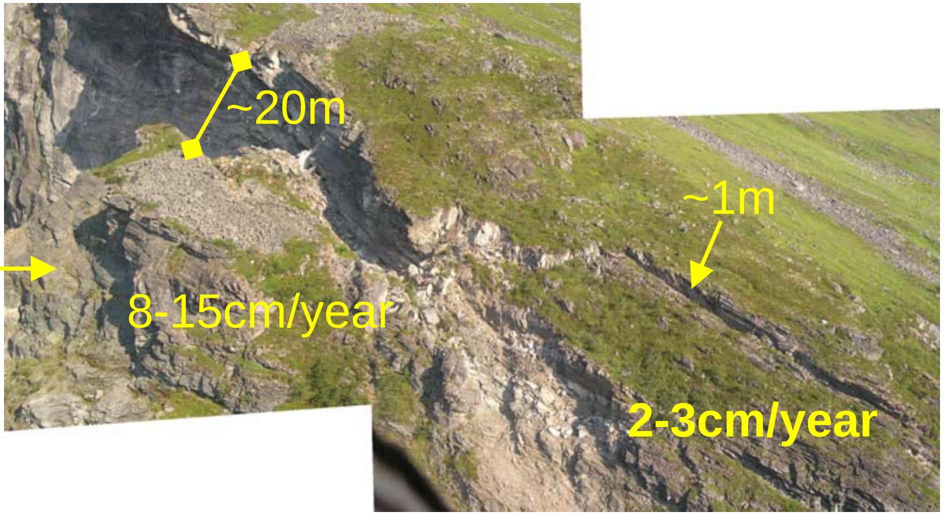


Artist's depiction of tsunami at Geiranger

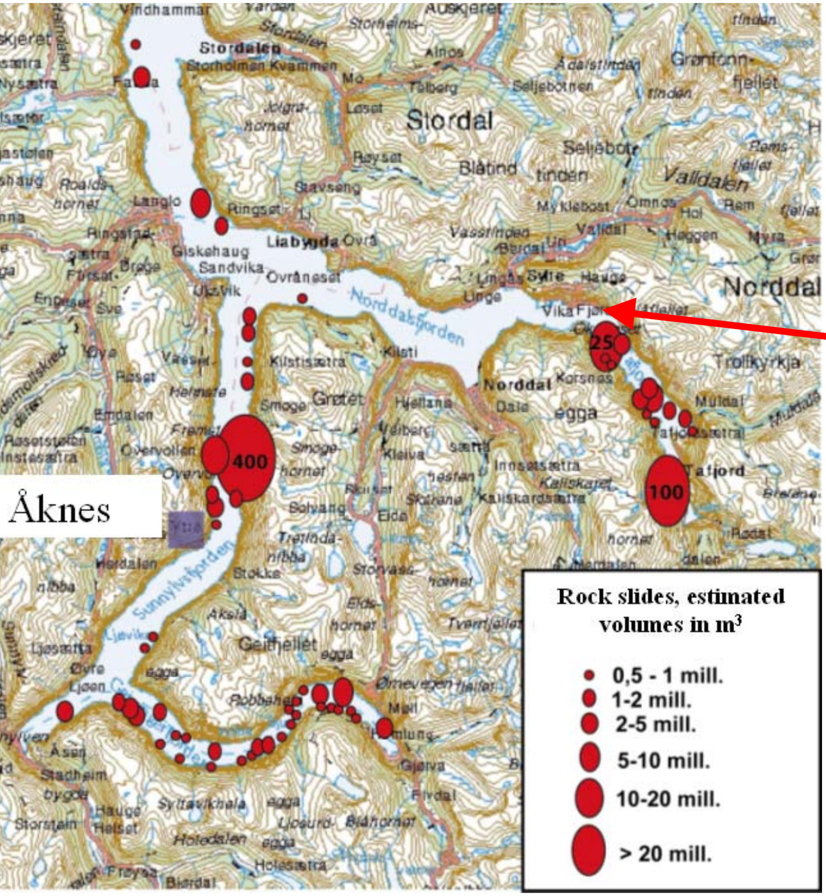
Flooding in Hellesylt with run-up 25 – 35m

Overview of the Åknes rock slope

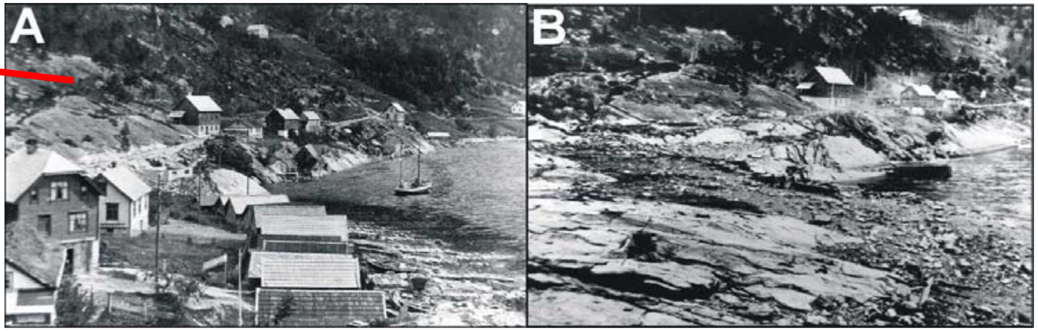




Rock slides on the sea bed

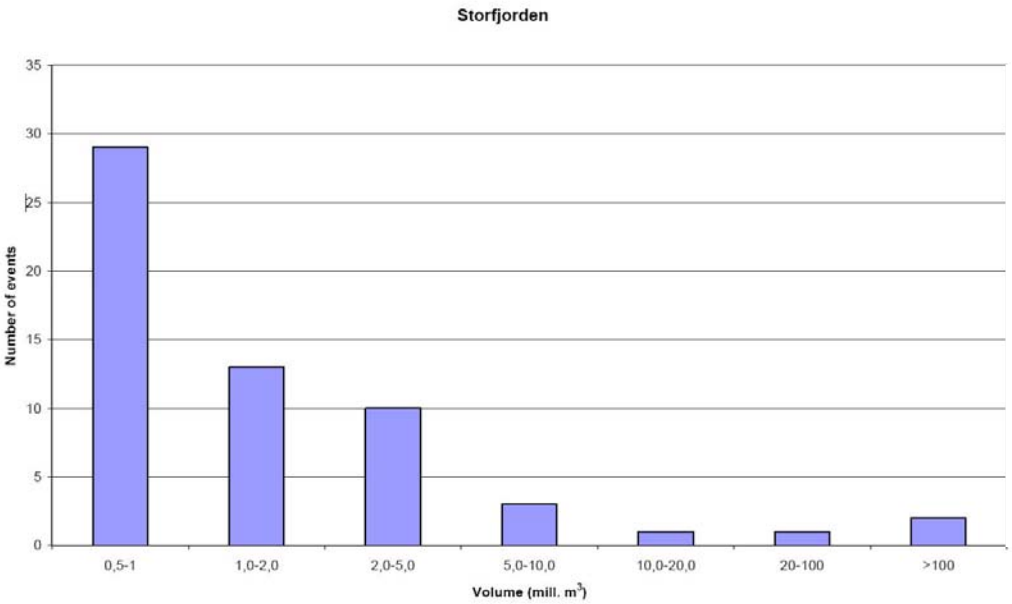


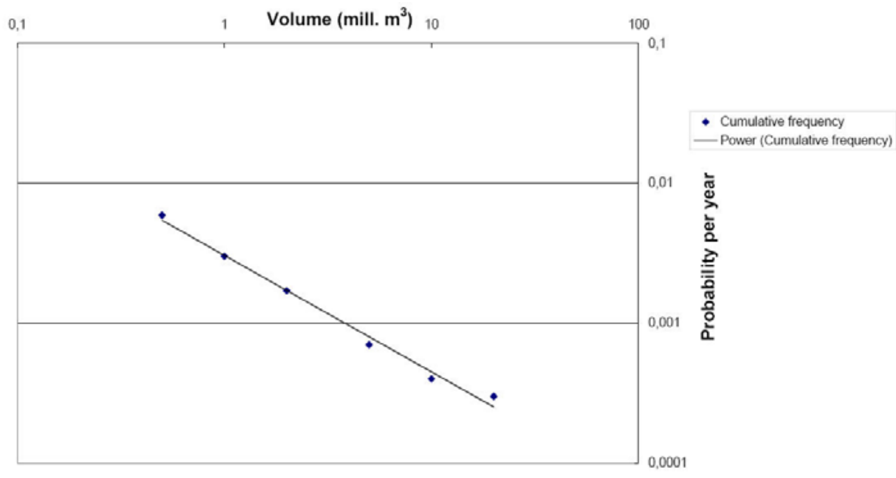
Tsunami in 1934 caused by a 3E6m^3 rock slide killed 40 people. Max. run-up≈60masl.



Number of rock slide events and the volume distribution in the entire Storfjorden

Rock volume exceedance probability





Present situation: no construction in the Hazard zone

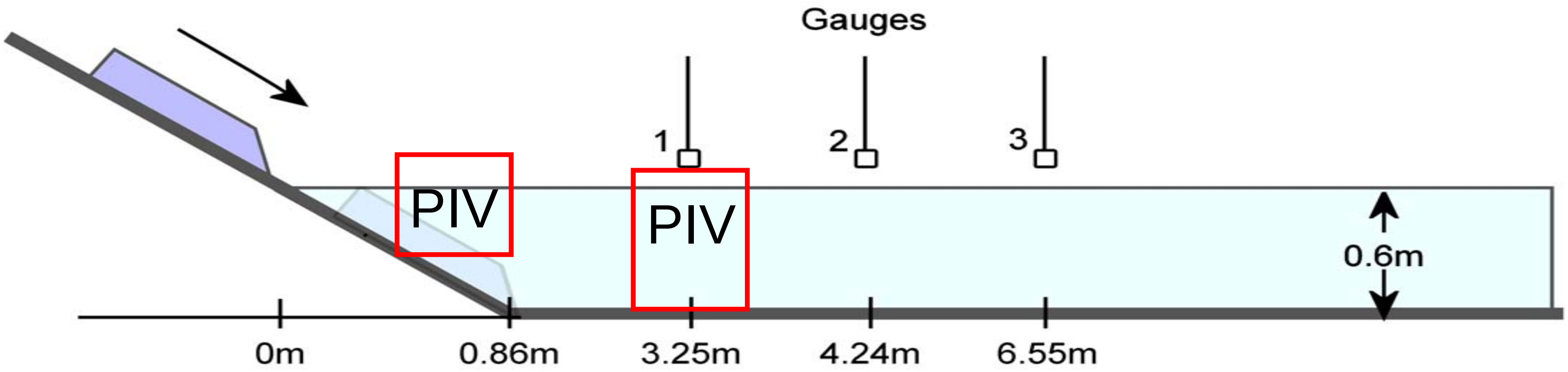
Tsunami modelling - The simulations of the rock slide and the tsunami are based on different slide scenarios and various numerical models:

- Numerical rock slide models
- Numerical wave models
- Laboratory experiments 2D (completed) and 3D (on-going) in scale 1:500 for input to and verification of numerical models
- The purpose of the 2D experiments was also to investigate the possible instrumentation for the 3D experiments

Modelling of a complex problem

- Large volume and high impact velocity
- Shape of the slide when hitting the water?

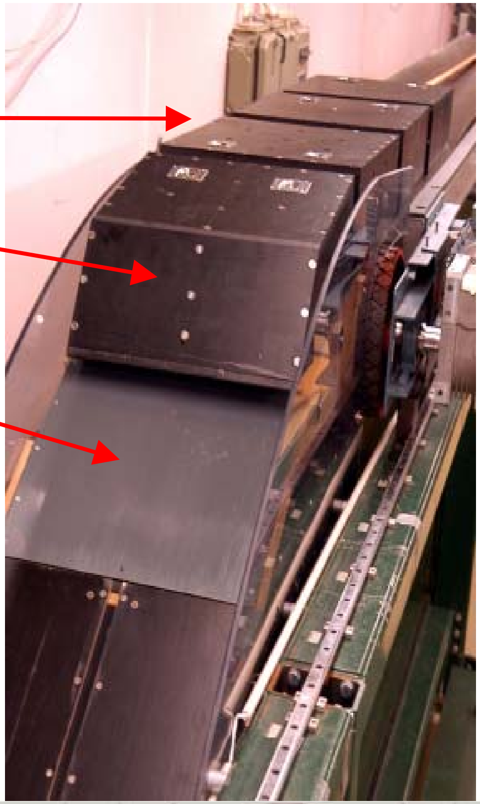
2D experimental setup



- Surface elevation measured at gauges 1-3
- Velocity field measured

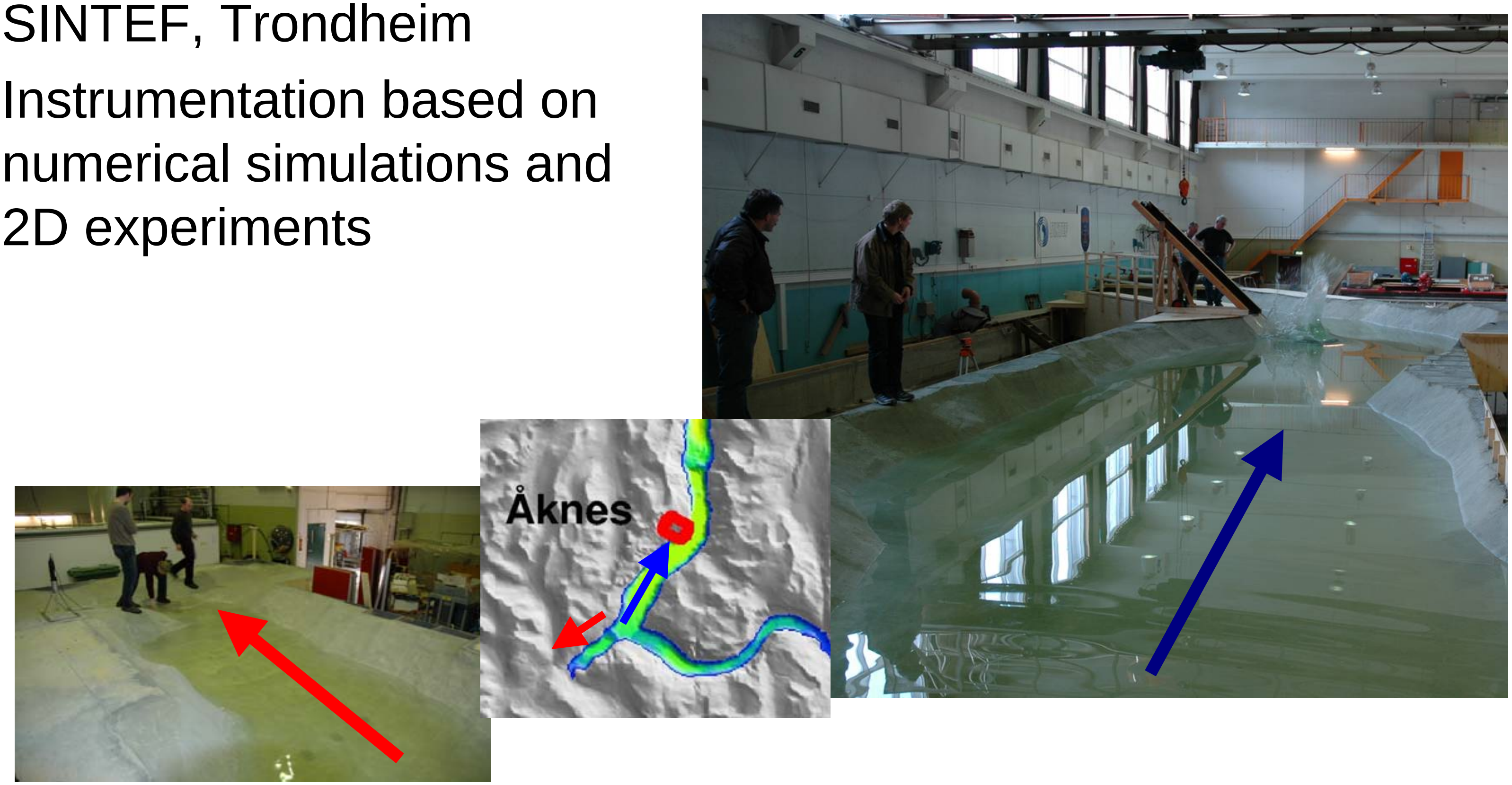
Glide plane, slide and conveyor belt

- The slide consists of boxes connected together
- Frontal angle of slide 45º
- Inclination of 35º
- Velocity controlled by the conveyor belt

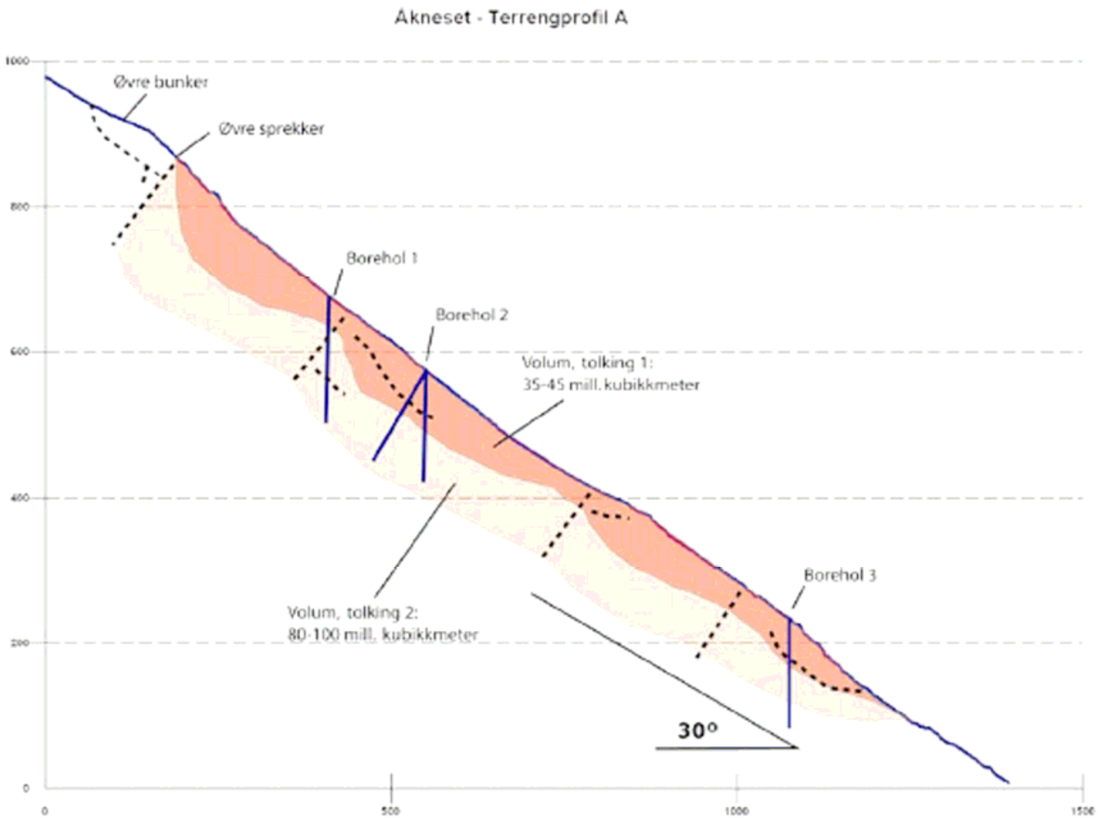


Ongoing 3D laboratory experiments

- Coast and Harbour Research Laboratory at SINTEF, Trondheim
- Instrumentation based on numerical simulations and 2D experiments



Slide scenarios



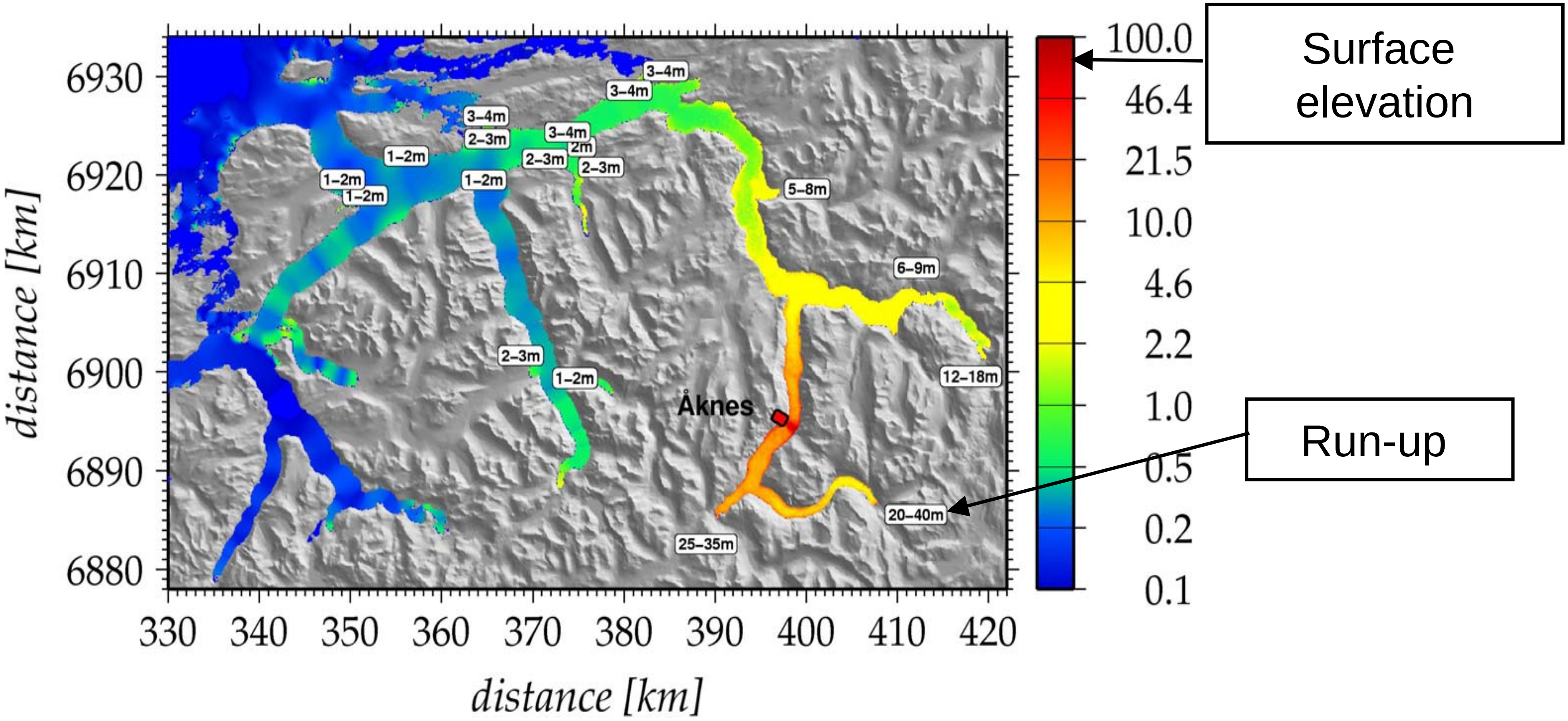
Scenario 1:
Volume 35E6m^3, average length 1000m, start 150masl.

Scenario 2:
Volume 18E6m^3, average length 500m, start 400masl.

Scenario 3:
Volume 10E6m^3, average length 800m, start 340masl.

Impact velocities: 45 or 65m/s

Results from initial numerical modelling – assumed worst case scenario



Future work on tsunami

- Calibration of numerical model
  - Compare to historical events
  - Compare to 3D laboratory experiments
- 12 scenarios (including historical events)
- Updating of hazard zoning

Monitoring systems

- <u>At the slope surface:</u>
  - Permanent GPS network with 8 antennas
  - Total station with 30 prisms
  - Ground-based radar with 8 reflectors (radar located accross the fjord)
  - Five surface rod extensometers
  - Surface crackmeters
  - Surface tiltmeters
  - Two single lasers measuring distances across the upper tension crack
  - 8 geophones: micro-seismic network

Monitoring systems

- Climate station:
  - Temperature
  - Precipitation
  - Two snow-depth sensors
  - Wind speed
  - Ground temperature

Monitoring systems

- In boreholes:
  - Two 50 m long DMS systems with 50 inclinometers
  - One 100m long DMS (not installed yet)
  - Pietzometers, conductivity and temperature sensors in 3 boreholes

Monitoring: overview

SLIK OVERVÅKES ÅKNES

Symbolene viser hvor på Åkneset instrumentene er plassert.

Meteorologisk stasjon

Meterologiske forhold er viktig, blant annet snøsmelting kan være en kritisk faktor for hastigheten på bevegelsen. Stasjonen måler lufttemperatur, nedbør, fuktighet, vindretning, vindhastighet, stråling, snødybde og fjelltemperatur.

GPS - 8 stk.

Det vil i løpet av høsten bli plassert ut 8 GPS-antenner. Antennene måler til enhver tid den nøyaktige posisjonen ved bruk av satellitter.

Strekkstag – 5 stk.

Et stag som er festet på hver sin side av sprekken. Hittil viser målingene en jevn bevegelse uten akselerasjon, men det har vært enkelte perioder med noe raskere bevegelse.

Laser – 2 stk.

Det sendes en laserstråle fra en laser på stabil grunn over til en reflektorplate i området med bevegelse. Dette gir meget gode målinger, og det kan måles bevegelse på under 1 mm. Totalt sett viser disse målingene en bevegelse i den mest ustabile flanken på 8-9 cm.

Borehull 7 stk.

Borehullene er plassert i tre ulike partier i ulike deler av det ustabile området. I disse hullene blir det målt bevegelse, vannivå, temperatur og ledningsevne. I løpet av høsten vil alle disse målingene bli overvåket kontinuerlig via Internett.

Geofoner – 8 stk.

Et fjellparti i bevegelse gir rystelser som utplasserte geofoner fanger opp. Denne seismiske overvåkingen registrerer også mindre fjellskred og steinsprang. Dataene blir i dag kontinuerlig overført til NORSAR via internett (VPN).

Web-kamera - 4 stk.

To av kameraene er plassert ved den meteorologiske stasjonen. Her sjekkes også værforholdene når man skal bruke helikopter. Det er også plassert to kameraer ved lasermåleren som sjekker snøforholdene ved reflektorene.

Totalstasjon/robot – 30 prismer

På en liten fjellrygg på sørsiden av sprekken skal det i høst utplasseres en totalstasjon. Det er en robot som måler avstanden til ca. 30 reflektorer plassert ut i det ustabile området. Roboten skal stå i et hus med strømforsyning og kommunikasjonssystem. Hvert punkt blir målt hver halvtime, og dataene overføres via bredbånd for kontinuerlig overvåking.

Bakkeradar – 6 reflektorer

Det vil i løpet av høsten 2006 eller vinteren 2007 bli etablert en radar i Oaldsbygda, på andre siden av fjorden for Åkneset. Denne skal måle avstanden til reflektorer som er utplassert i det ustabile området.

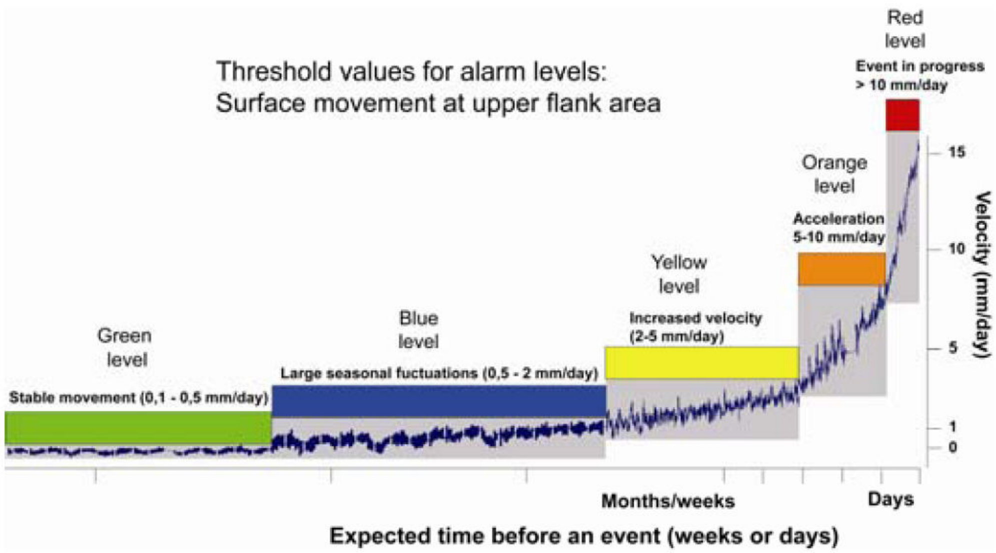
Radarmålinger fra satellitt

Det er utplassert 4 store reflektorer som blir fanget opp av satellitter. Analyse av disse dataene kan gi svært nøyaktige målinger av den vertikale bevegelsen i det ustabile området. Dette er en del av et større nasjonalt forskningsprosjekt.

Early warning centre: now in operation 24hrs a day

Alarm tresholds criteria based on:

- Total displacements
- Velocity inn defined time periods
- Acceleration
- Treshold values need to be defined and updated



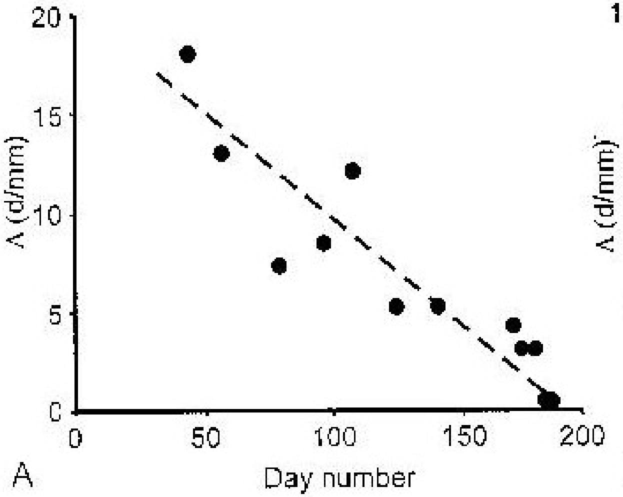
Sirens in all the villages located in the tsunami hazard zone

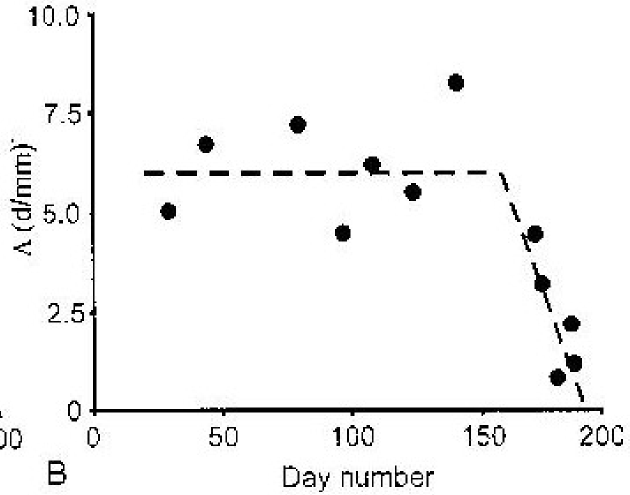
Phone messages

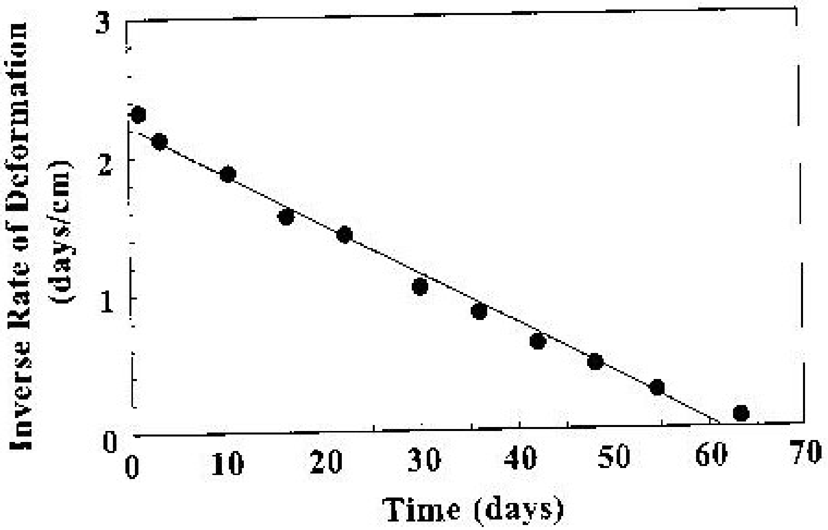
Evacuation procedures and routes

The police responsible for the evacuation

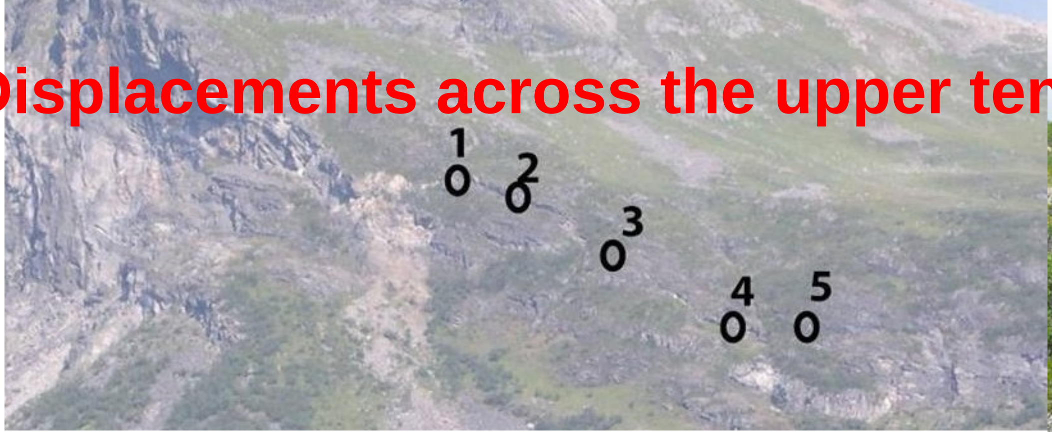
Prediction of catastrophic failure

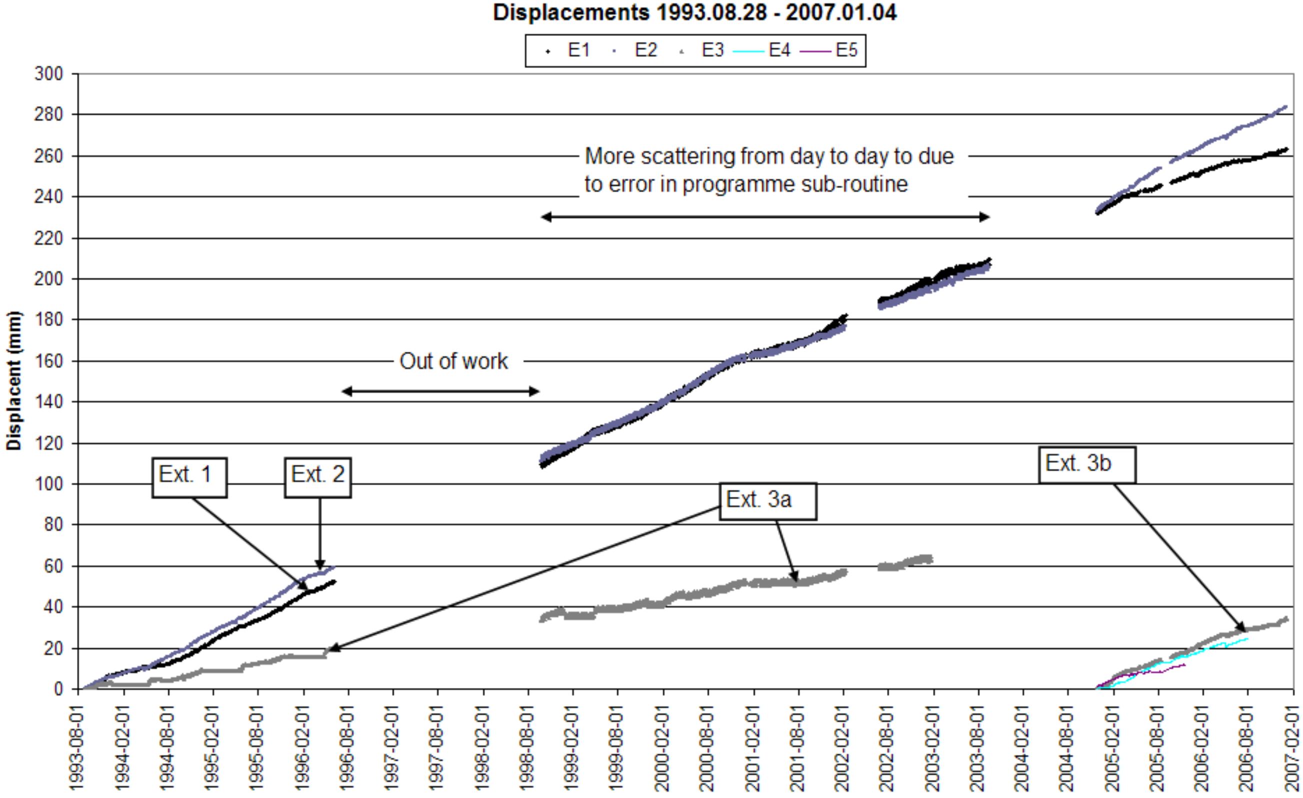




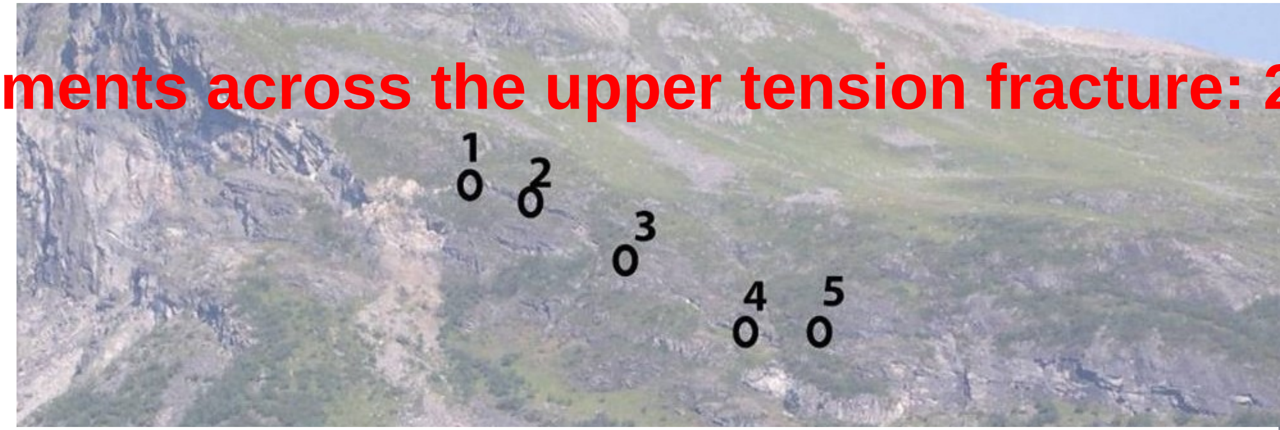


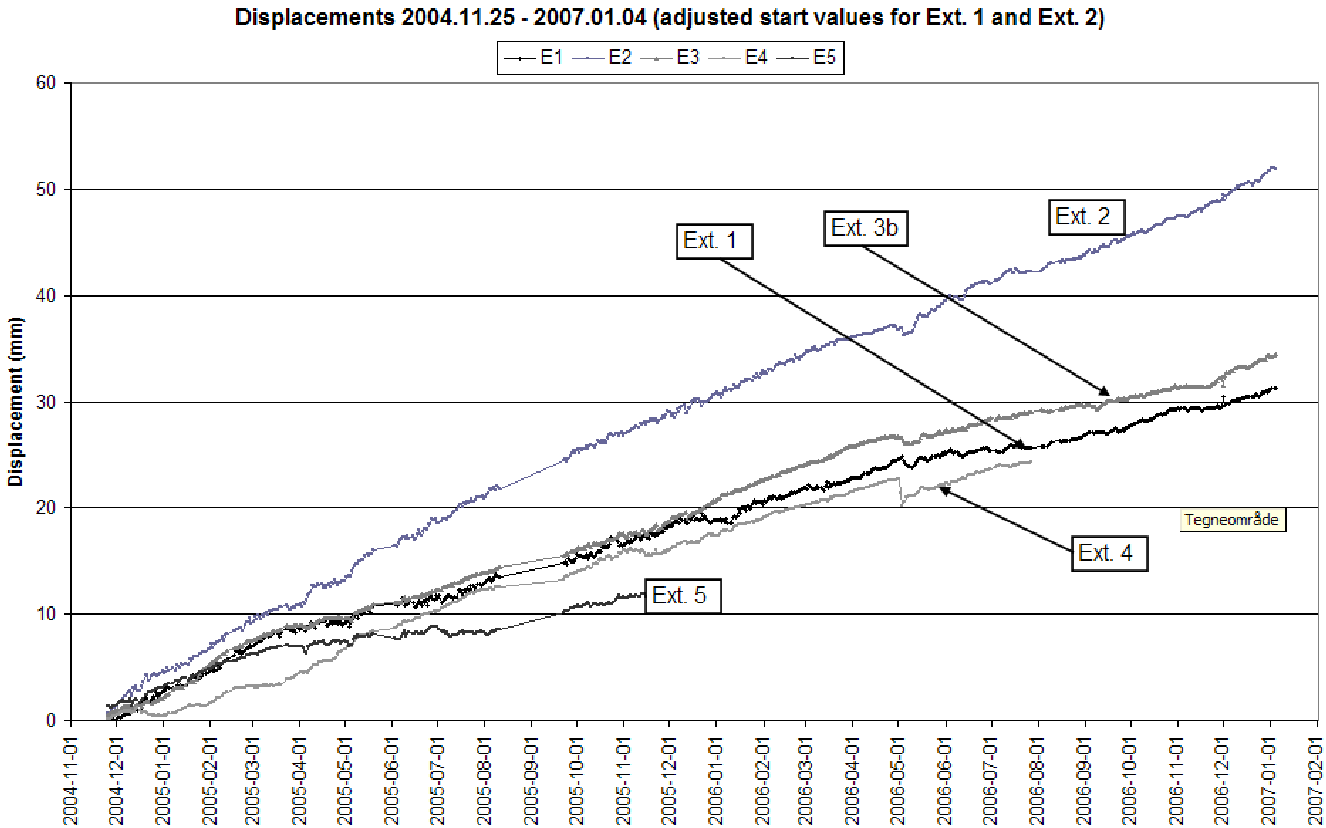
Displacements across the upper tension fracture: 1993-2007





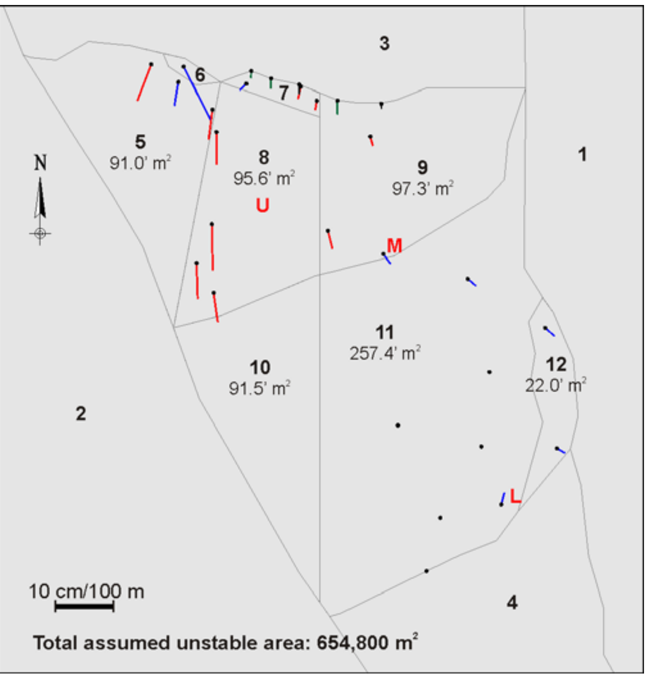
Displacements across the upper tension fracture: 2004-2007



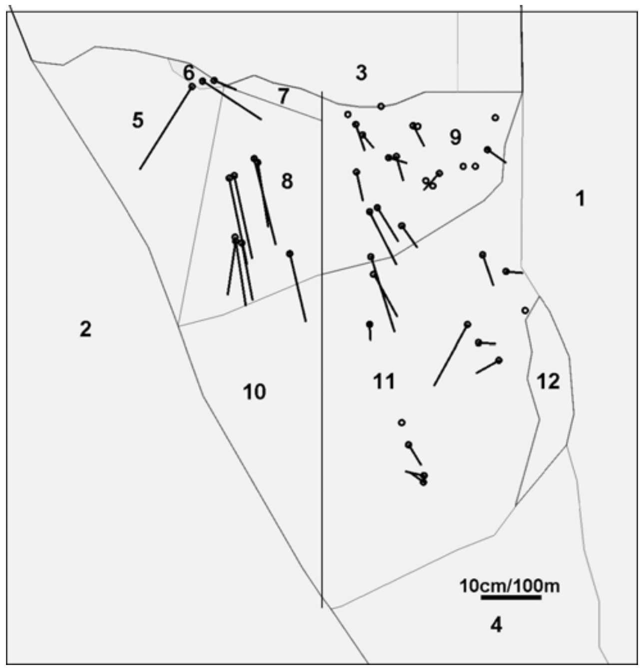


Displacements per year - horizontal component shown on a possible block model

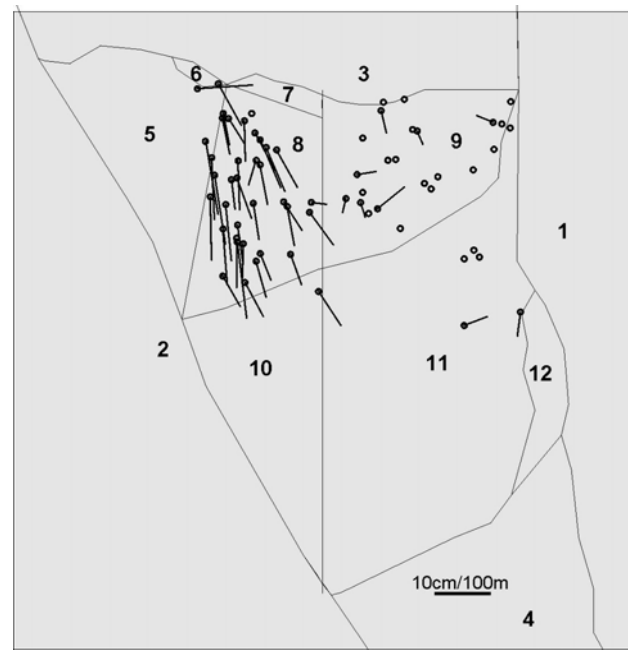
2004 -2006: GPS, Tot. stat., Extensometers



1961-1983: Photogrammetry



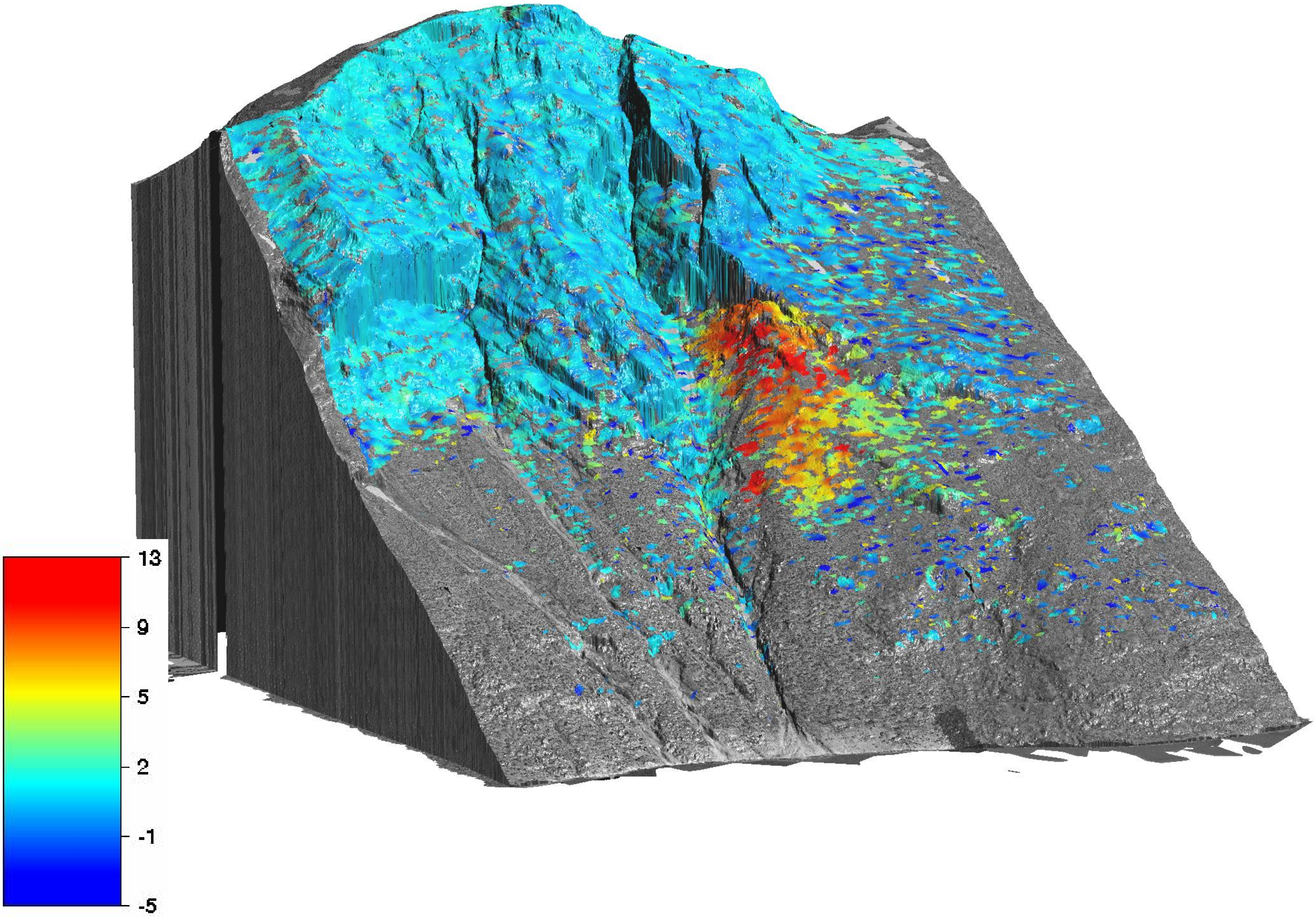
1983-2004: Photogrammetry



More displacements in the NW part from 1961 to 1983 than later

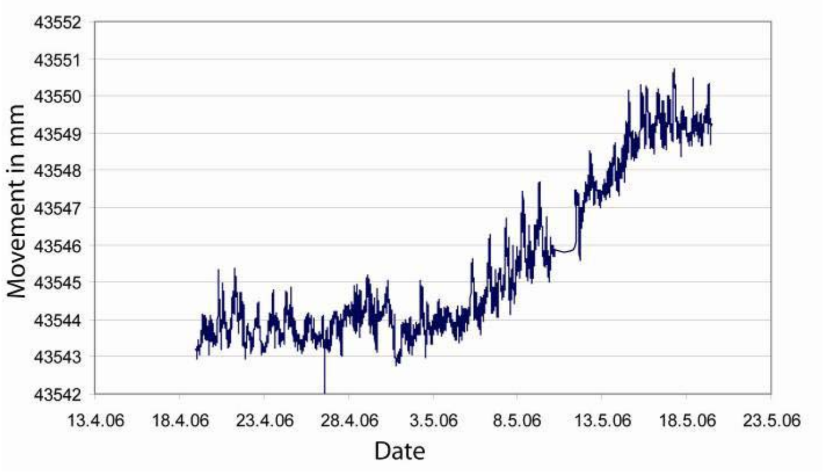
LISA Radar

LISA Radar results

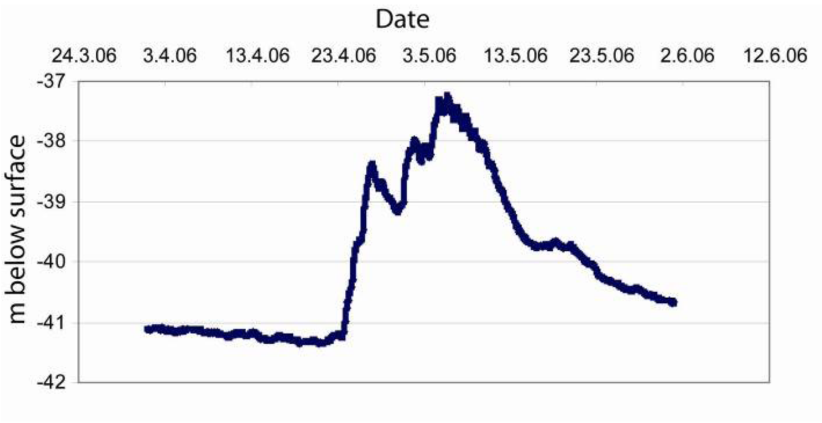


Example from monitoring data during snowmelt in spring 2006 show also seismic recordings

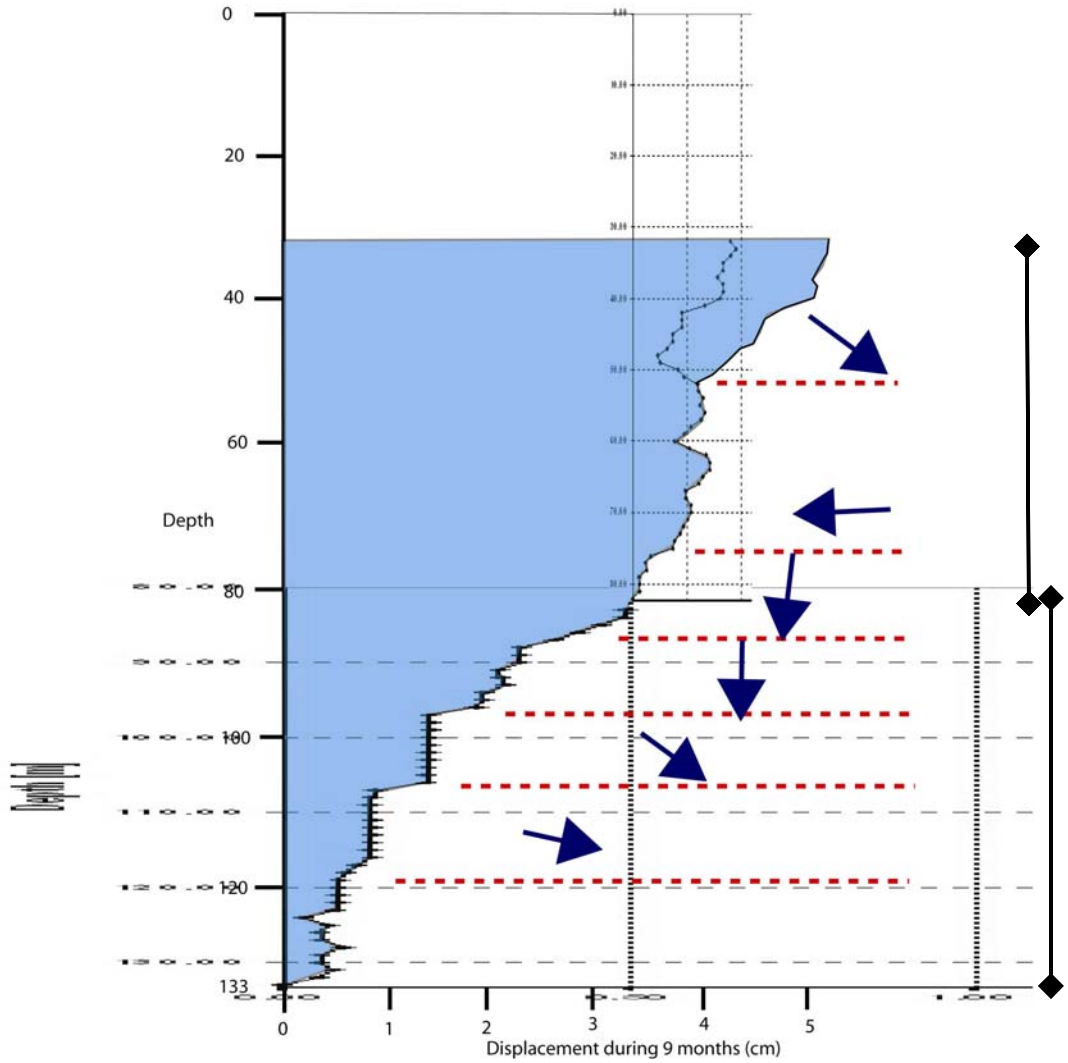
Laser measurements in the upper western flank



Water level in the middle borehole

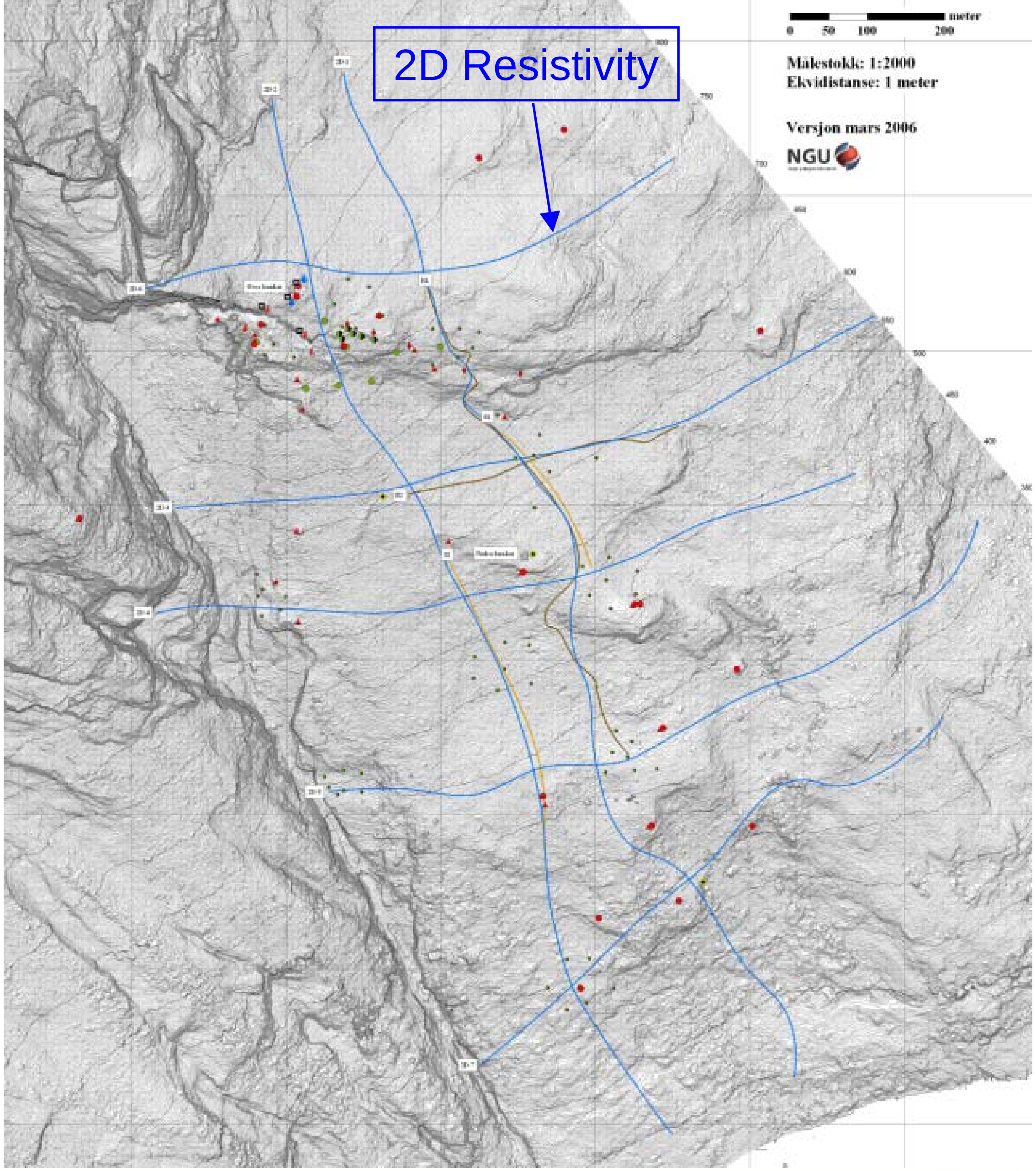


Displacements in the upper borehole



1st interval of measurements

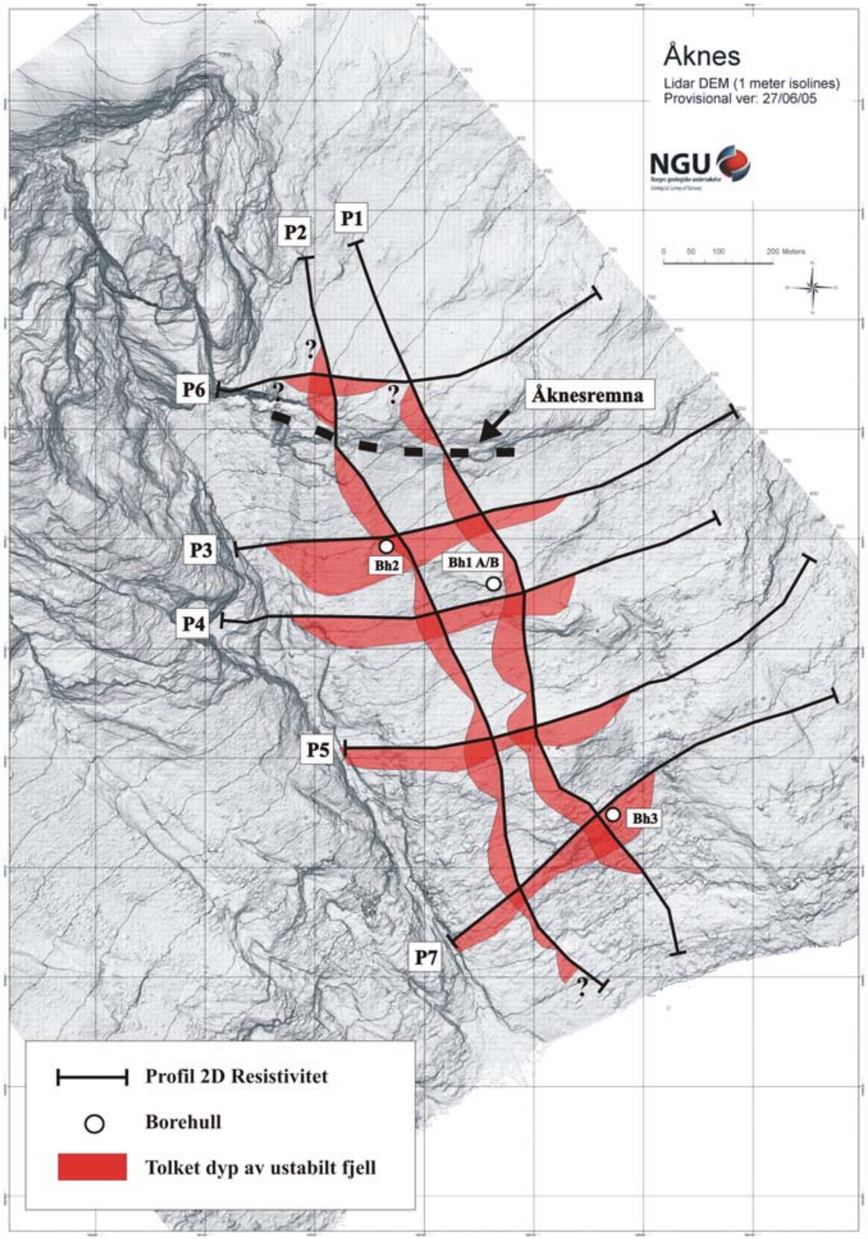
2nd interval of measurements



Geological and geotechnical investigations

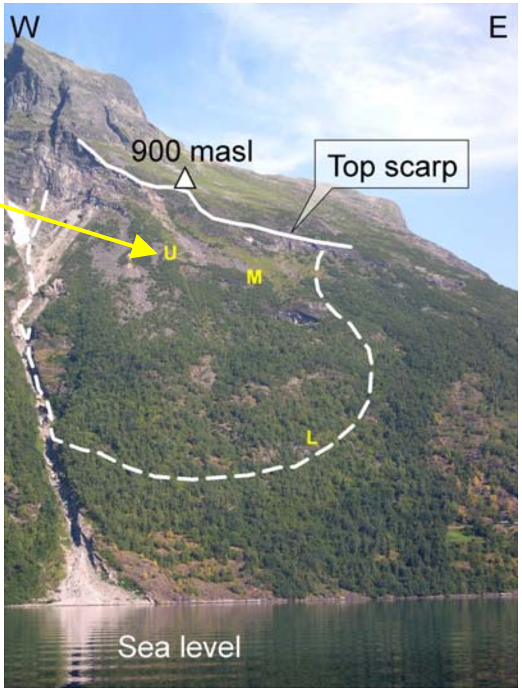
Geophysical surveys: resisitivity, georadar and seismic

2D resistivity: Interpretation of depth of unstable rock mass

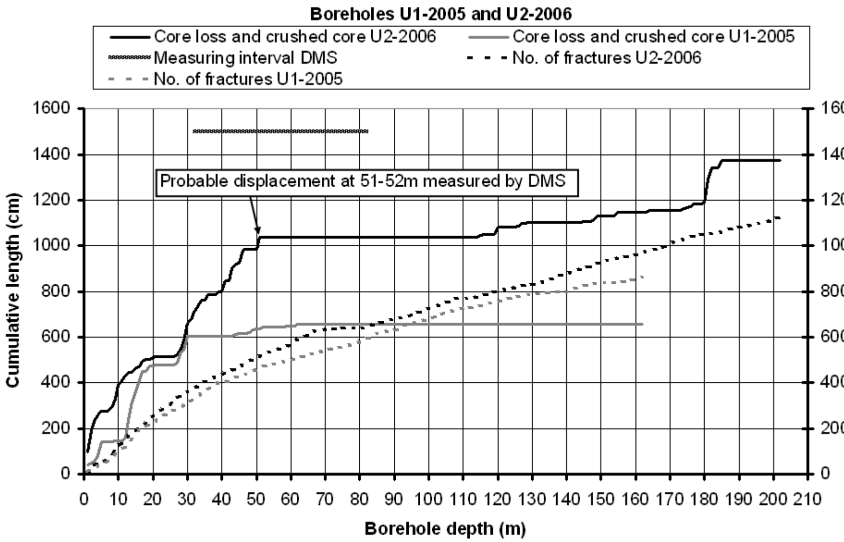


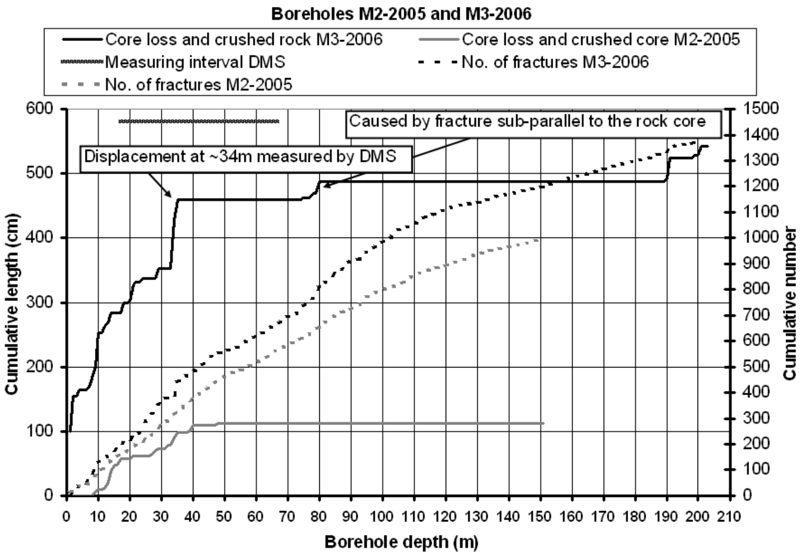
Boreholes

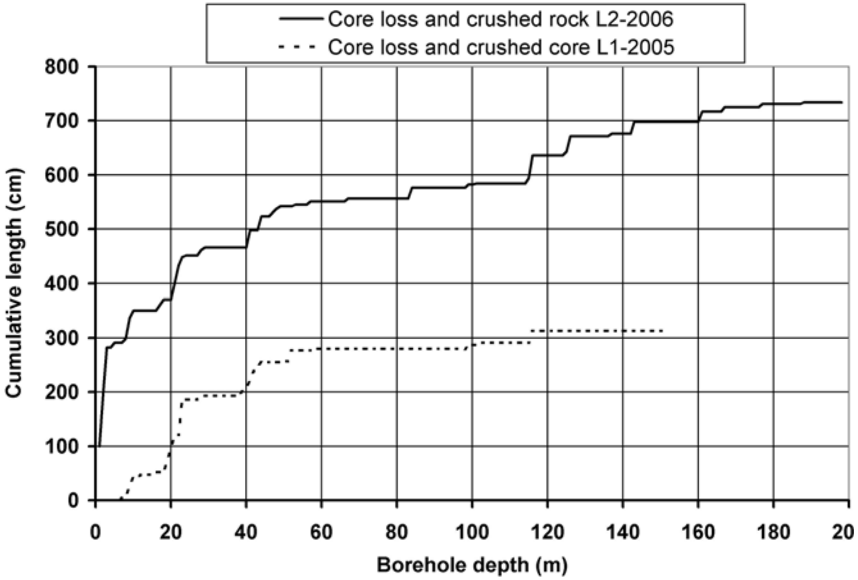
- Core logging
- Samples for lab testing
- Optic televiewer and borehole logging
- Instrumentation



Core loss/crushed core and fractures







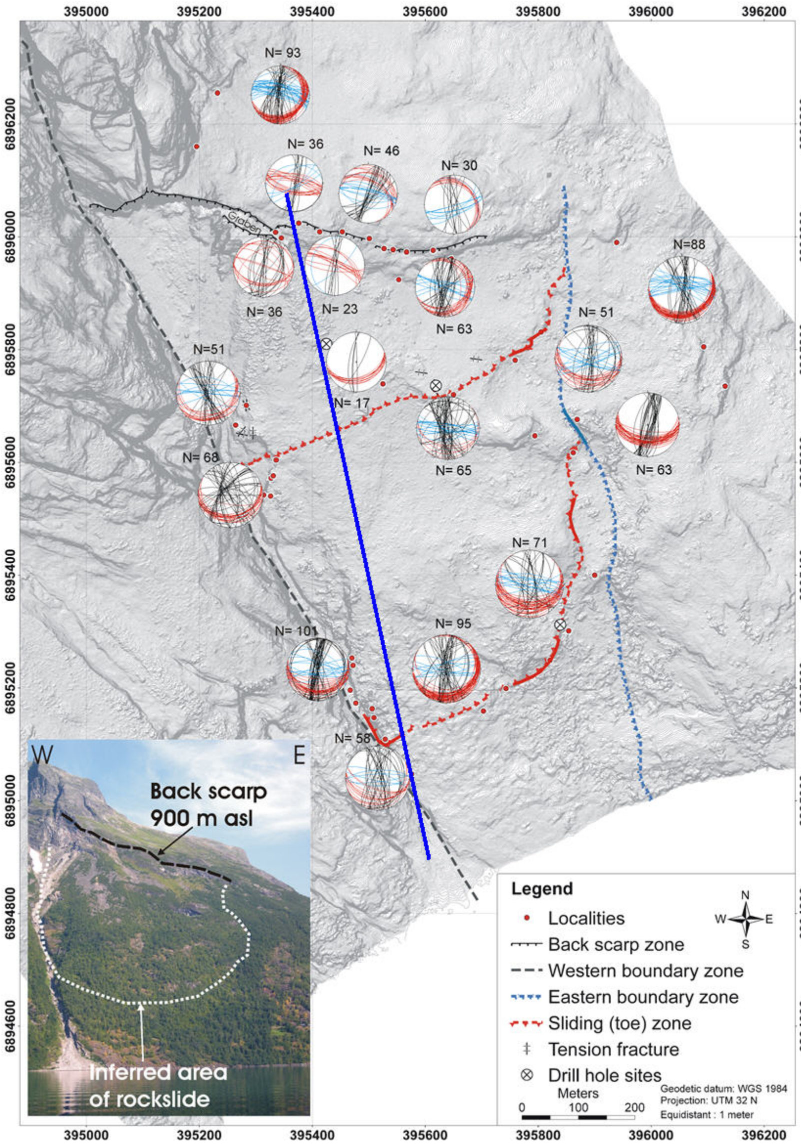
Field mapping of rock outcrops

- Orientation of fractures
- Fracture spacing
- Fracture length

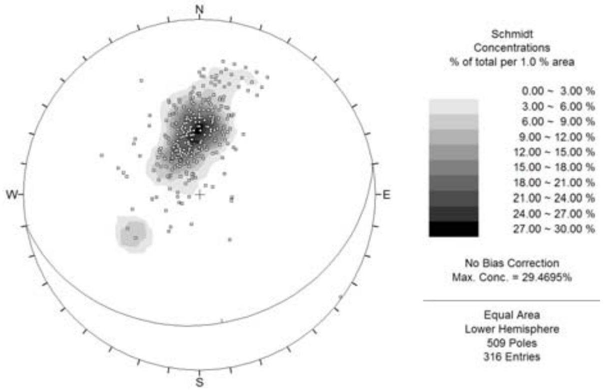
- Shear strength parameters (Barton – Bandis shear strength criterion)

Figure 12: Surface roughness amplitude measured on meter-scale in the field.

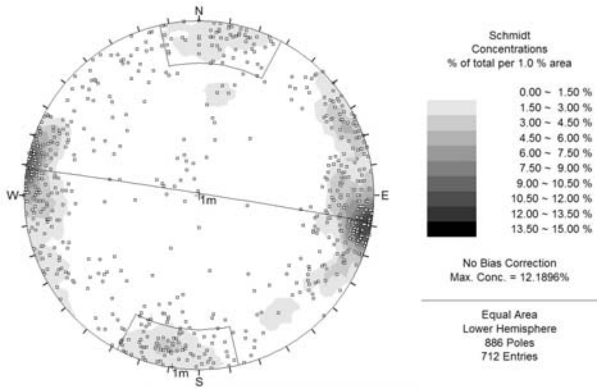
Results of field mapping: fracture orientation



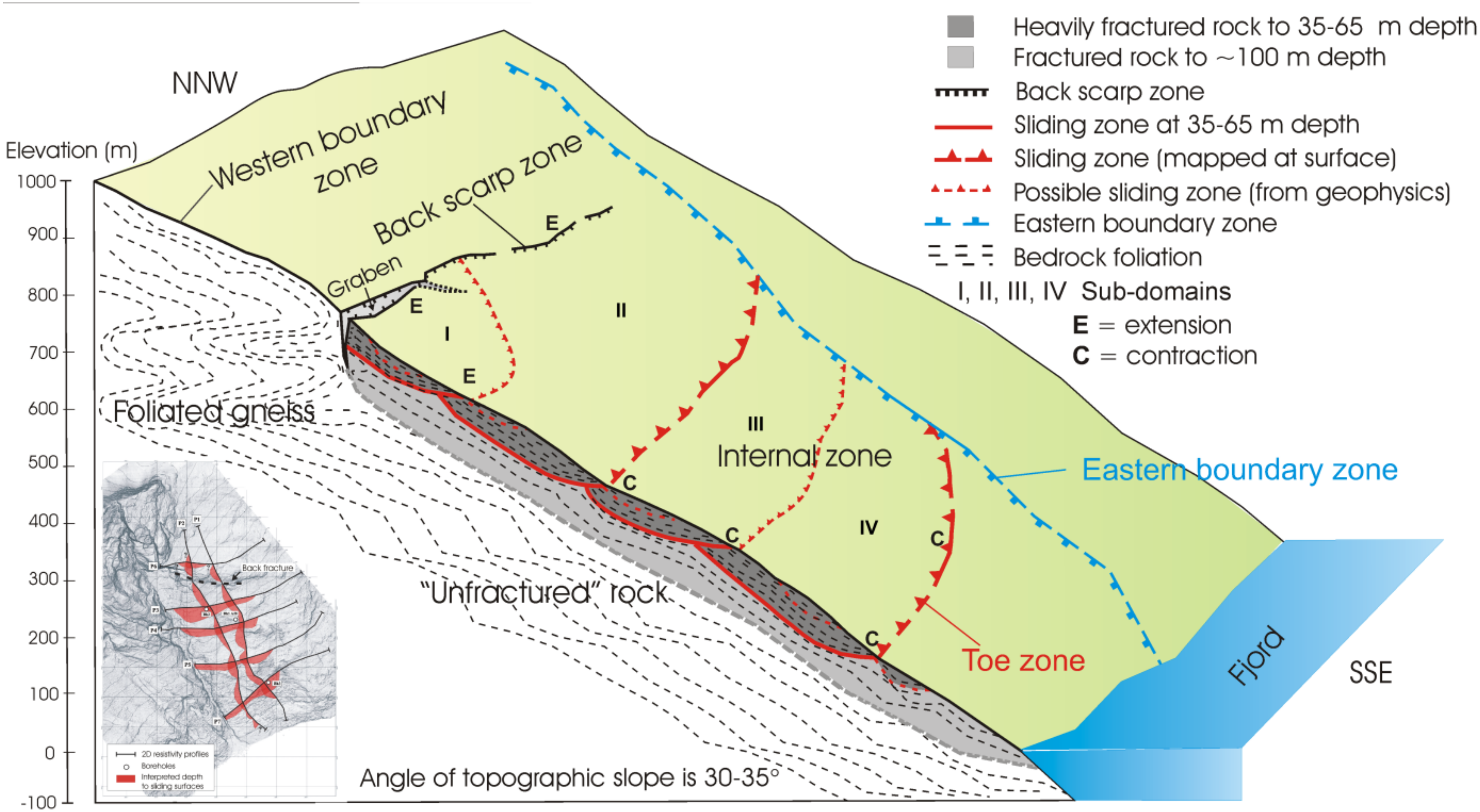
Fol. frac. downslope the upper tension fracture: mean dip 32deg.



Fractures non-parallel with the foliation

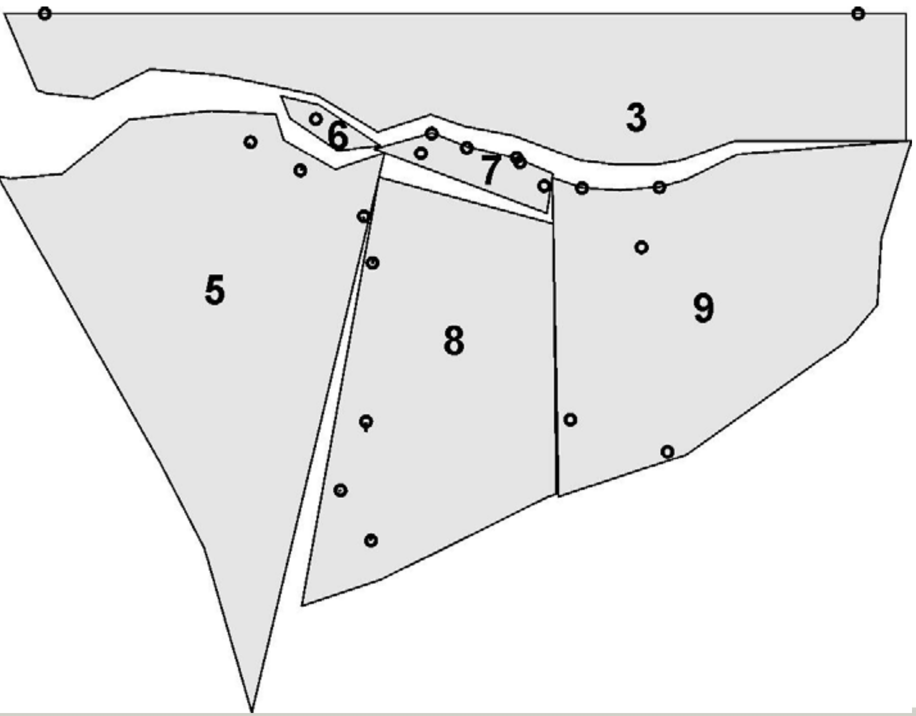


Geological model

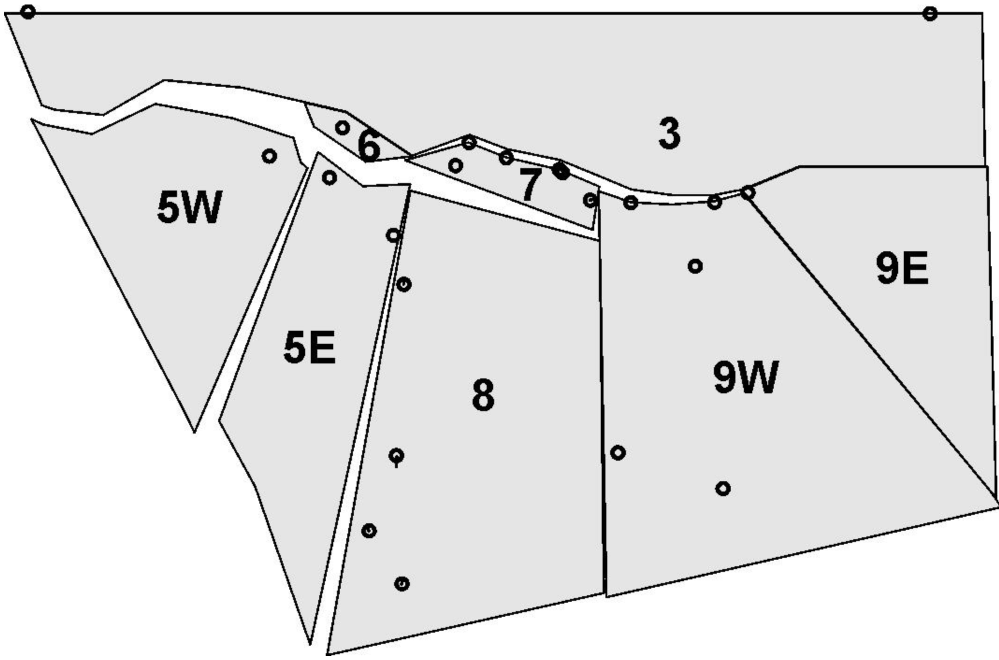


Block model based on surface displacements using Discontinious Deformation Analysis (DDA) – Backward modelling mode

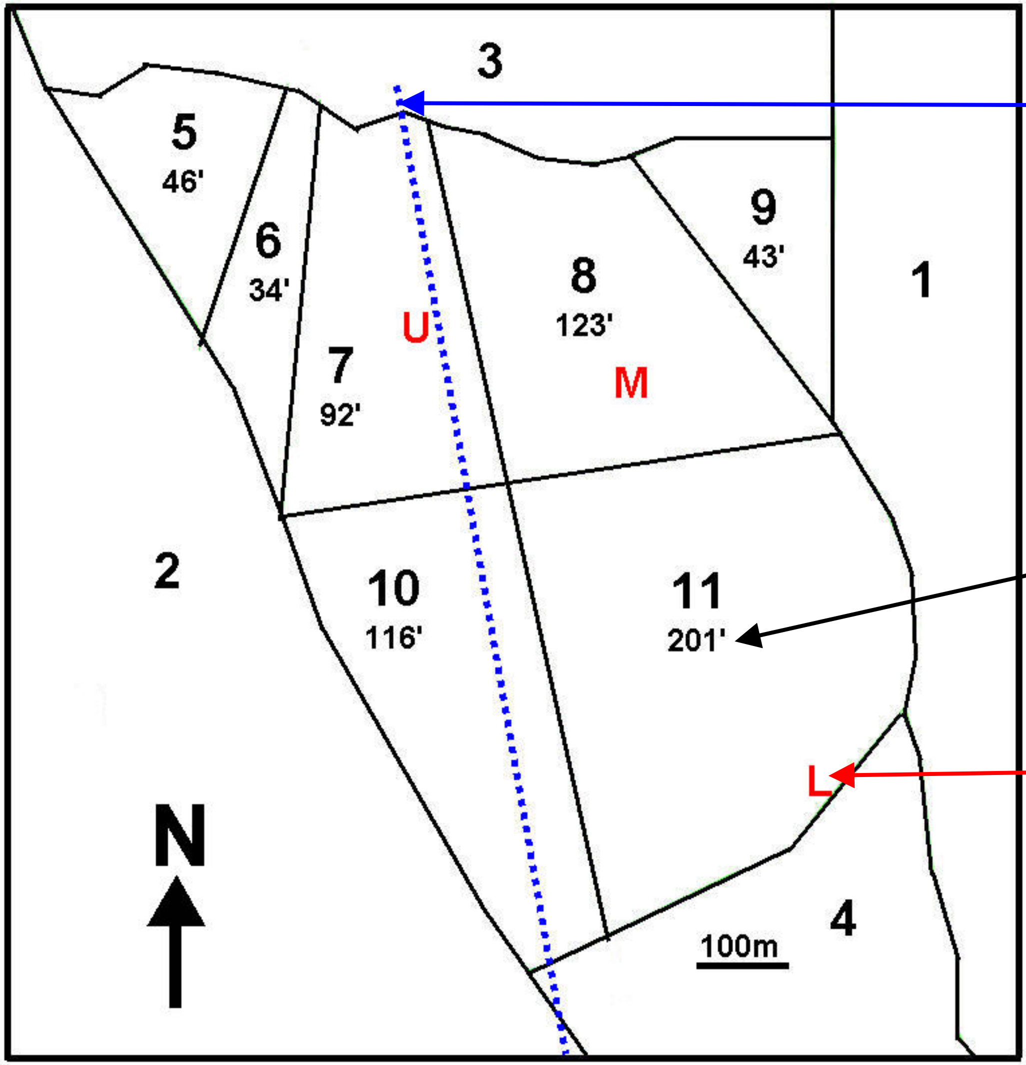
2004-06 displacements: not so good model of the upper part of the slope



2004-06 displacements: more appropriate model of the upper part of the slope



Block model: possible block boundaries based on all three displacement data sets



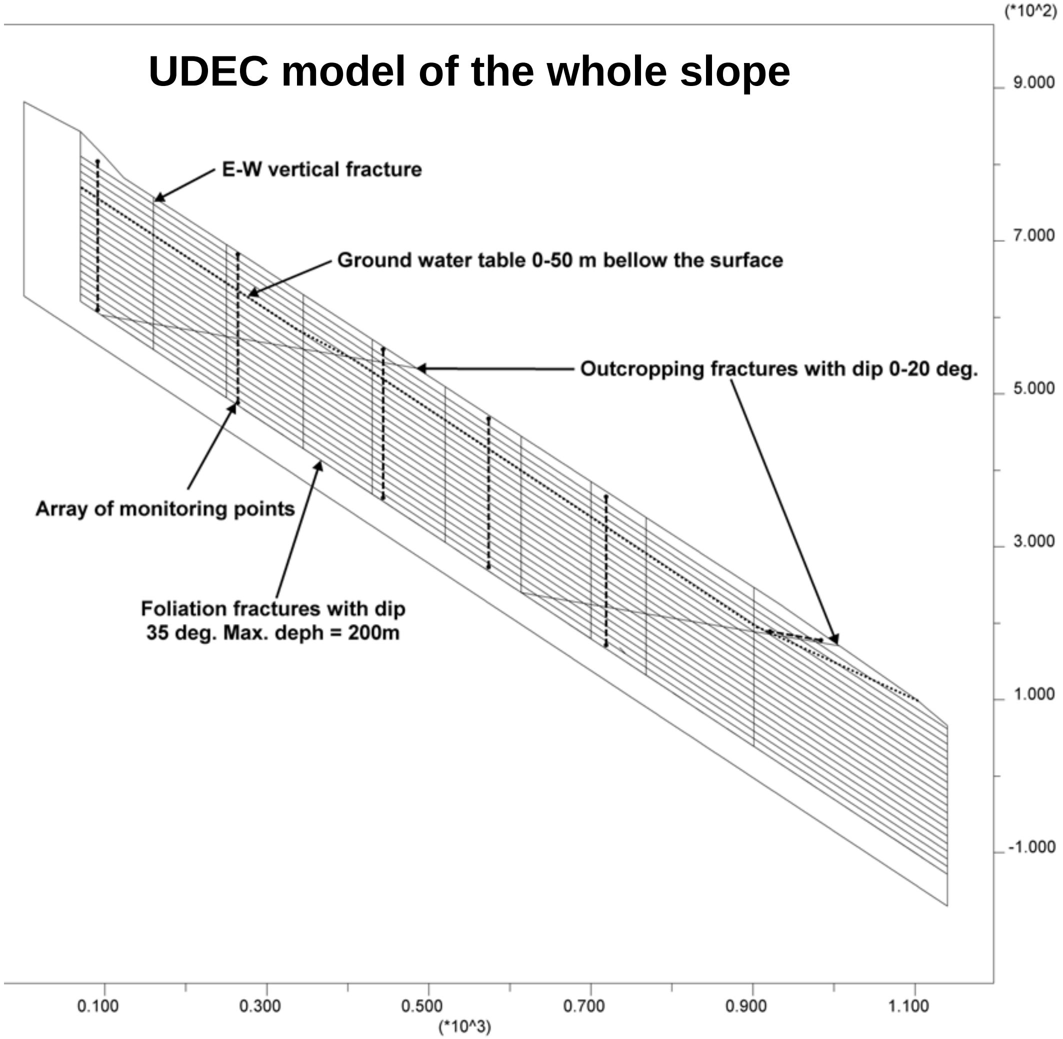
Profile for stability analyses

The area of Block 11 is 201,000m^2 and a major part moved insignificantly from 2004 to 2007

Borehole location

Big question: does Block 10 move????

Stability analyses: static

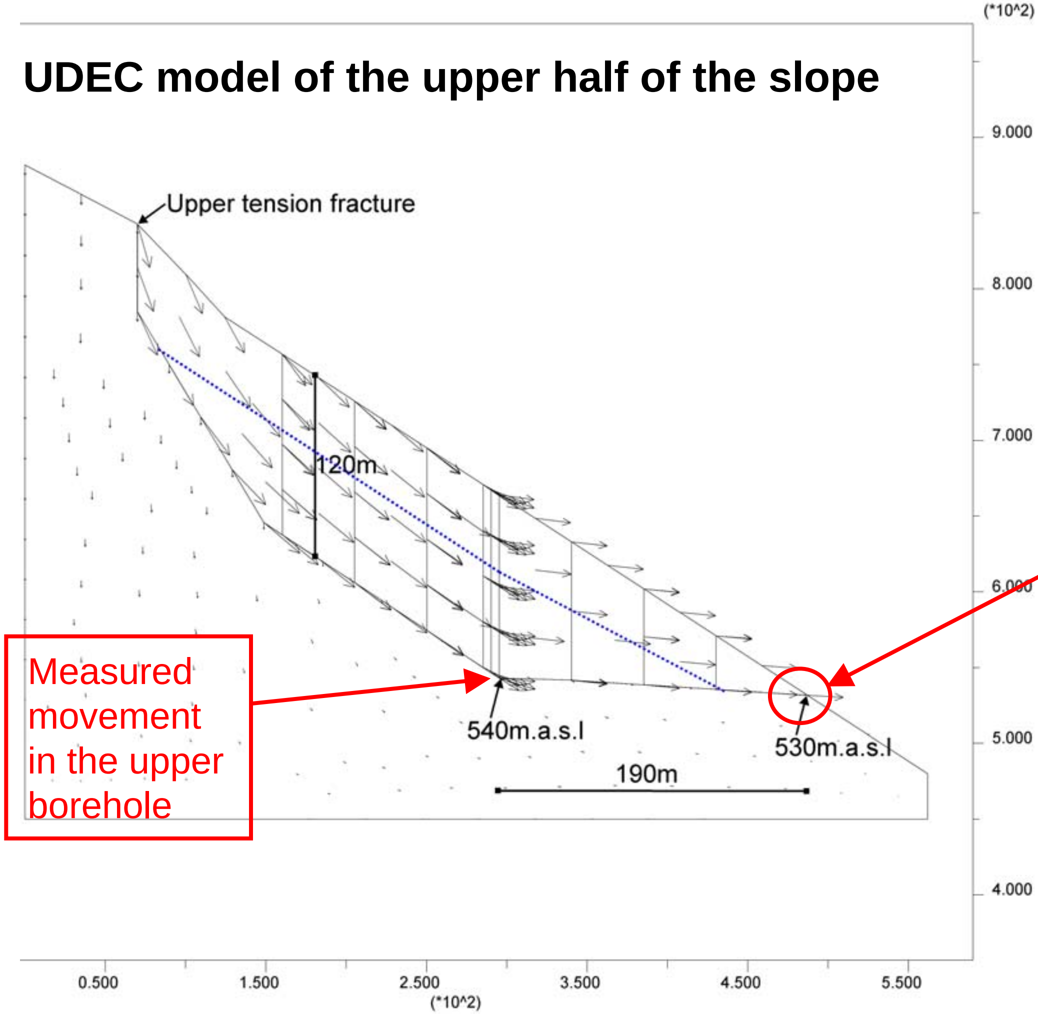


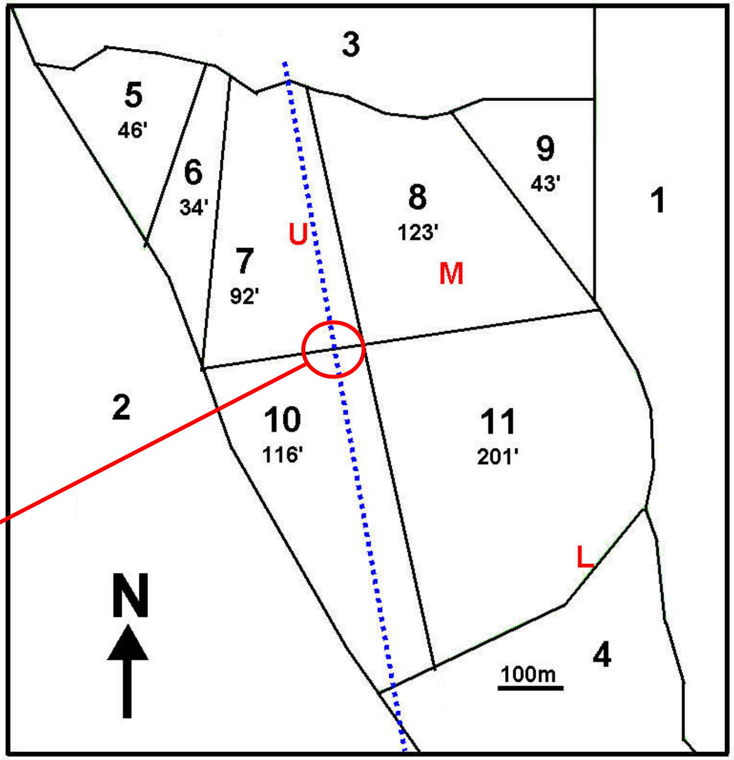
Stability analyses: static

•One major conclusion from the numerical modelling: **Instability at great depth agrees with the back-calculated limiting friction angle of the unstable area**

•Instability at 120m later indicated by borhole measurements

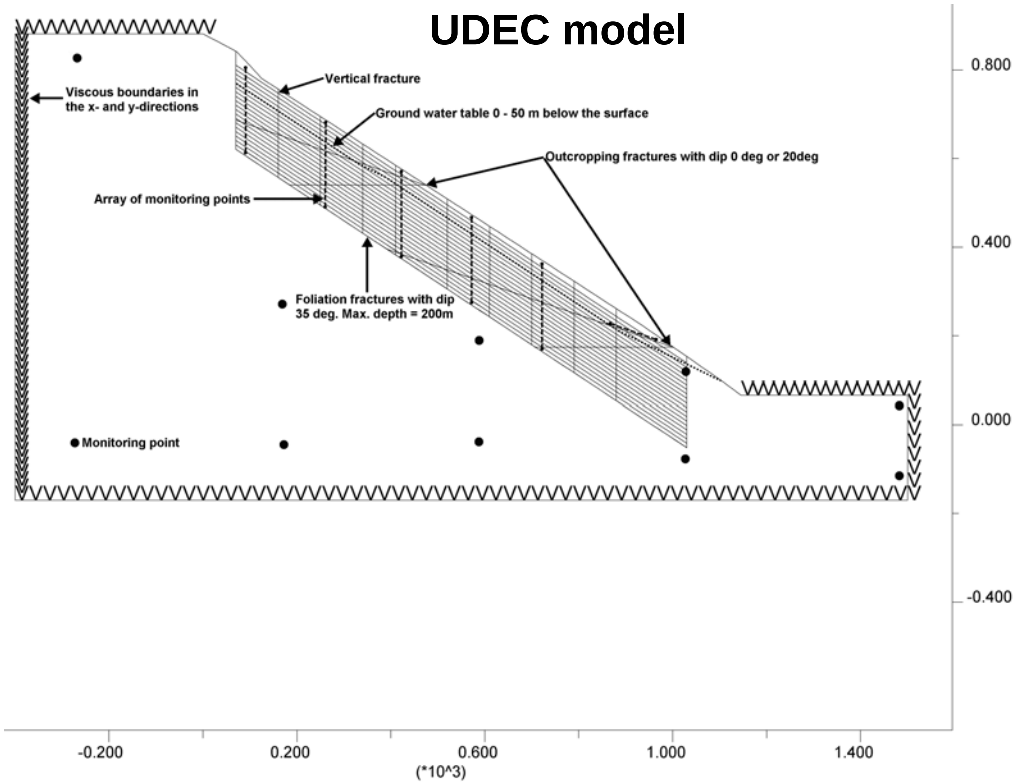
Stability analyses: static

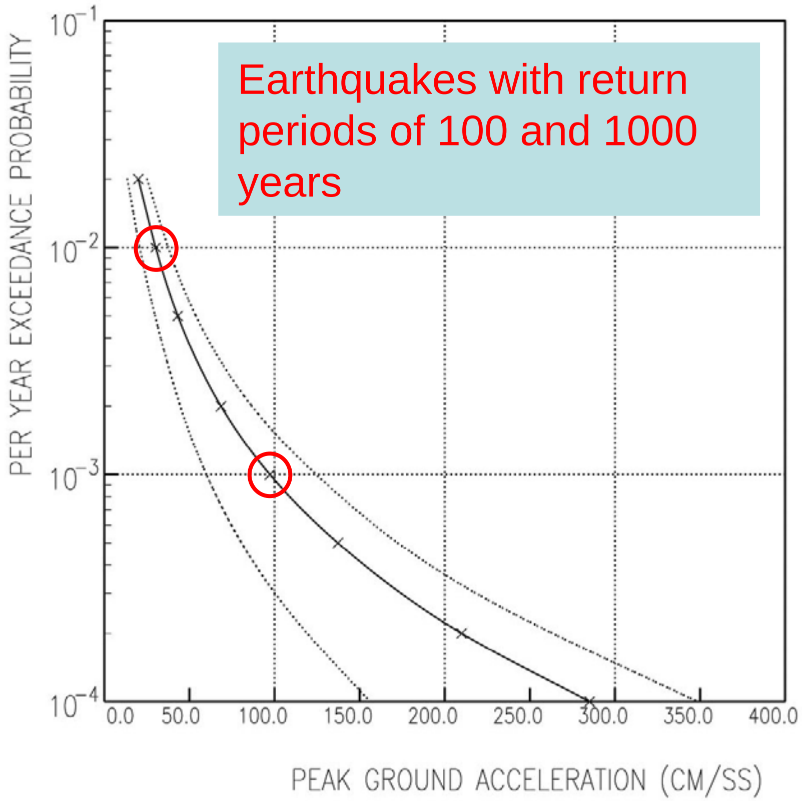




The model is possible with friction angle ≈ residual friction angle

Stability analyses: dynamic





The analyses indicate that an earthquake with a return period of 1000 years is likely to trigger a slide to great depth at the present ground water conditions and that the slope will remain stable if it is drained.

An earthquake with a return period of 100 years is not likely to trigger a slide at the present ground water conditions.