# Structure of the Åknes rock slope – comparable to other sites with drainage?

# Workshop – Drainage of large rockslides - Oslo 30- 31th of January 2017

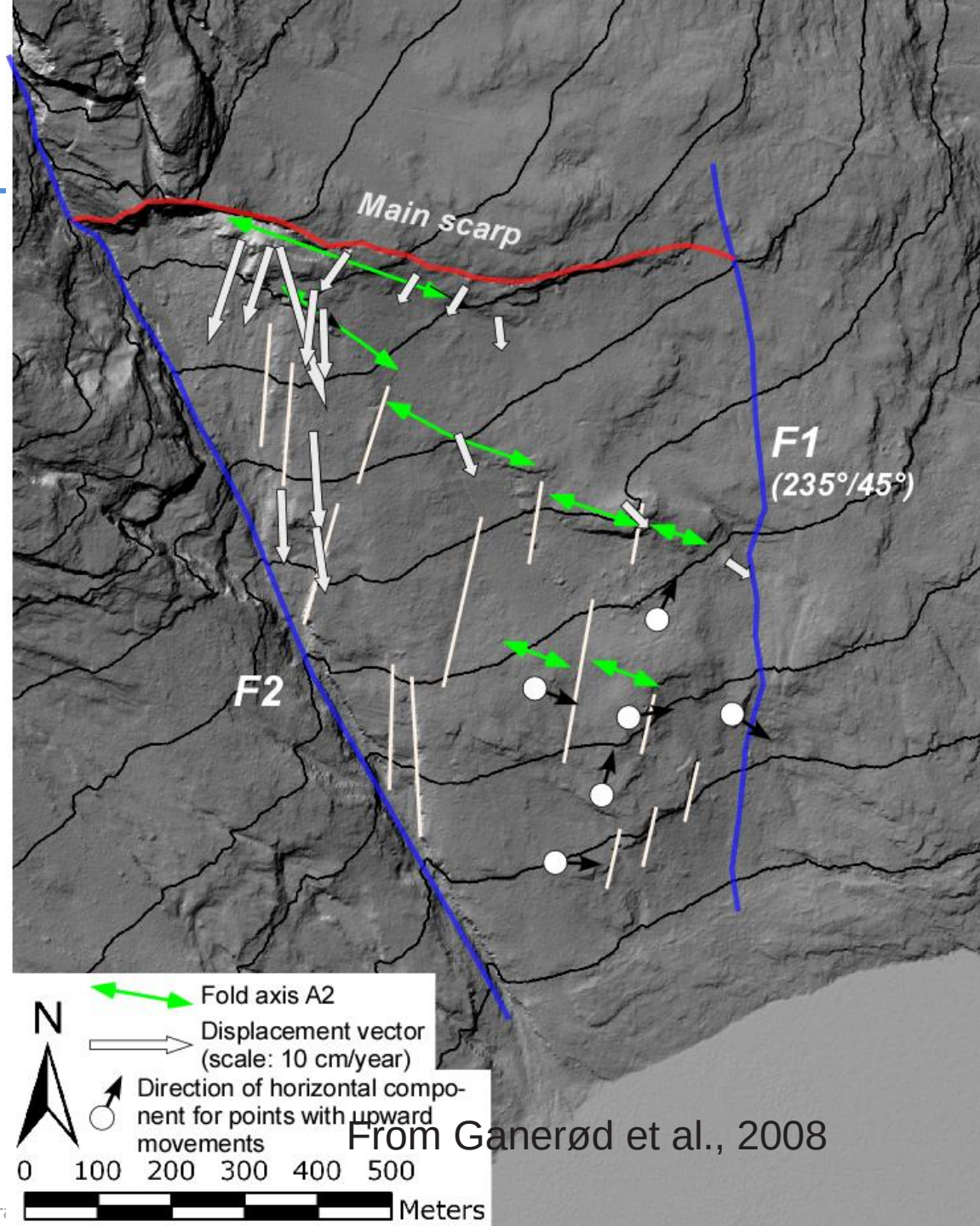
**Jaboyedoff M. [1] & Oppikofer T. [2]**

*[1]Institute of Geomatics and Risk Analysis – University of Lausanne, Switzerland;*
*[2]Geological Survey of Norway*

UNIL | Université de Lausanne
**Institut de géomatique et d'analyse du risque**

# Displacements

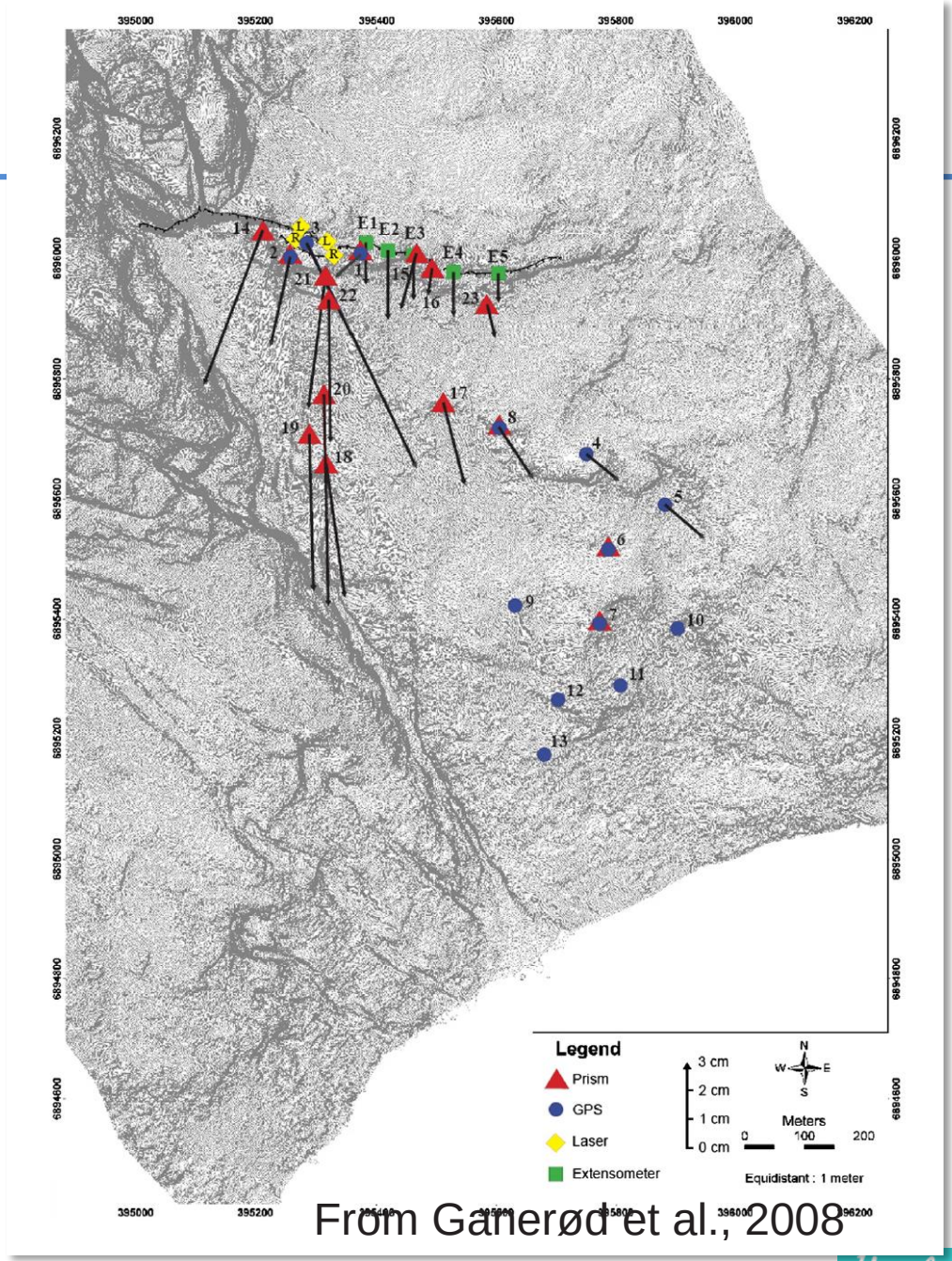
•Hillshade model of the Åknes rockslide displaying the measured displacements (data from Blikra, 2008) and the main structural features. The two lateral faults (F1 and F2) are represented as blue line, the JNS joint set as white lines and fold axis A2 are shown in green.




From Ganerød et al., 2008

# Displacements

- Hillshade model of the Åknes rockslide displaying the measured displacements (data from Blikra, 2008) and the main structural features. The two lateral faults (F1 and F2) are represented as blue line, the JNS joint set as white lines and fold axis A2 are shown in green.

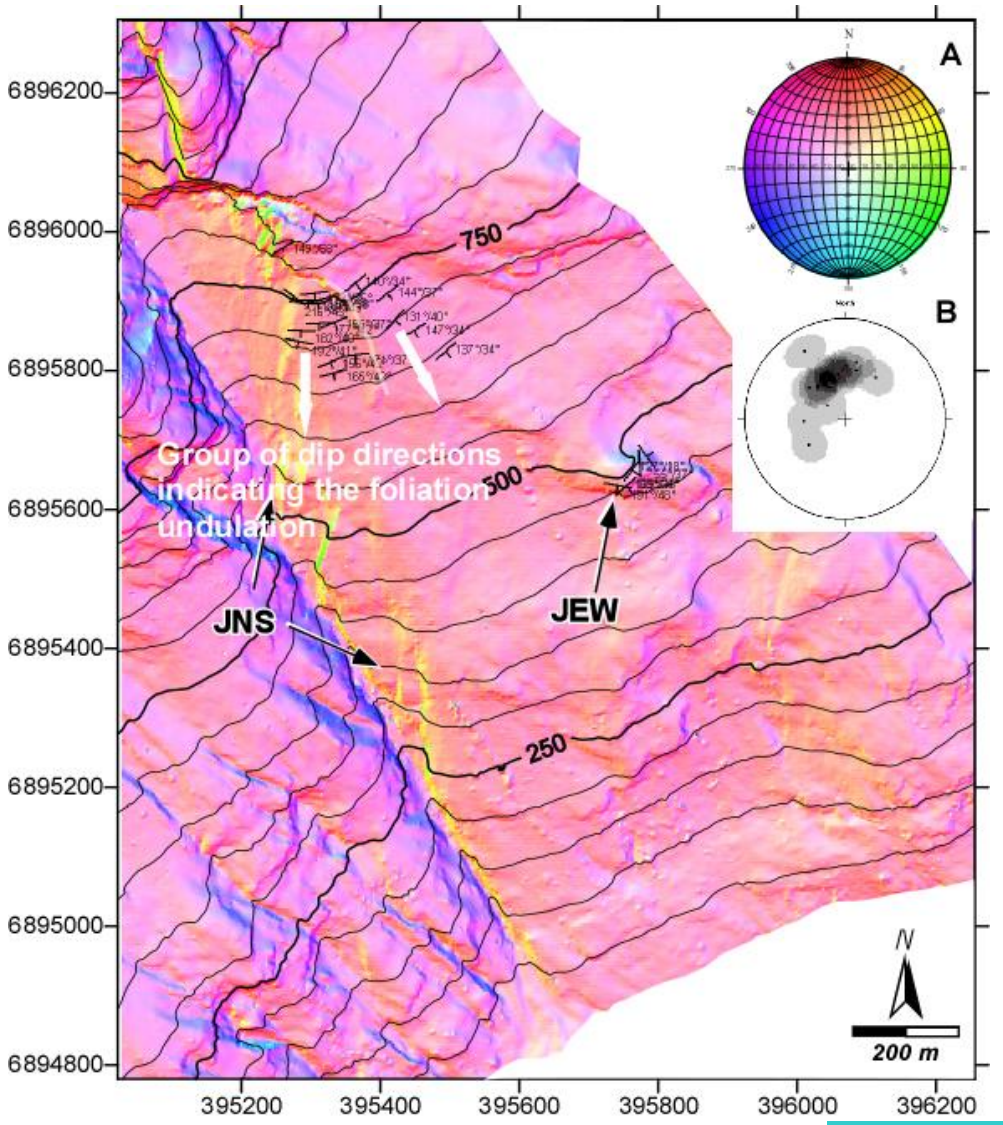



From Ganerød et al., 2008

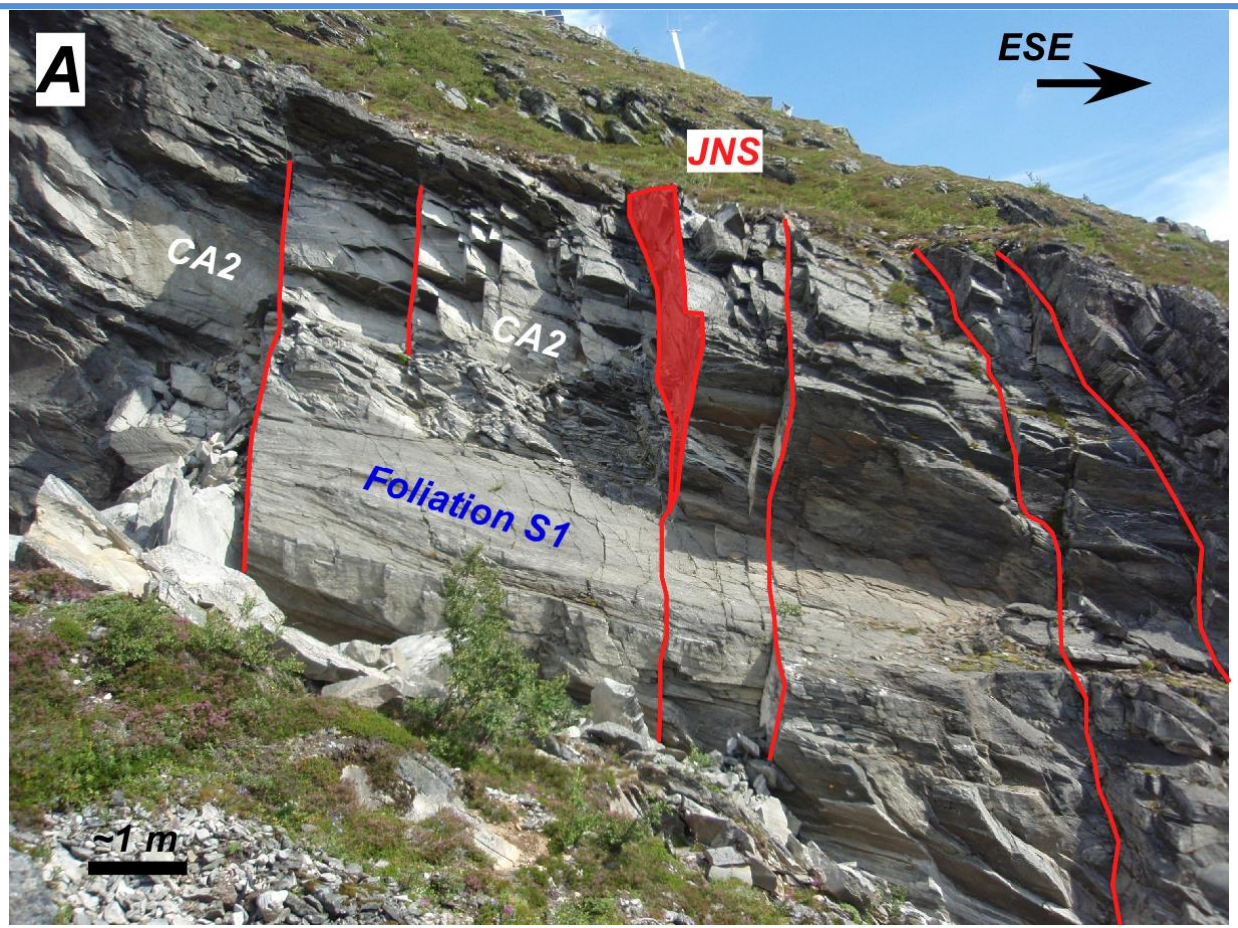
# Surface structures

Orientation-specific colouring of the ALS-DEM in COLTOP showing the rapid variation of the foliation's orientation (white arrows). The slope orientations are displayed by a unique colour given by the pole in a lower hemisphere Schmidt stereonet in association with a Hue-Saturation-Intensity wheel (A).

The measurements on this COLTOP image were performed assuming that the slope follows the foliation, which is confirmed by field measurements. The poles of the measured foliation surfaces are shown in the density stereonet (B).



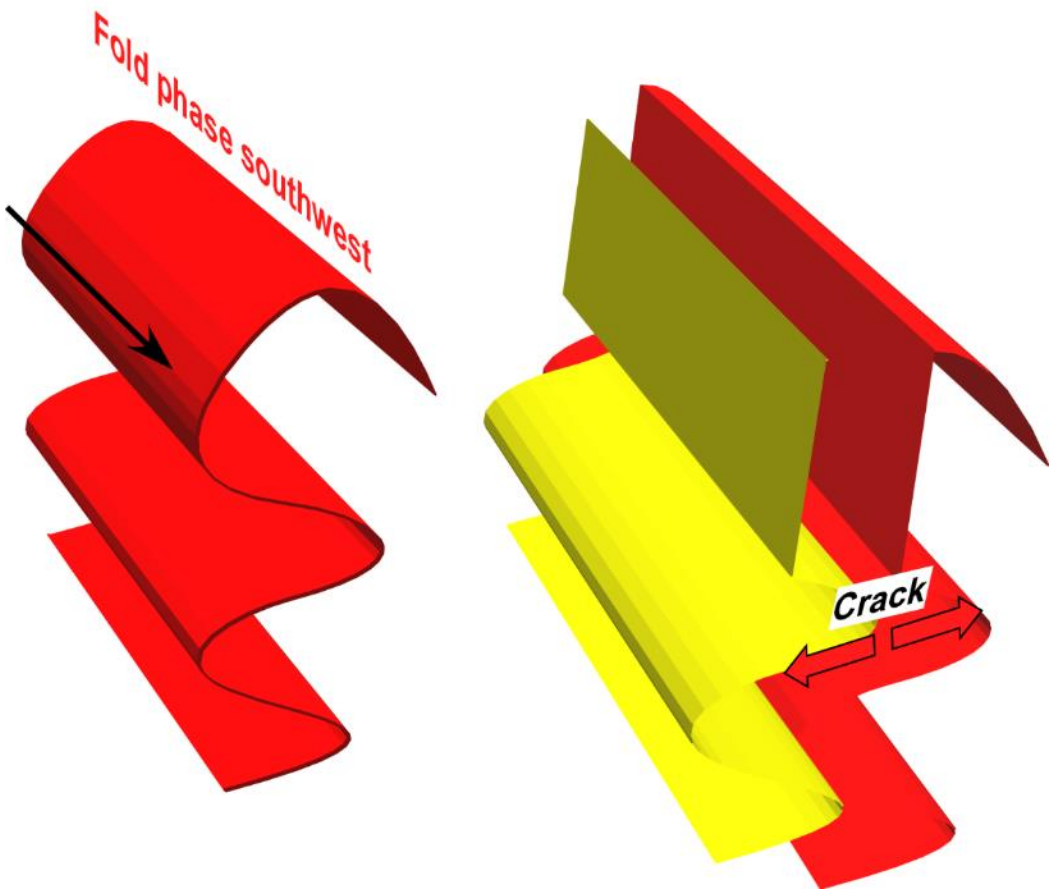
# N-S system




(A) Outcrop in the main back-scarp showing the vertical foliation S1 folded within folds A2 and the cracks (CA2), the N-S-trending joints JNS are found everywhere and they cut quasi perpendicularly the folds. Note the variation in S1 orientation due to large-scale folding. North 10-20° are cutting the moving mass (also 175°)

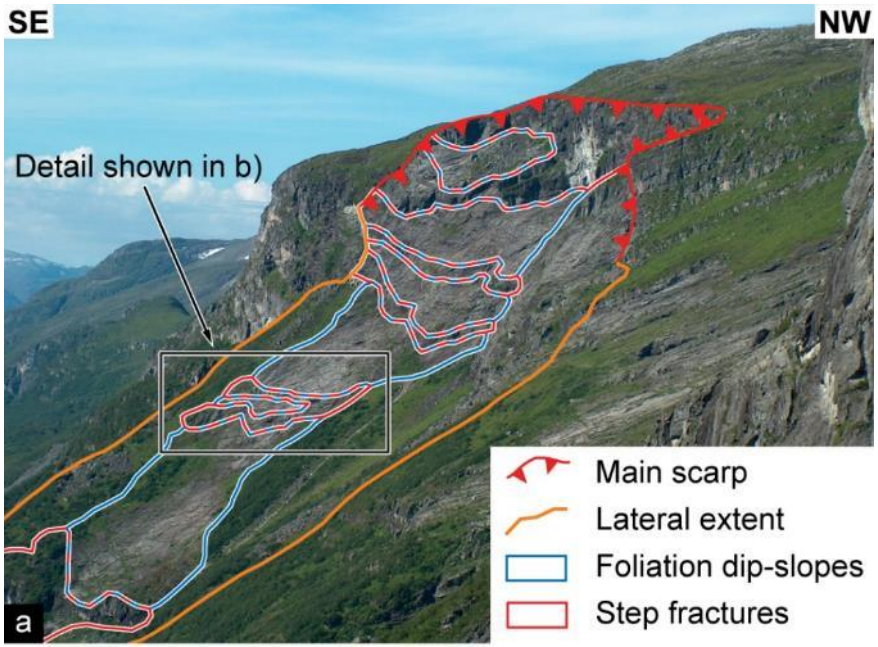
# Failure along the fold

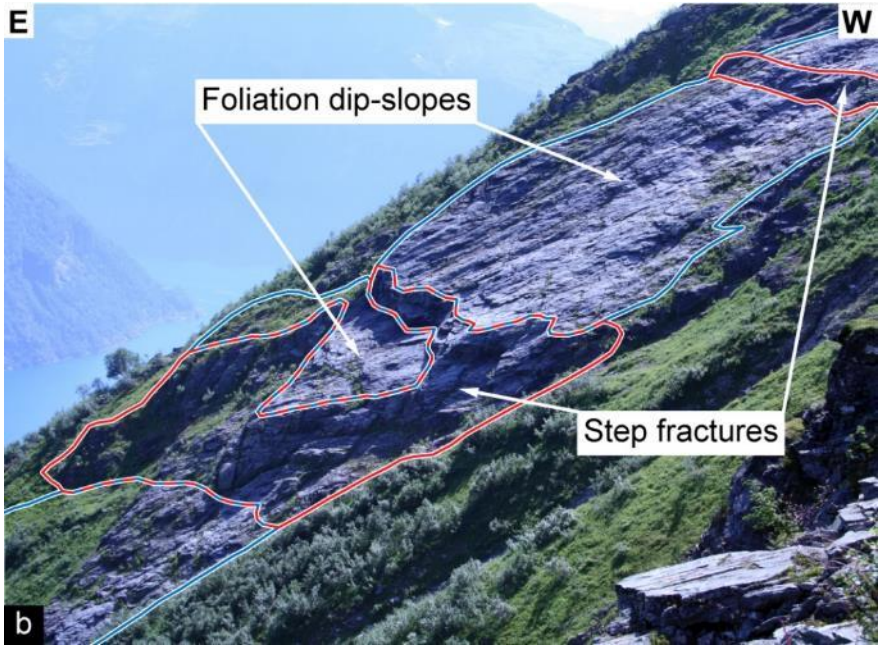
Scheme explaining how the weaknesses (cracks CA2) are induced by folds A2 in combination with folds A1. The cracks CA2 and the subvertical foliation S1 forms the backcracks of the Åknes rockslide and the former rockslide scars detected on the morphology of the slope.



# Sliding surface characterization

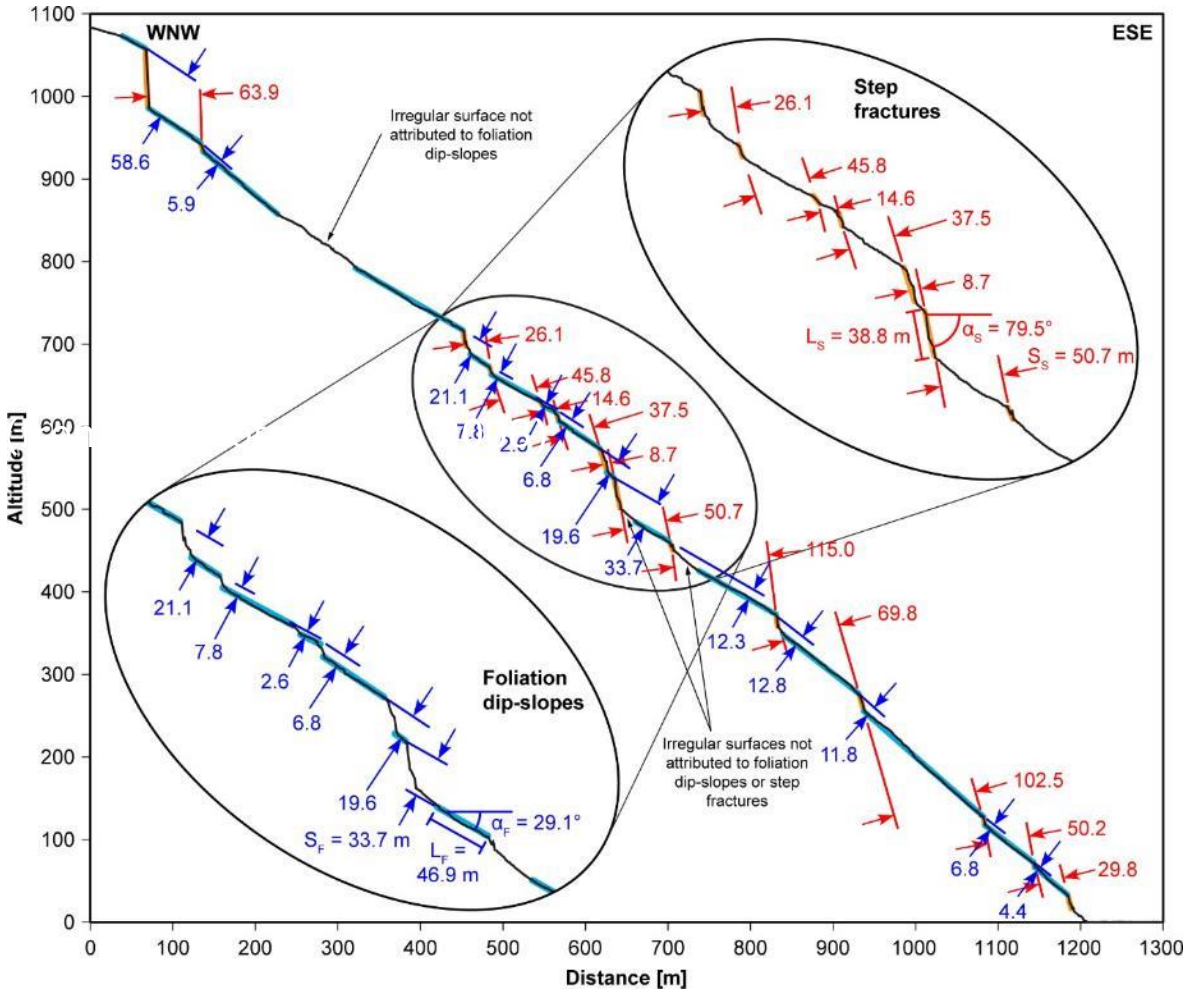
- Rockslide scar (6-8 $Mm^3$; 10-11 ka BP)
- Stepped sliding surface formed by gneiss foliation dip-slopes and steeply dipping step fractures



# Sliding surface characterization

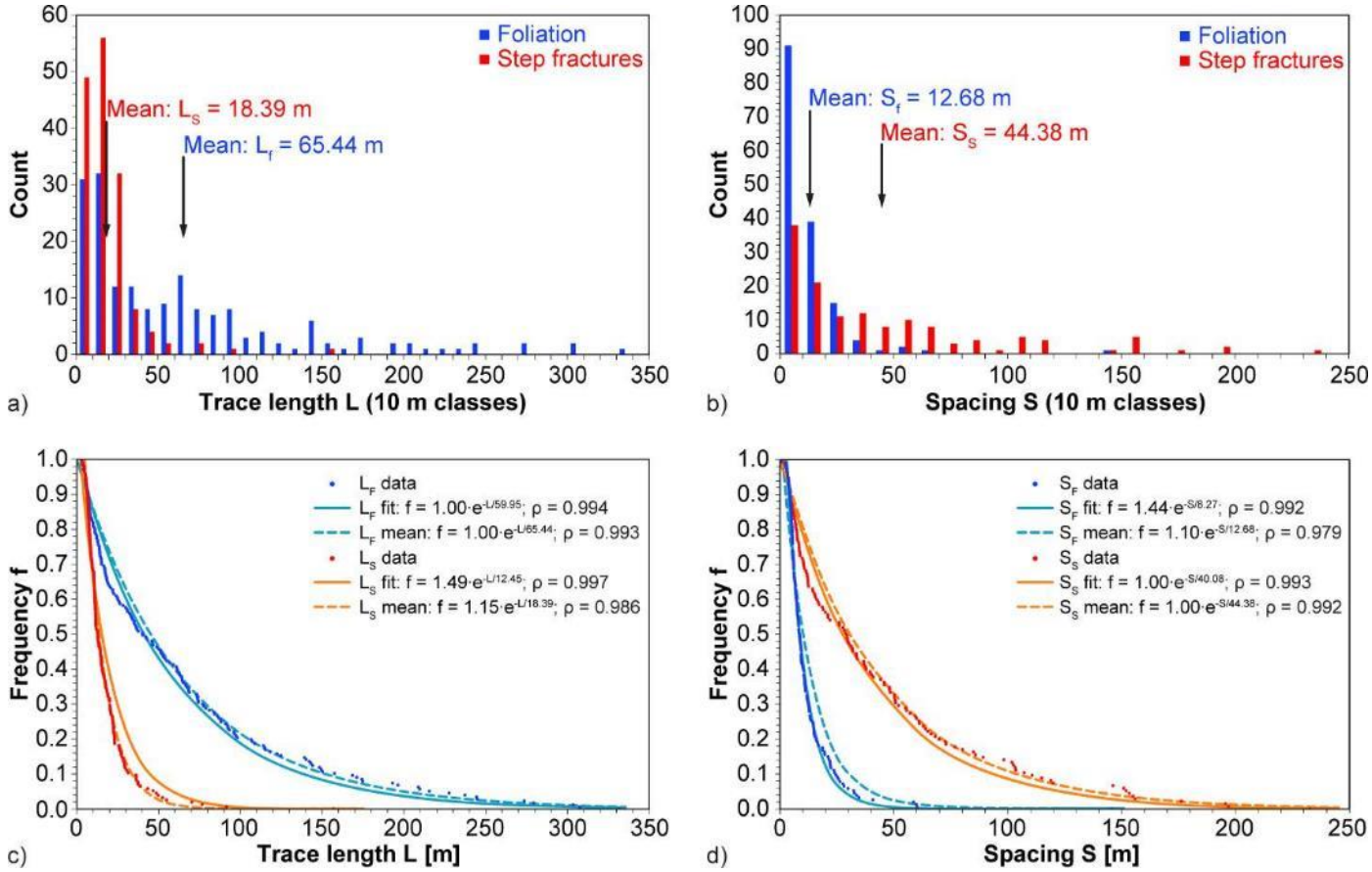
- Negative exponential distributions for trace lengths and spacings
- Normal distributions for dip angles
- Used for stochastic simulations of basal sliding surfaces




(from Oppikofer et al., 2008)

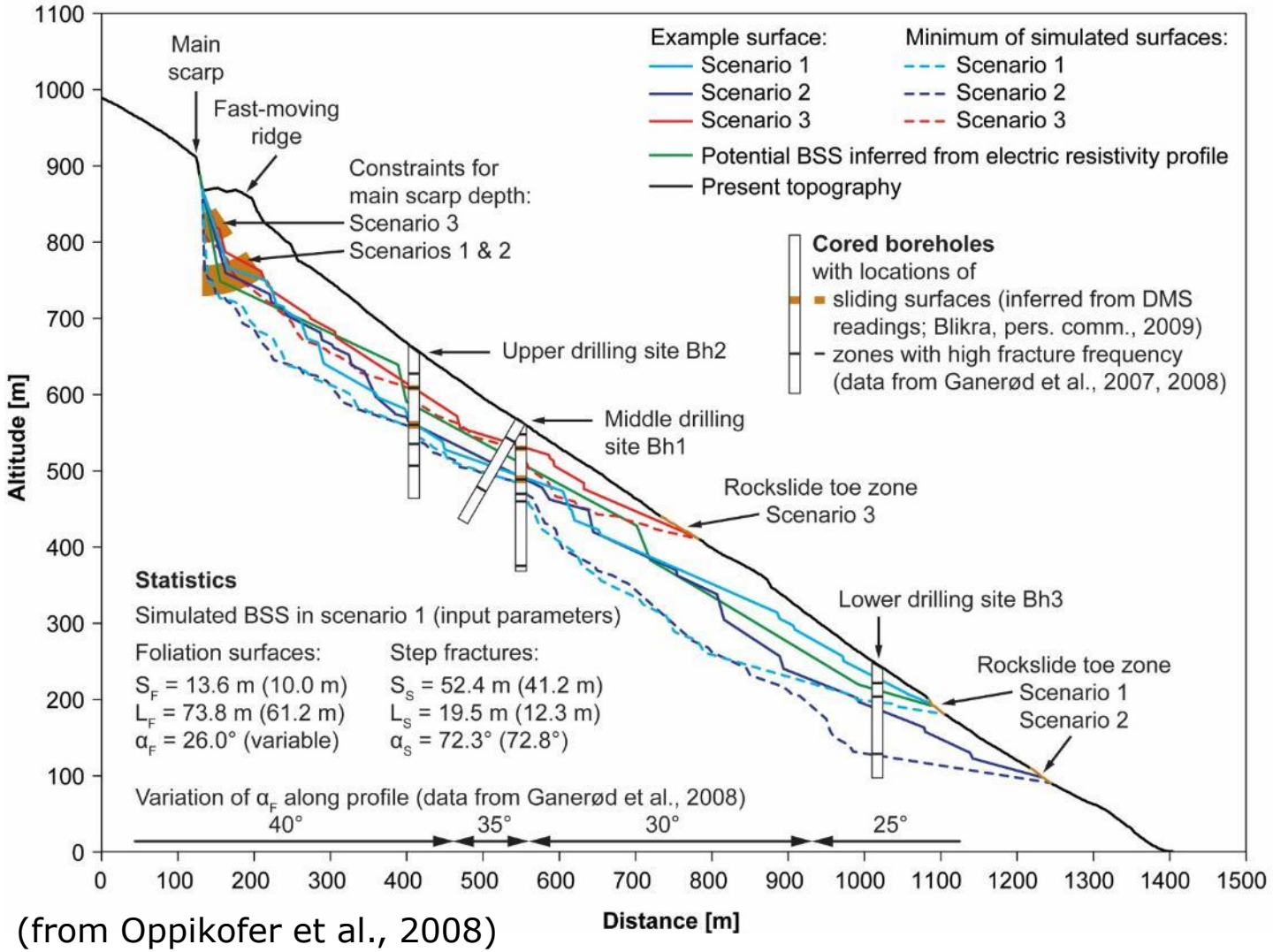
# Statistics

- Spacing and trace lengths show exponential negative distributions (from Oppikofer et al., 2008)



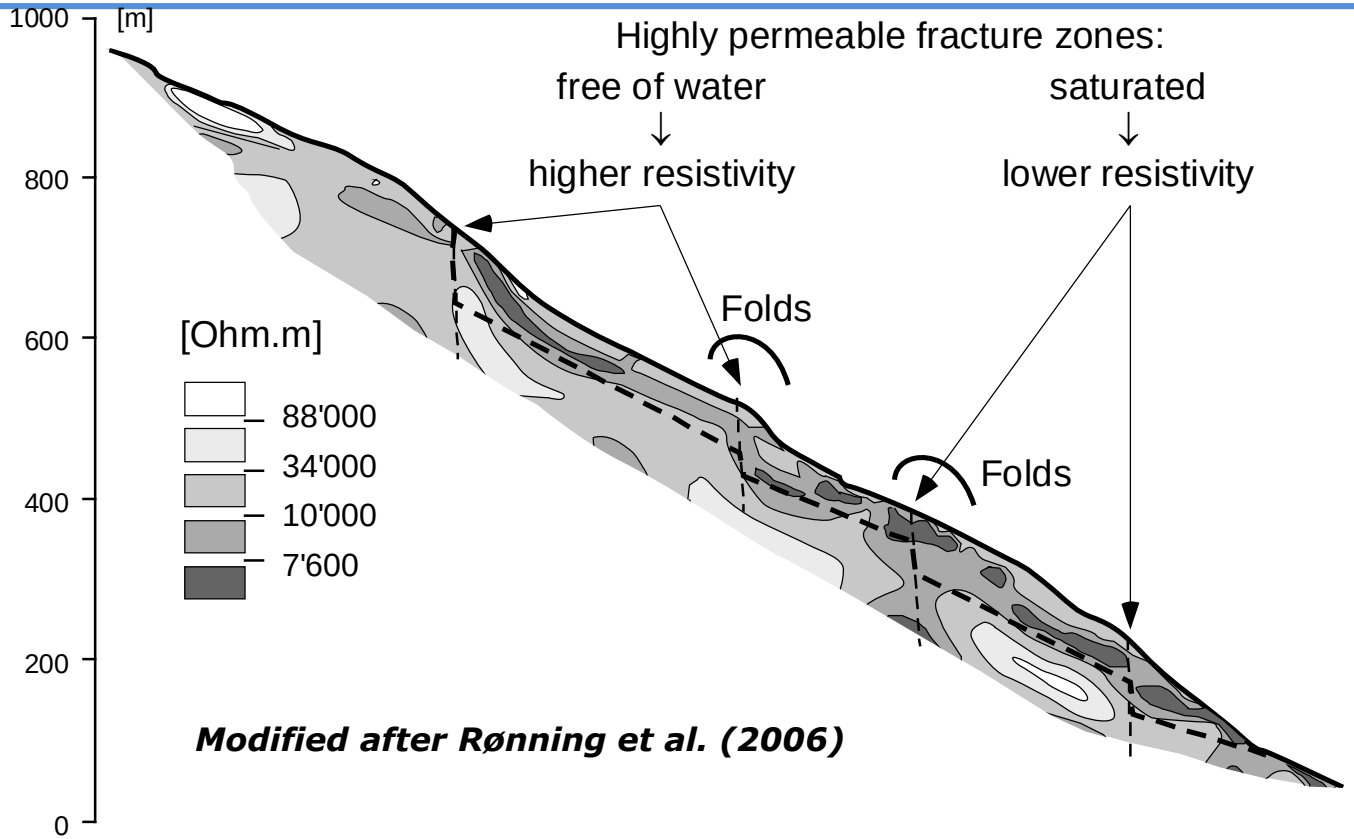

(from Oppikofer et al., 2008)

# Stepped sliding surface at Åknes using fracture simulations



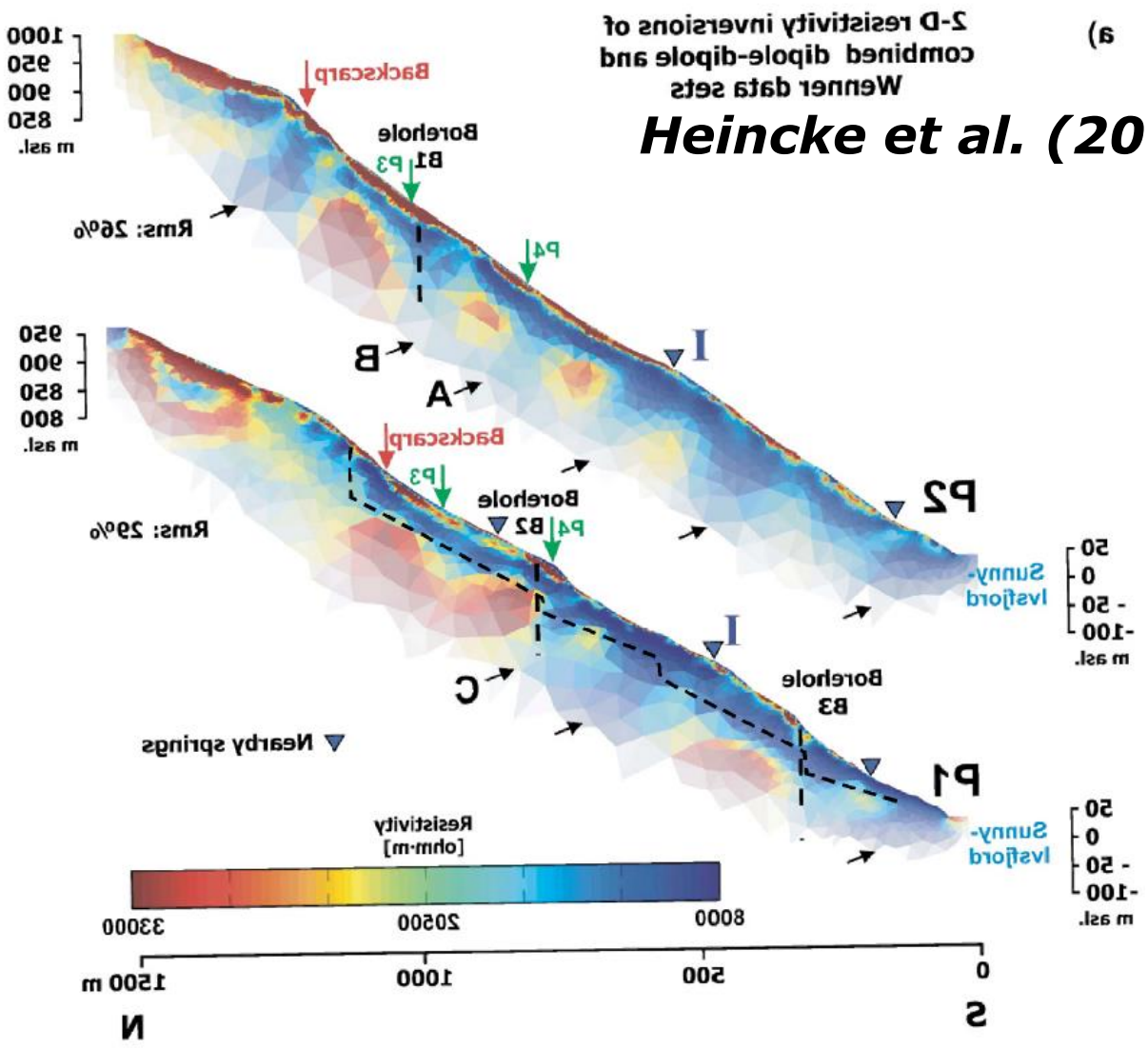

(from Oppikofer et al., 2008)

# Interpretation of electrical profiles

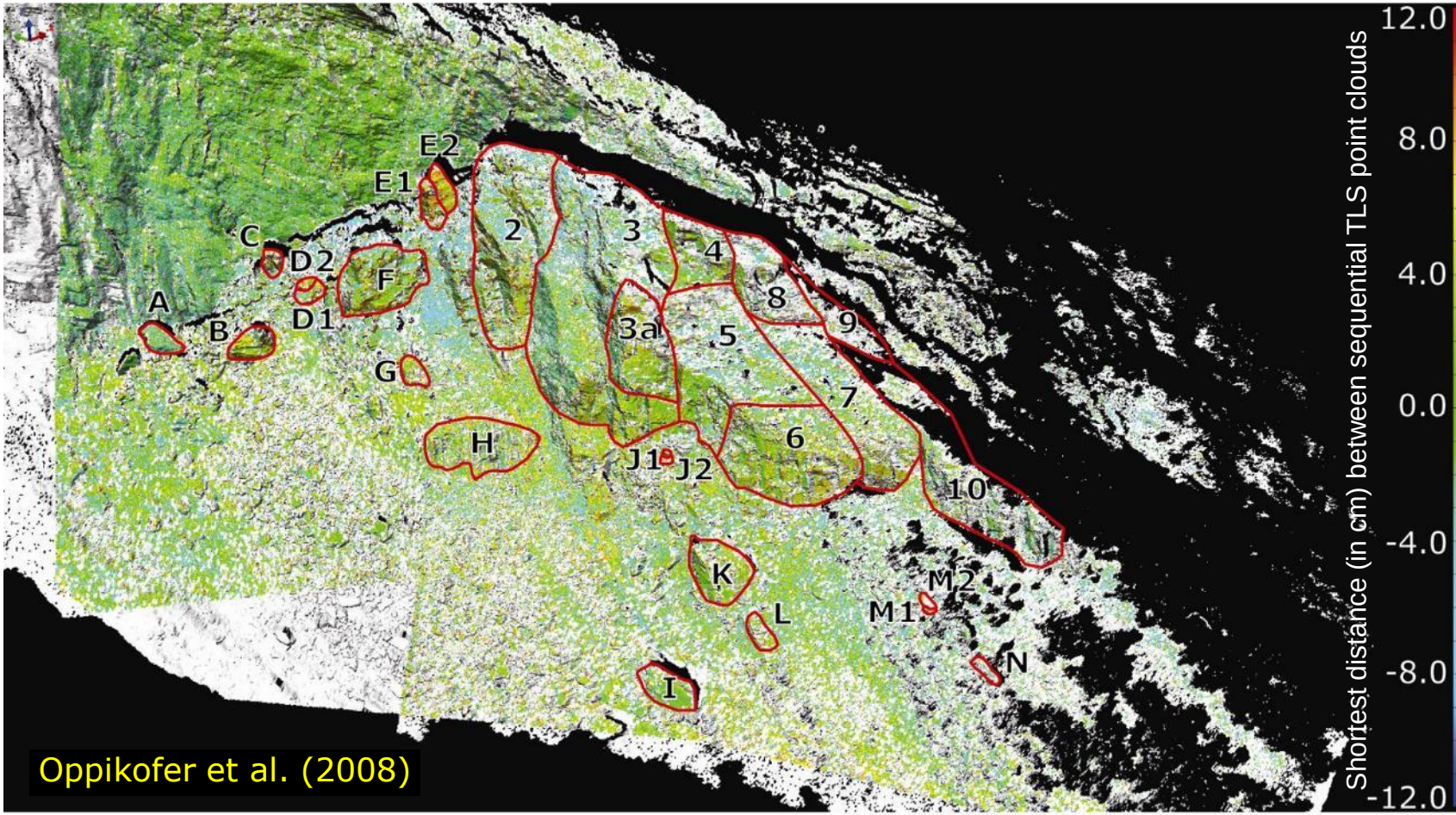



- Interpretation of the stepped failure surface (dashed black line) based on an inversion of a longitudinal 2D electrical profile (electrical profile modified after Blikra et al., 2006). The vertical dashed lines indicate the vertical fractures linked to weaknesses (CA2) created by folds or to the JEW joint sets. It is assumed that they are creating highly permeable zones that are either saturated or free of water and therefore giving opposite electrical responses.

# Interpretation of electrical profiles

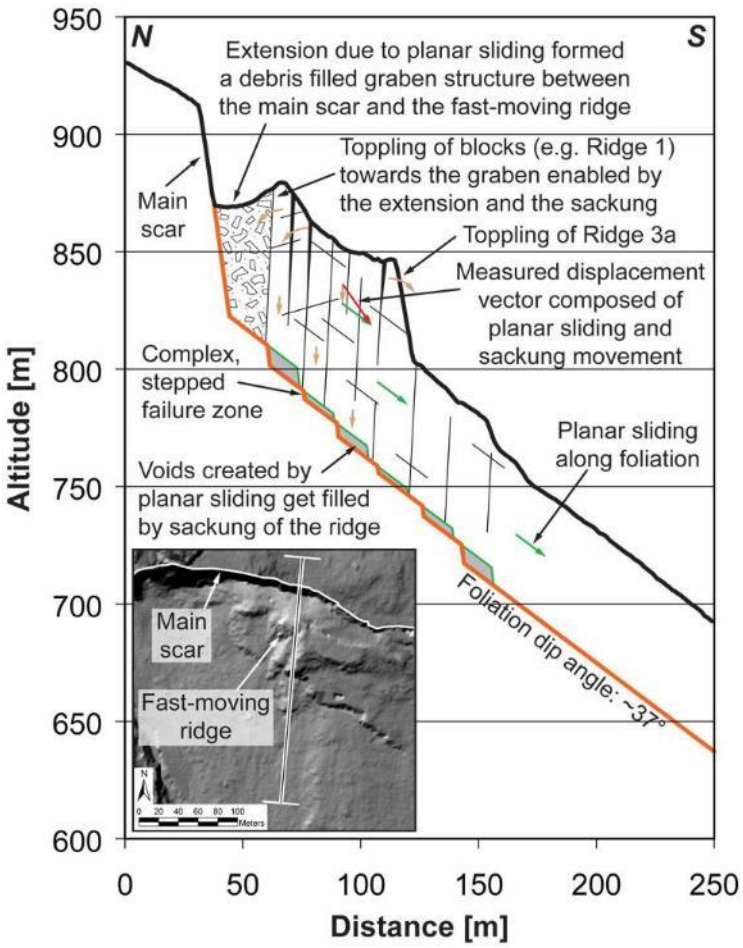


# Terrestrial laser scanning monitoring



# Rockslide mechanism – upper part

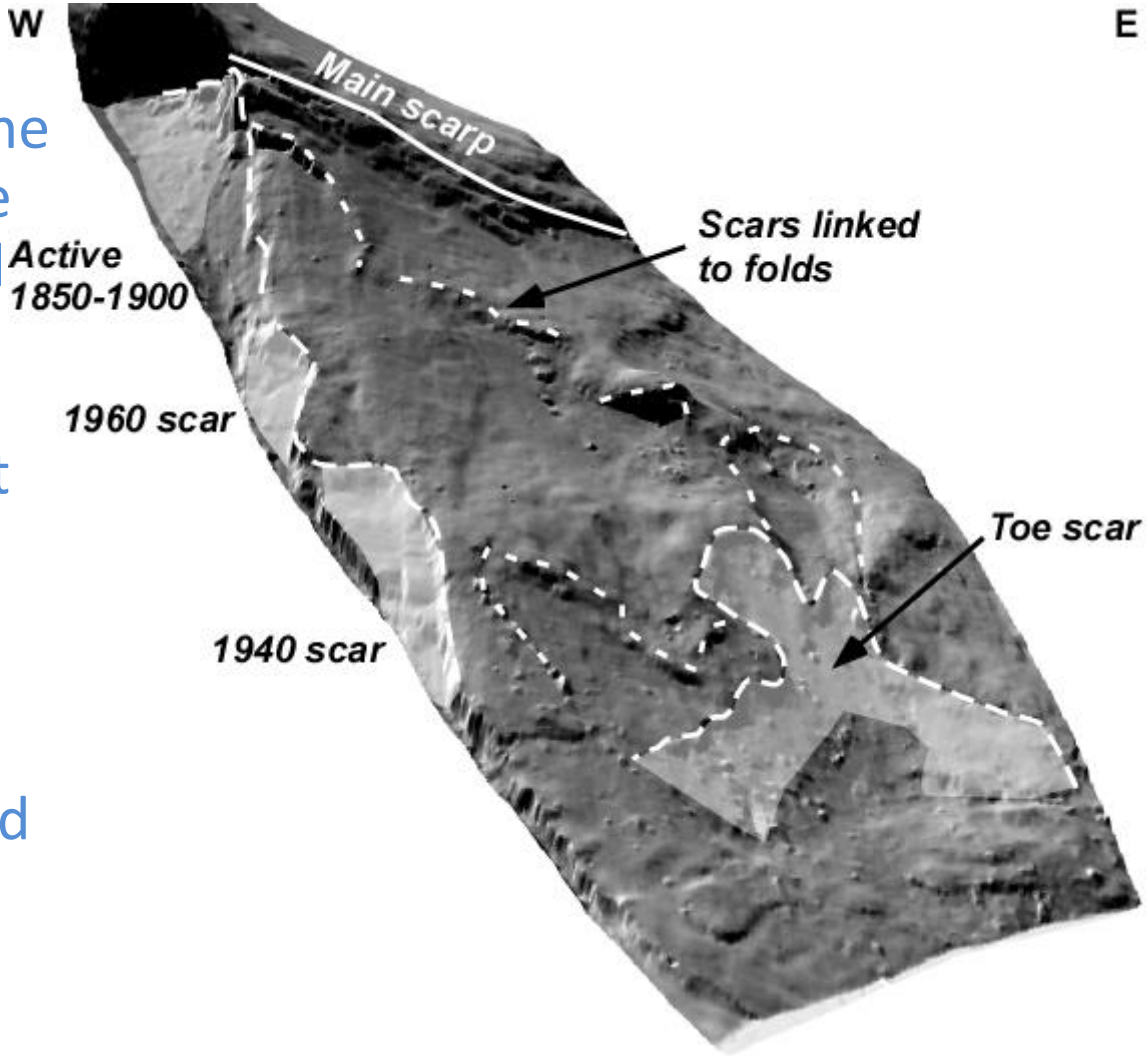
- Translational sliding parallel to the foliation planes
- Complex stepped basal failure surface creates higher downward displacements of the ridge
- Extension creates rear-bounding graben structure → filled by debris, enables back rotational toppling of the ridge




(from Oppikofer et al., 2008)

# Some of the apparent old scars, part of them are still active

3D representation of the hillshade indicating the former scars. Historical rockslide activity was located at the western boundary (next to fault F2), like the 1940 and 1960 scars. More ancient scars can be detected in the rockslide's toe zone and in the middle eastern part.

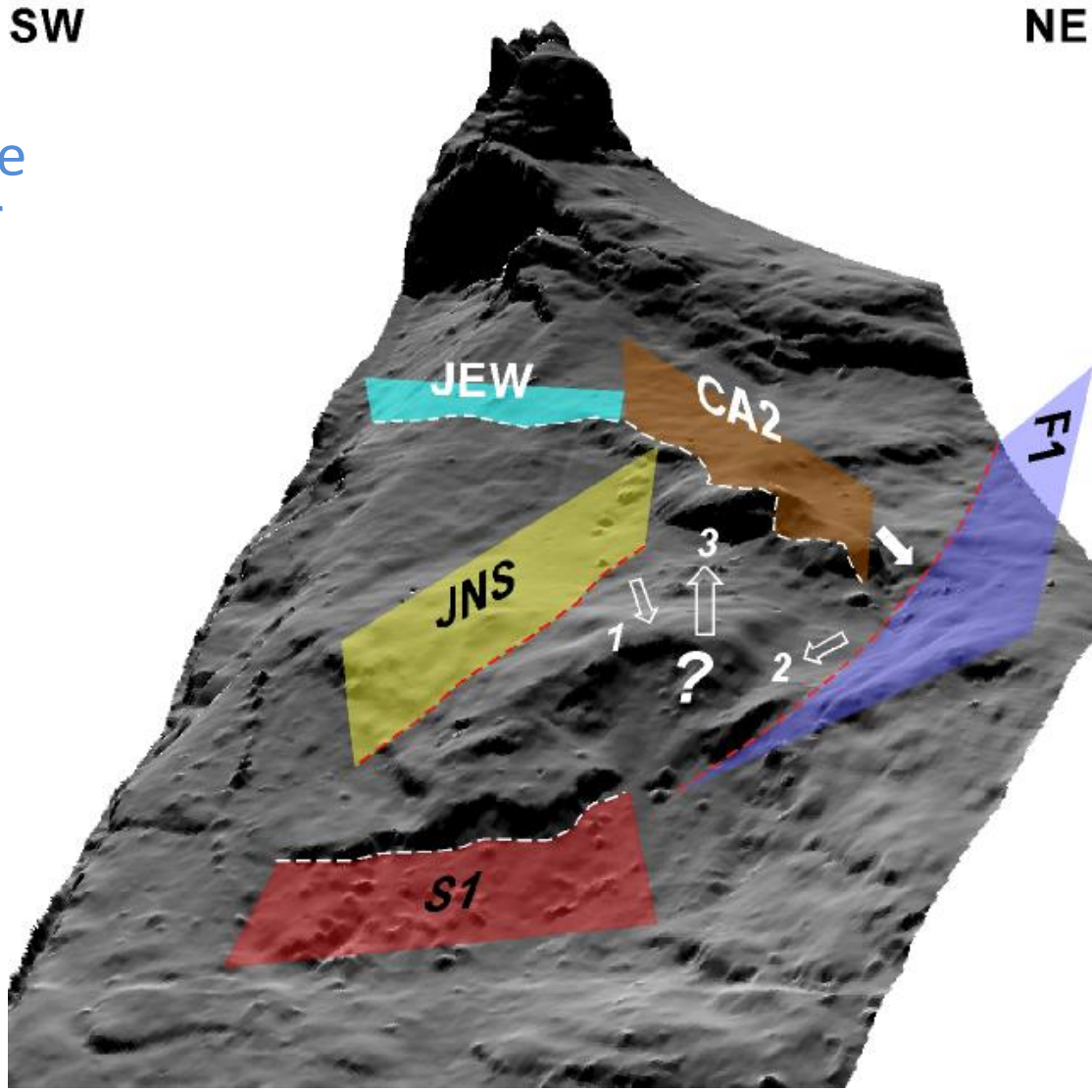


# Åknes points

- Folds
  - Creates large amplitude variations that leads to two principal directions of sliding along the main foliation (south – ESE)
  - Are making ridge in the direction 125° maybe some echelon
  - Are creating back cracks
  - Spacing between ridge are constant

# Summary

Possible interpretation explaining the potential upward movements at the toe. (1) The middle upper part of the rockslide moves down to the SSE along S1 and (2) the eastern part slides down to west along F1.



# Comparisons

# Downie landslide (Piteau et al., 1978)

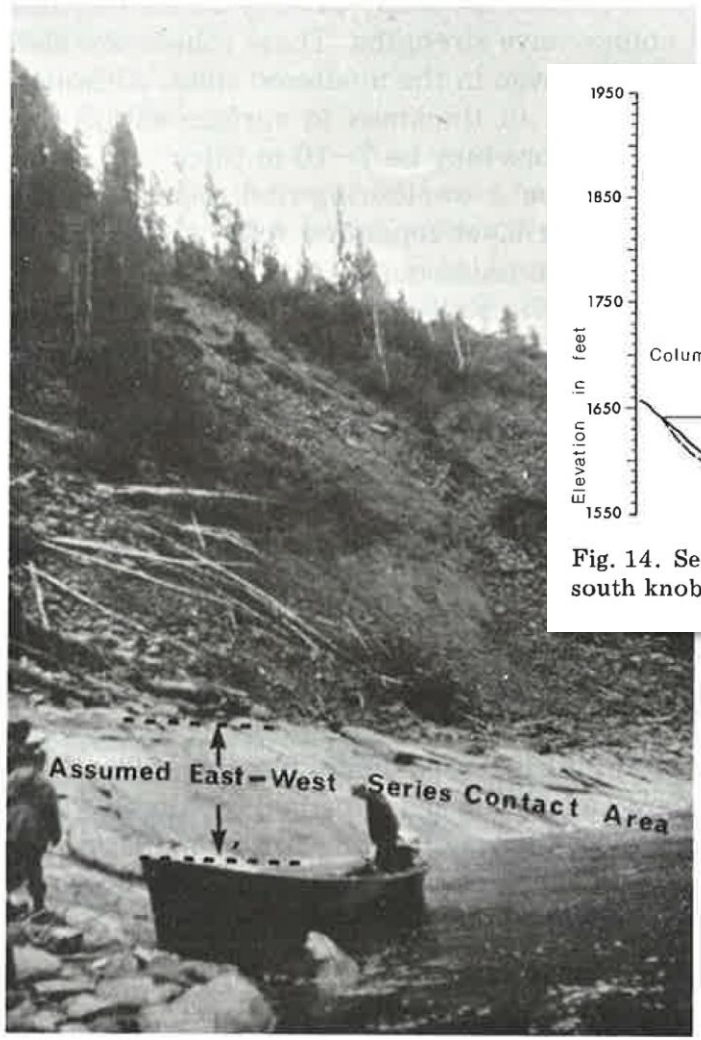



Fig. 13. Rock of the East Series near the assumed East-West Series contact at the toe of Downie slide. Looking west and upstream at the upstream edge of the toe of the south knob area. The sound rock shown is exposed only during low water.

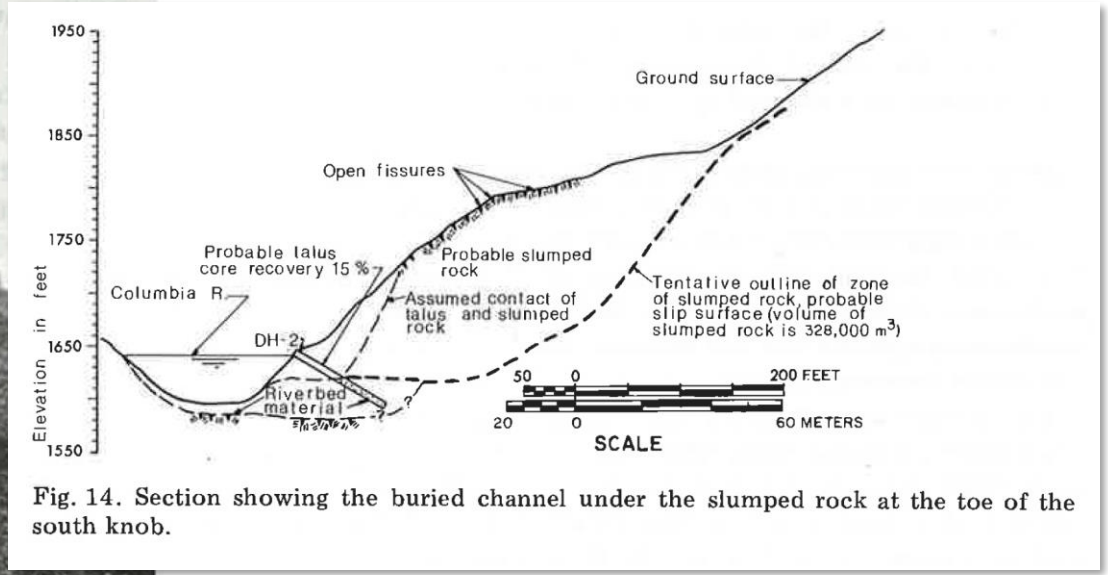



Fig. 14. Section showing the buried channel under the slumped rock at the toe of the south knob.

# Downie landslide (Piteau et al., 1978)

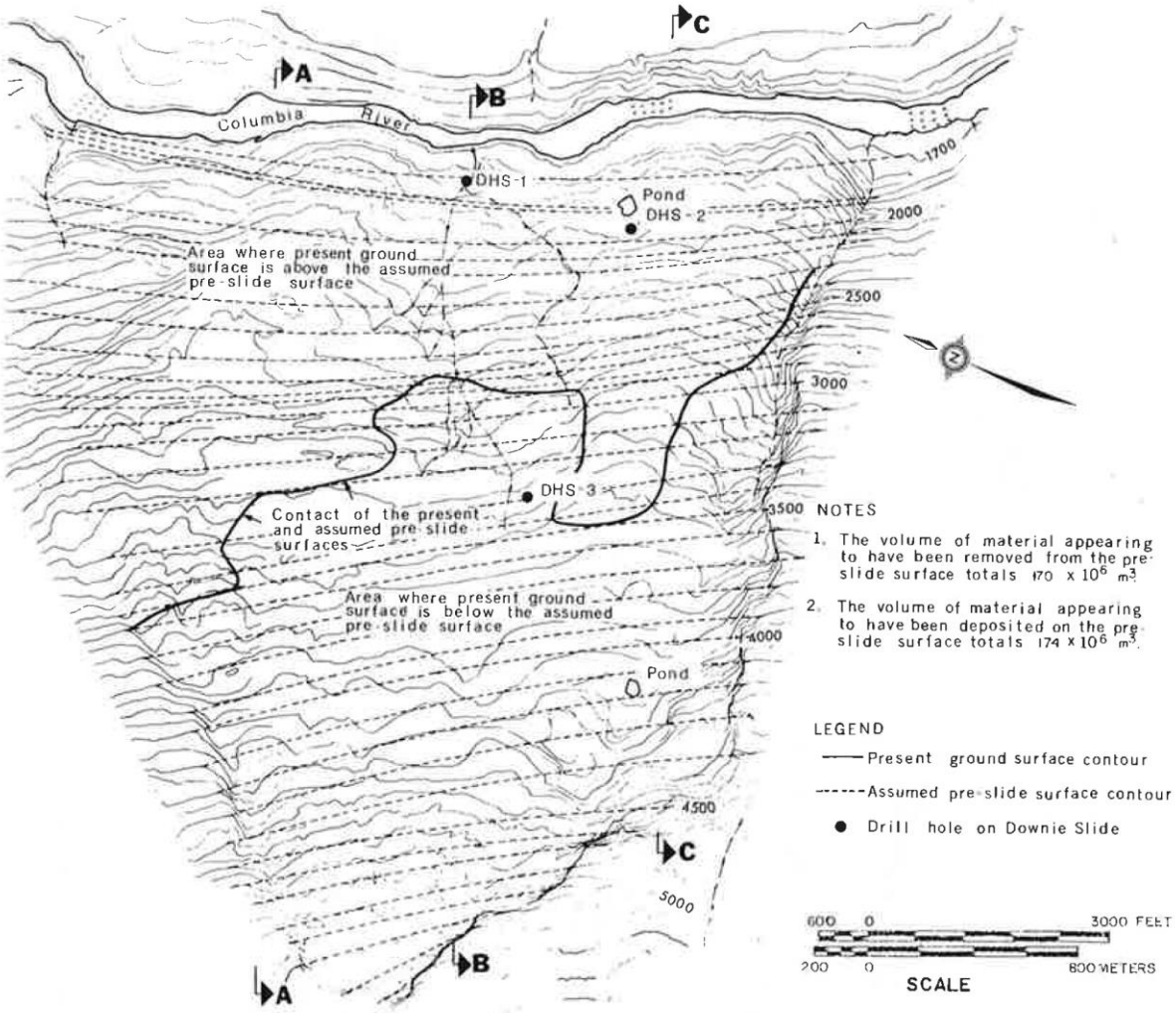



Fig. 19. Plan of the Downie slide showing the contact between the present ground surface and the estimated pre-slide ground surface. Contours are in feet.

# Dutchman's Ridge landslide (Moore and Imrie,1995)

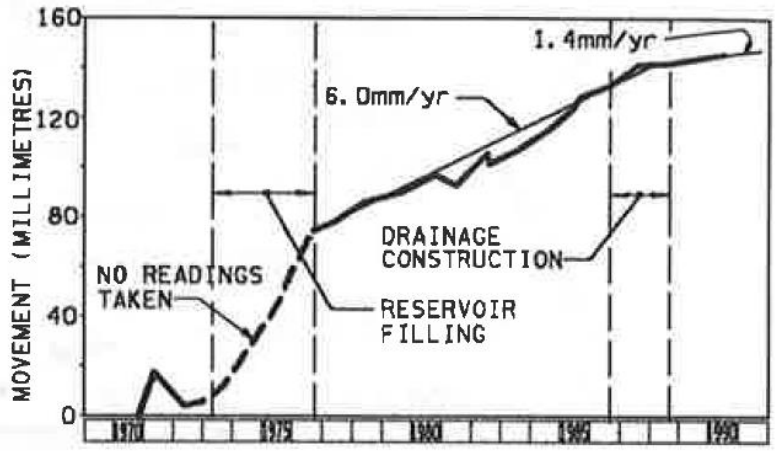



Fig. 1 - Rate of Movement on the Basal Fault

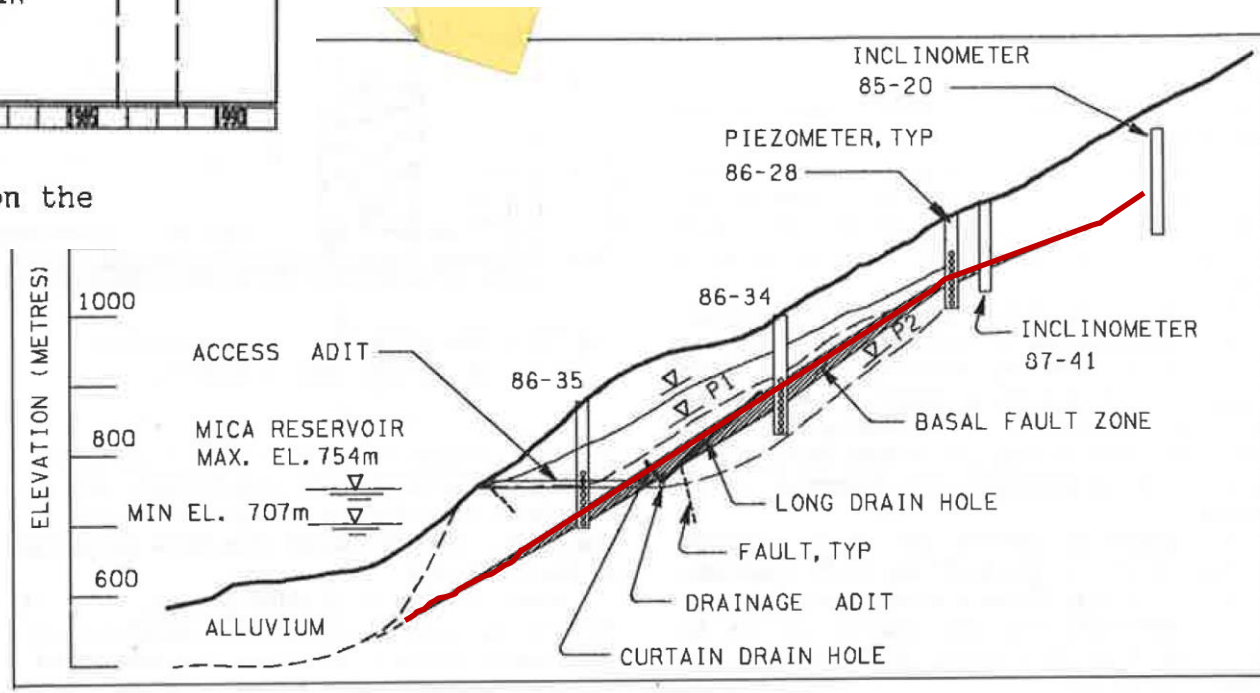
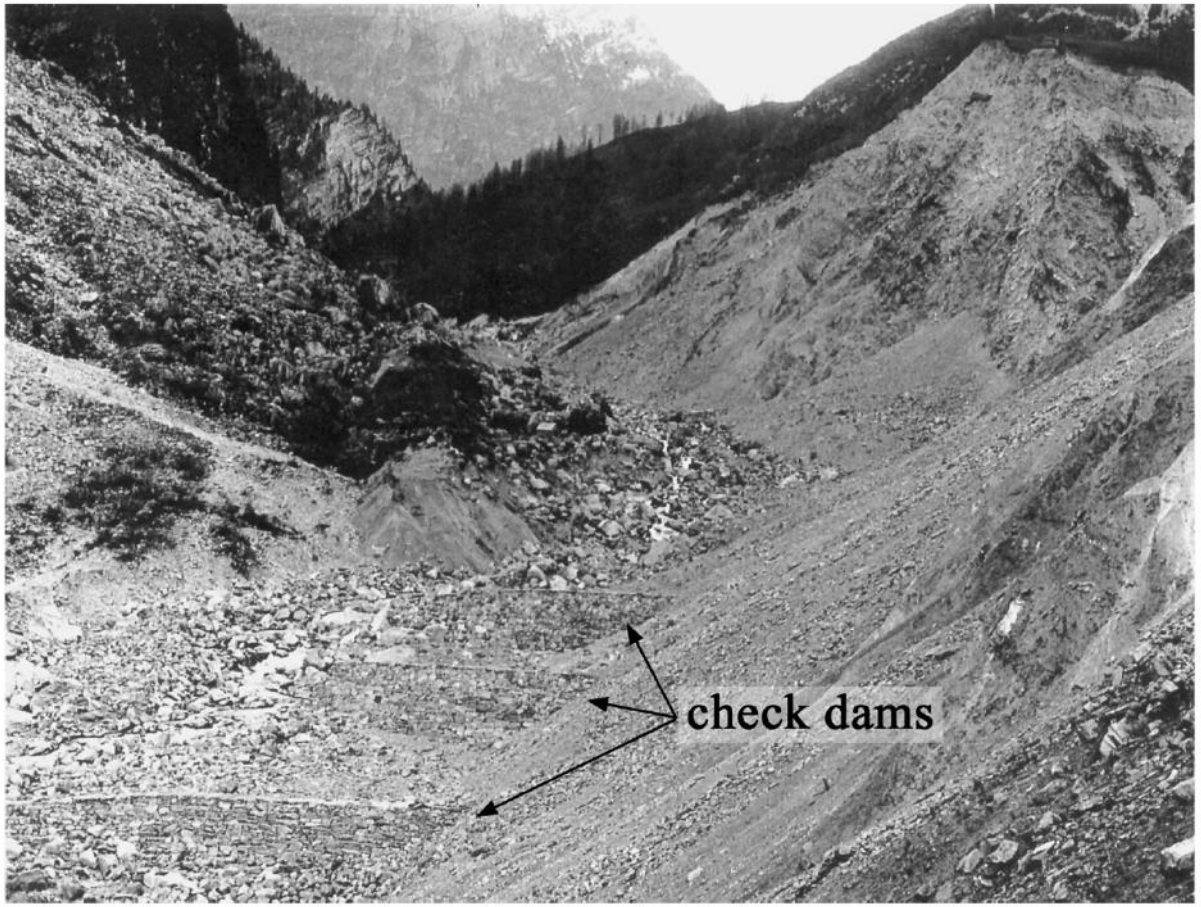



Fig. 3 - Cross section. Water levels before drainage and after drainage below (P2) and above (P1) the Basal Fault

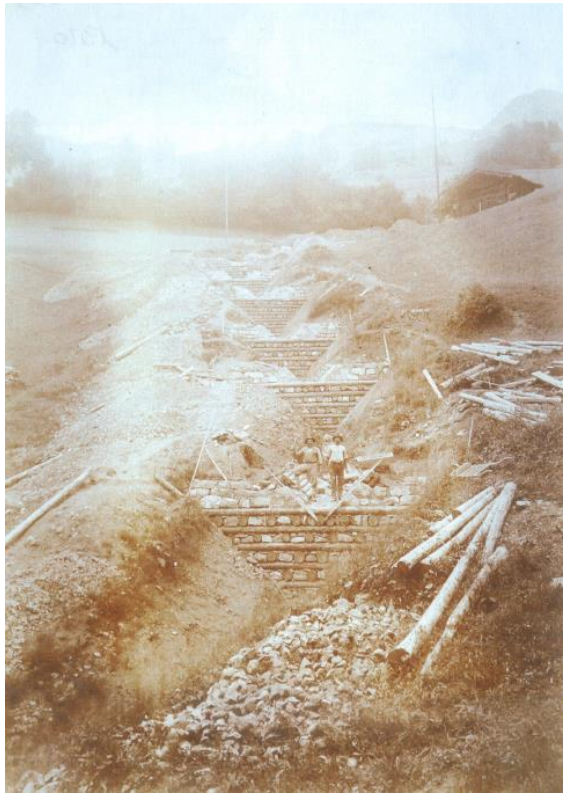
# Campo Vallemaggia (Bonzanigo et al., 2007; Eberhardt et al., 2007)

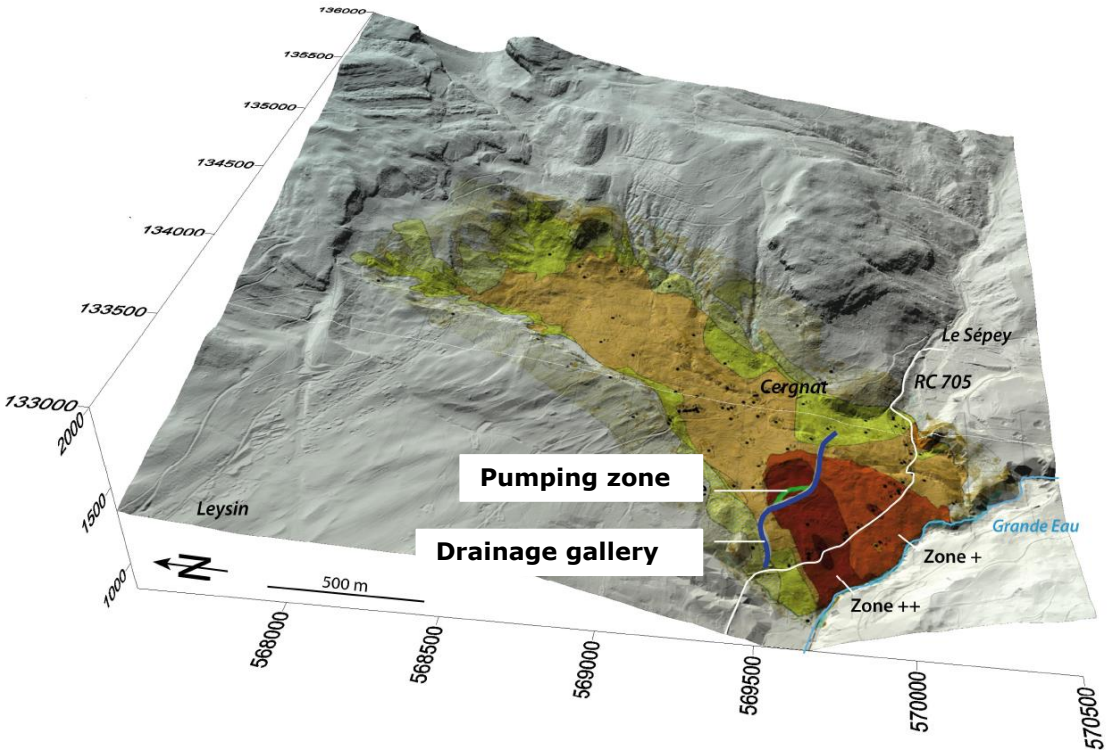
**Fig. 2.** A photo taken in 1890 of the transversal check dams built to control the erosion along the toe of the Campo Vallemaggia landslide. The check dams were subsequently washed away later the same year during flooding of the river. The toe of the landslide appears along the right half of the photo.



# Following slides
# From
# BEG (Bureau d'études géologiques)
# Tacher et al. (2005)

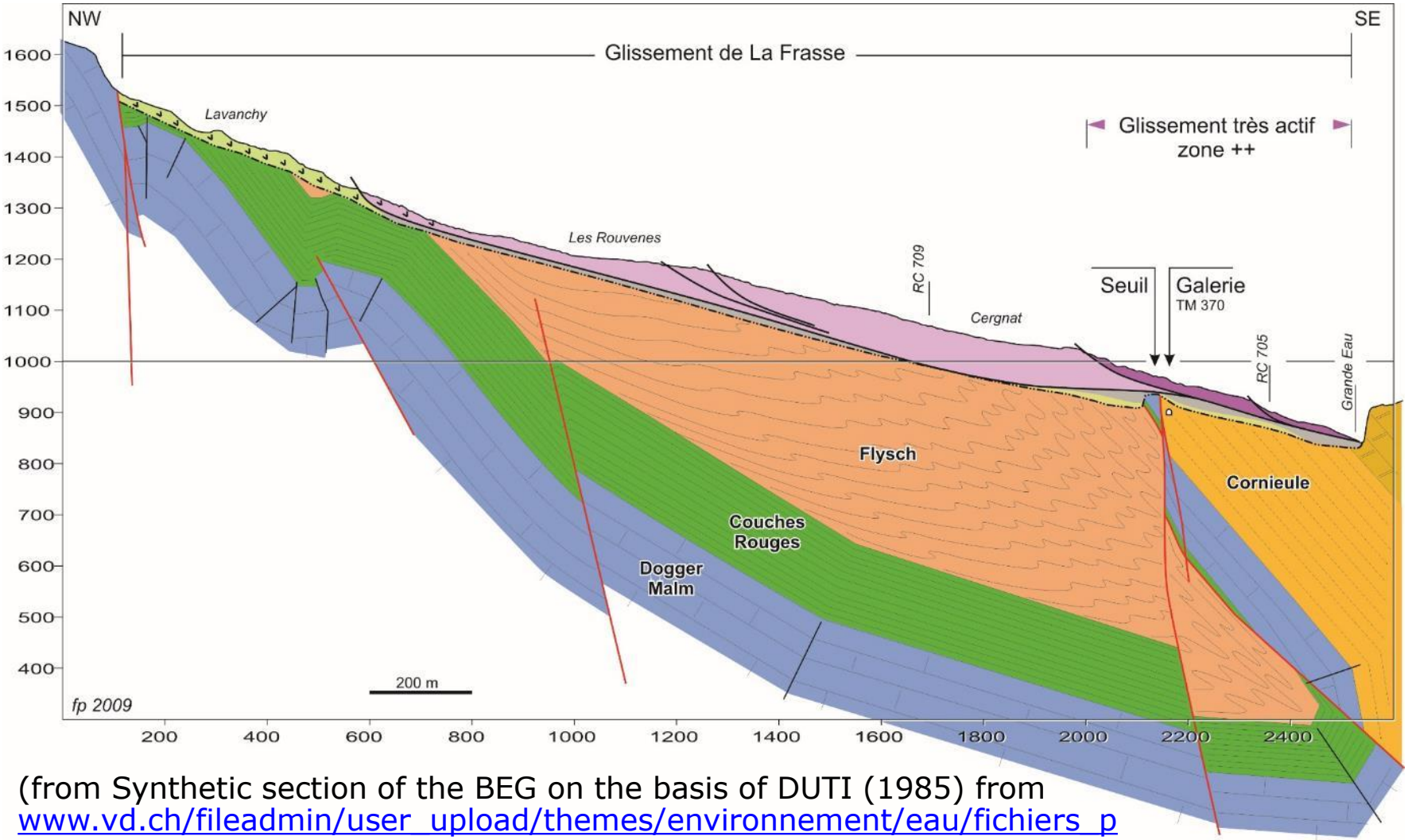
# La Frasse





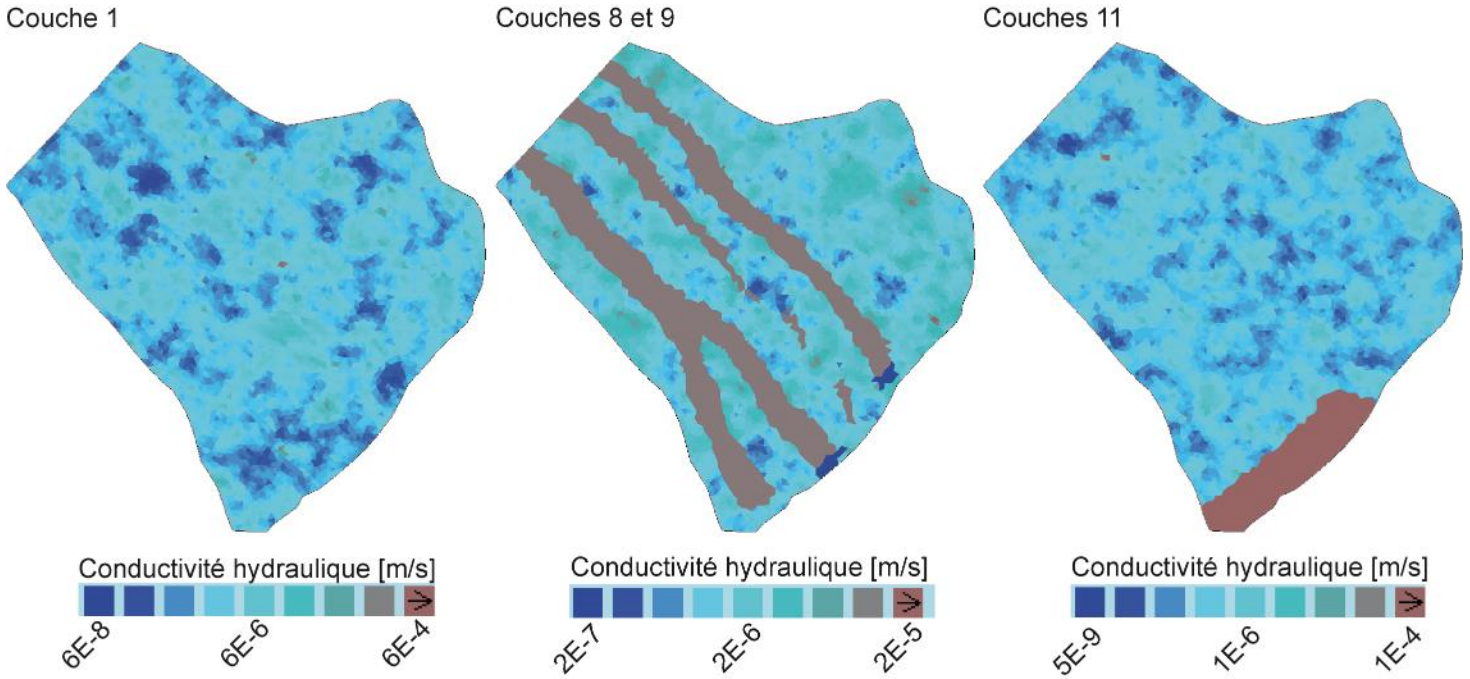

- (Left) Works to clean the slip of La Frasse, circa 1910 (picture fromthe Ormonts museum). (Right) Drawing of the drainage gallery with follow-up of the BEG company (from www.vd.ch/fileadmin/user_upload/themes/environnement/eau/fichiers_pdf/Frasse_POSTER5_AO_Geologie_page1.pdf )

# Cross-section




(from Synthetic section of the BEG on the basis of DUTI (1985) from www.vd.ch/fileadmin/user_upload/themes/environnement/eau/fichiers_pdf/Frasse_POSTER5_AO_Geolgie_page1.pdf )

# Hydromechnical models, which choice(Tacher et la., 2005)?



# Hydromechnical models, which choice(Tacher et la., 2005)?

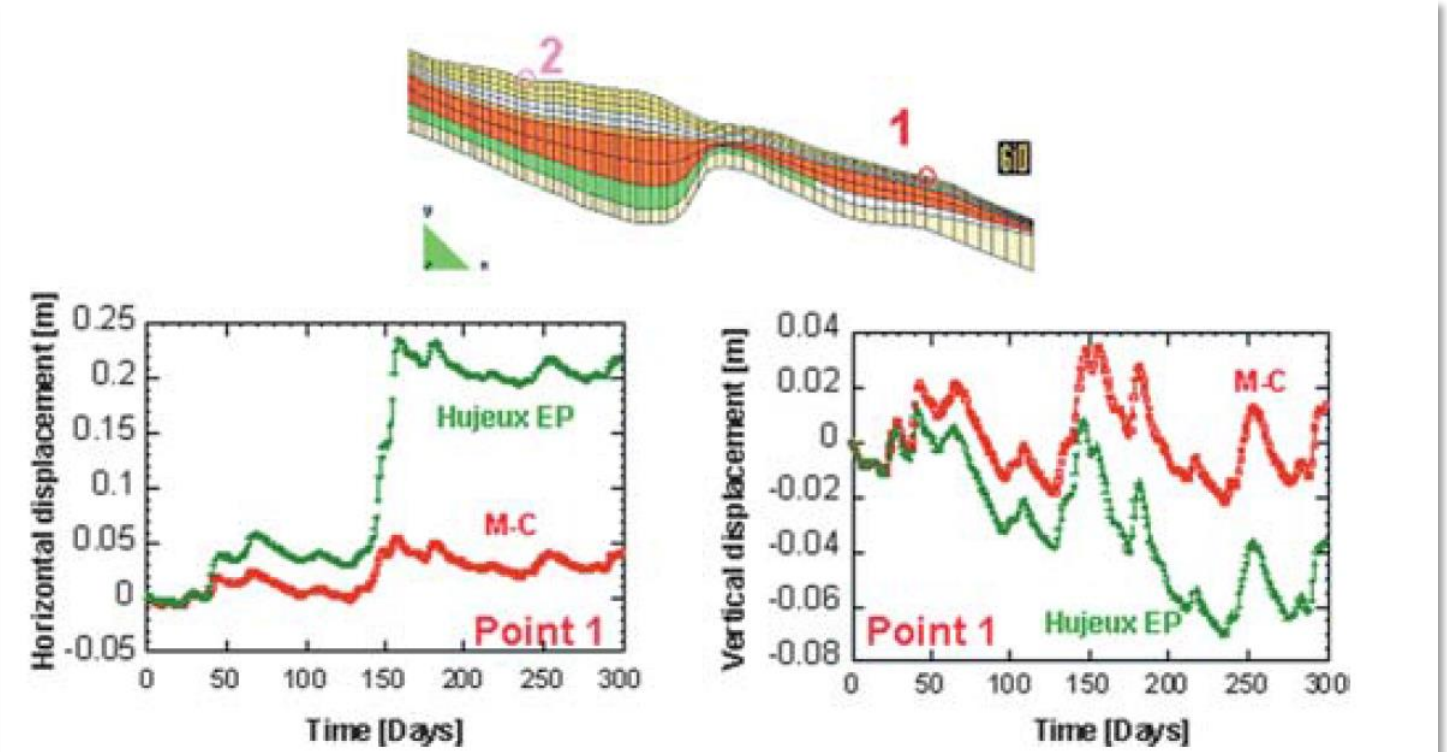



**Fig. 20** Numerical simulation of the landslide displacements using two constitutive models for the slide layer: Hujeux elasto-plastic and Mohr-Coulomb (M-C) constitutive models

# Table of comparaison?

| LANDSLIDE | Presence of curved failure surface | Erosion effect | Broken and/or weathered | Main foliation | Reactivated by reservoir filling | Total displacement | Rheology or constitutive models | Multiple failure surface |
|---|---|---|---|---|---|---|---|---|
| **Downie** | On top | Yes | Yes | Yes | Yes | Large | MC? | Yes |
| **Dutchman's Ridge** | On top | ? | Limited | Fault | Yes | Small | ? | ? |
| **Campo Vallemaggia** | Yes | Yes | Yes partly | Yes partly | No | Large | Hydro-mechanical + MC | Yes |
| **La Frasse** | Yes | Yes | Yes fully | No | No | Large | Hydro-mechanical; MC + Elasto-Plastic | Yes |
| **Åknes** | No | No | No | Yes | No | Small | MC? | Yes |

# Gerneral conclusions about Åknes

- Different
  - No toe in water
- Mainly a true rock slide
- Structures implies flow channels
- Questions?
  - Locations – efficiency of drainage
  - Blasting sensitive ?
  - Boreholes drainage before gallery…