What is the influence of regional groundwater flow on the mechanical stress field, and thus the stability of hill sides? What groundwater-related surface-phenomena may indicate reduction in effective stresses of a slope?

Student Competition on Regional Groundwater Flow

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Montpellier, 2016.09.26.

MISKOLCI EGYETEM
UNIVERSITY OF MISKOLC

N°abstract

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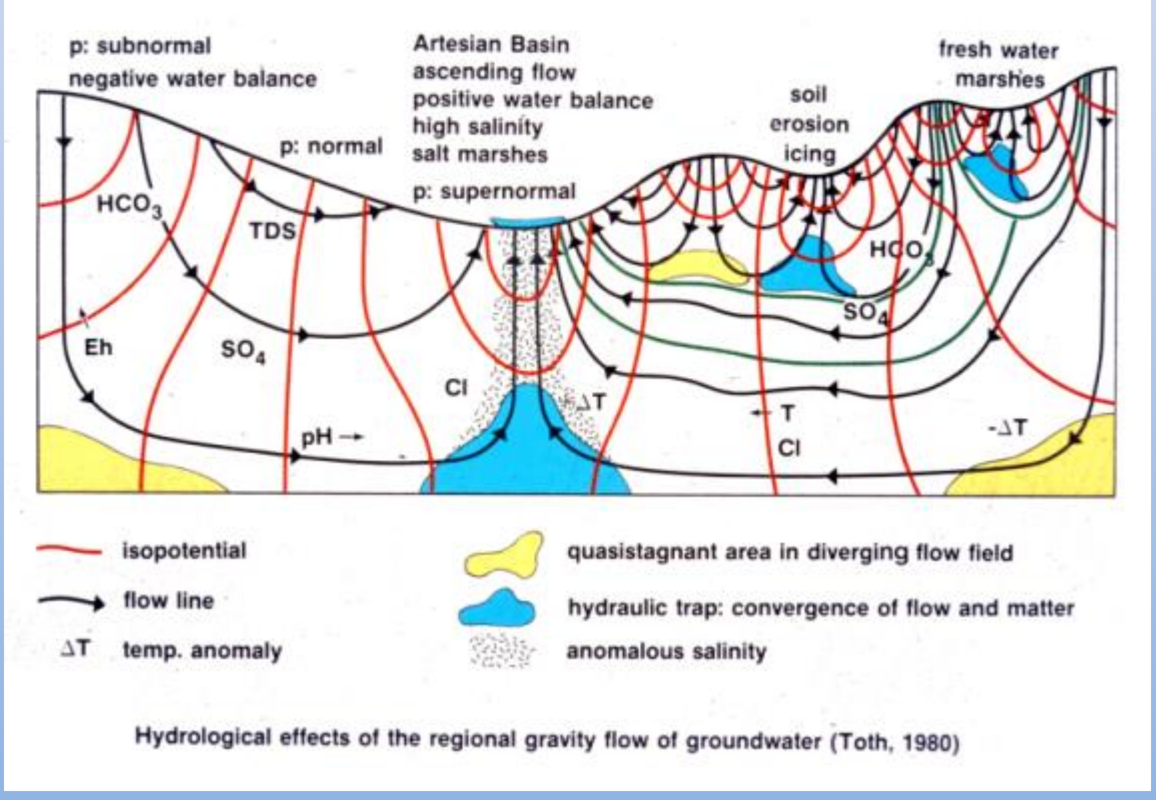
Hydraulic discharge of groundwater

(according to Tóth, 1971)

Primary attributes

- Positive gradient of the fluid potential
- Low relative topographic position
- Allochthonous water quality
- Allochthonous water temperature



Hydrological effects of the regional gravity flow of groundwater (Toth, 1980)

<u>Hydraulic discharge of groundwater</u>

(according to Tóth, 1971)

<u>Secondary attributes</u>

http://www.weatherwizkids.com/wp-content/uploads/2015/04/landslide3.jpg

- Springs
- Seepages
- Quicksands
- Soap holes
- Geysers
- Frost mounds
- Goundwater lakes, marshes
- Salt accumulations
- Landslides, slumping, soil creep and gullying

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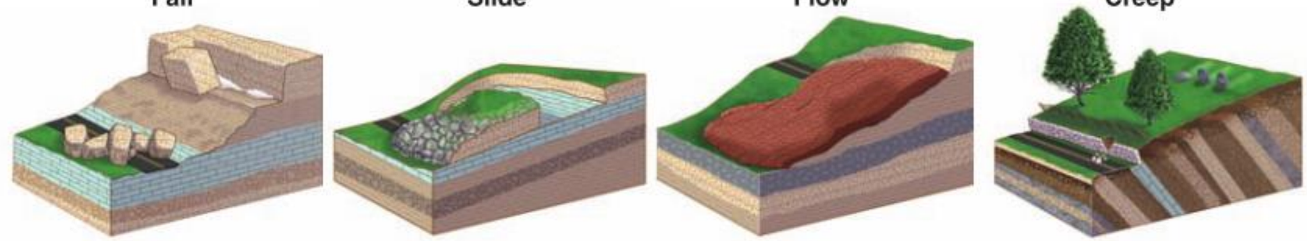
Types of mass wastings

- Slope movements of surface deposits
- Slides of solid rocks
- Specific types of slope movements



Type of material	Fall	Slide	Flow	Creep
Rocks (large blocks of solid rock)	Rockfall	Rockslide		
Debris (mixture of rock, earth, plants, and mud)	Debris fall	Debris slide	Debris flow	Creep
Earth (loose sediment, weathered rock fragments)	Earth fall	Earth slide	Earth flow	Creep
Mud (mixture of water and finer-sized sediment)			Mudflow	

Type of motion

Reichard, 2011

Zaruba and Mencl, 1969

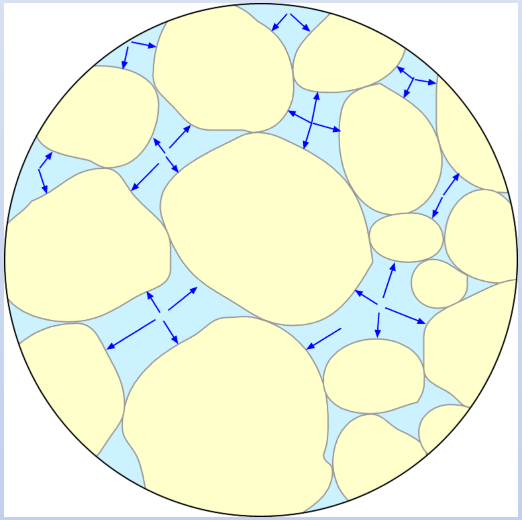
The main reasons of the landslides

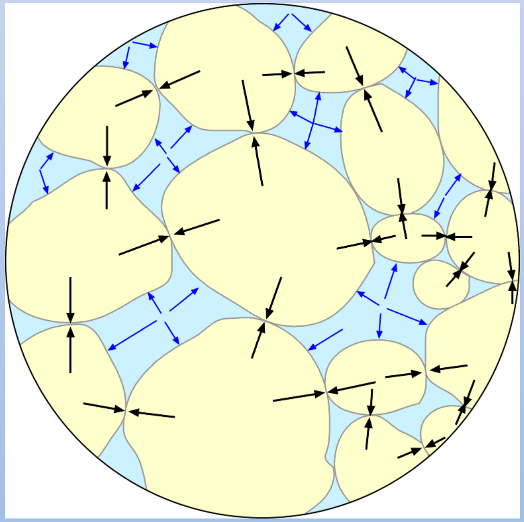
1. Increased pore pressure (reduction of the intergranular pressure)

2. Lubricating effect of water facilitating the displacement of rock particles relative to each other

Mechanical background I.

- Pore pressure





- Effective normal stress

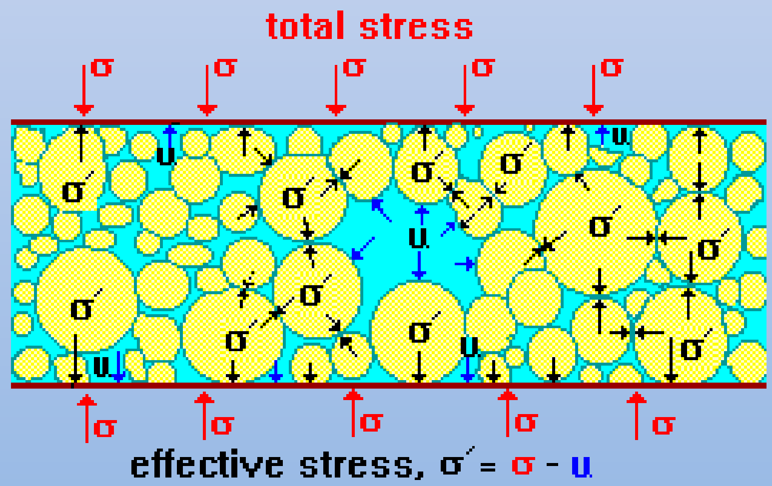
Effective stress = total stress – pore pressure

http://myweb.cwpost.liu.edu/vdivener/notes/mass_wasting_601.htm

Mechanical background II.

- **Terzaghi's principle:**

All measurable effects of a change of stress, such as compression, distortion and a change of shearing resistance are due exclusively to changes in effective stress.



http://environment.uwe.ac.uk/geocal/SoilMech/stresses/stresses.htm

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The influence of topographically controlled groundwater flow on the failure potential

- *Based on the study of Iverson and Reid (1992):*

comprehensive mathematical model to calculate the changes in the effective stress distribution and failure potential induced by gravity-driven seepage forces in case of dry and saturated hillslopes

$$\frac{\partial}{\partial x}\left(K\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial h}{\partial y}\right)=0$$

- In the study:
  - Various slope profiles, material properties, hydraulic heterogeneities
  - Do not assess failure surface locations or factor of safety
  - 2D periodic, infinitesimal topography /the bottom boundary is located at a large depth (10x slope height)/
  - Steady-state groundwater flow
  - Porous medium that is hydraulically isotropic

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- Coulomb failure rule

  [Lamb and Whitman 1979]:

$$\frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3} = \left|\frac{\tau'_{max}}{-\sigma'_m}\right| = \sin\varphi$$

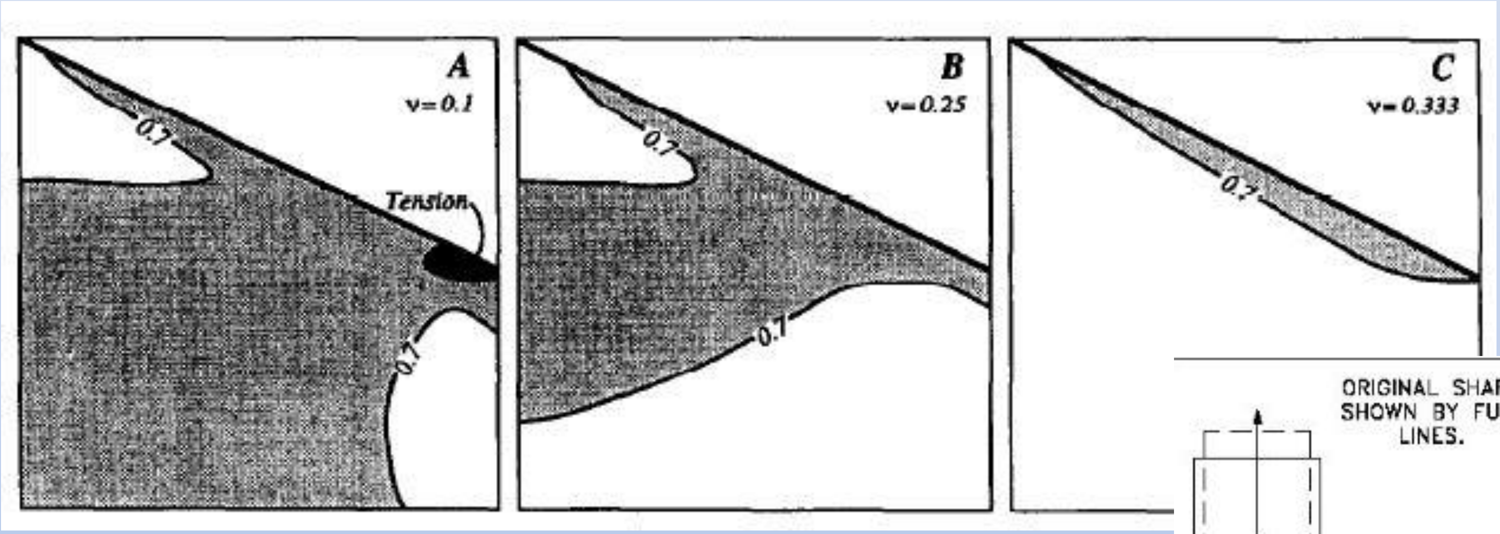
maximum shear stress

angle of the internal friction

mean normal stress

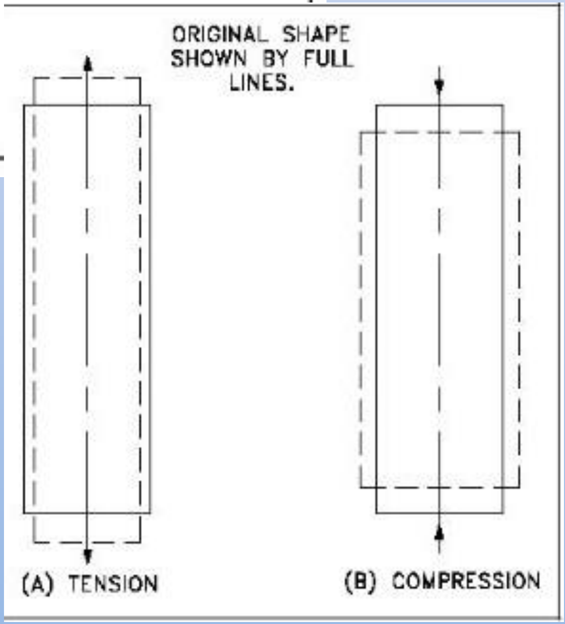
- Coulomb failure potential: $\left|\frac{\tau'_{max}}{-\sigma'_m}\right| = \varphi$

Material properties



Failure potential distribution > 0.7 with different ratios in saturated hillslope

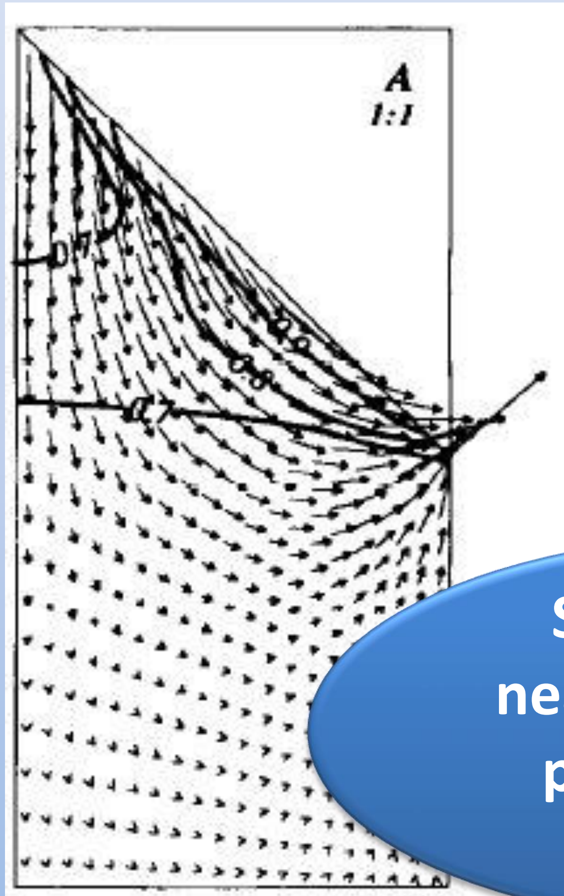
$$\nu = -\frac{\varepsilon_{lateral}}{\varepsilon_{axial}}$$

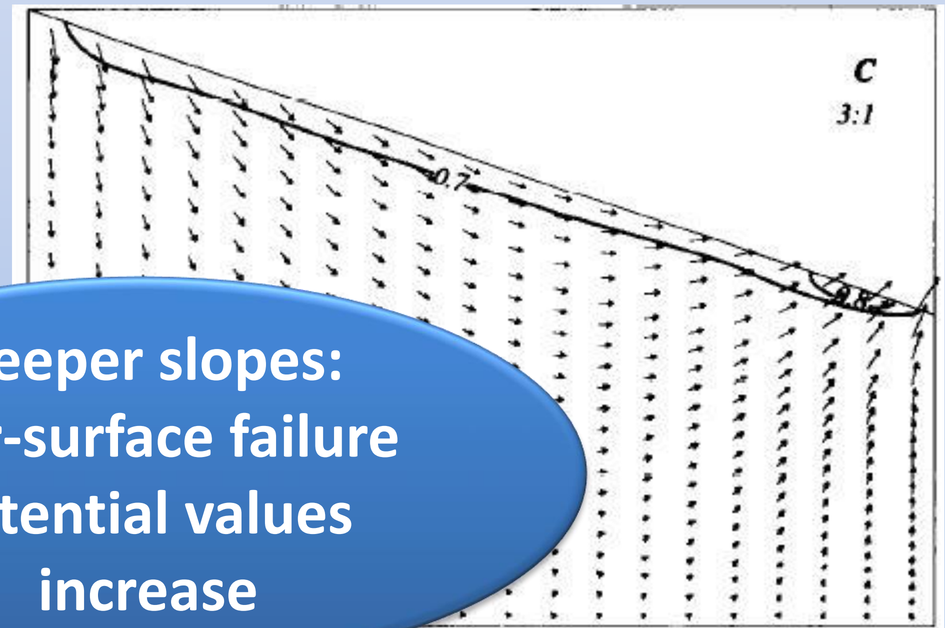


https://www.engineersedge.com/material_science/poissons_ratio_definition_equation_13159.htm

Slope inclination

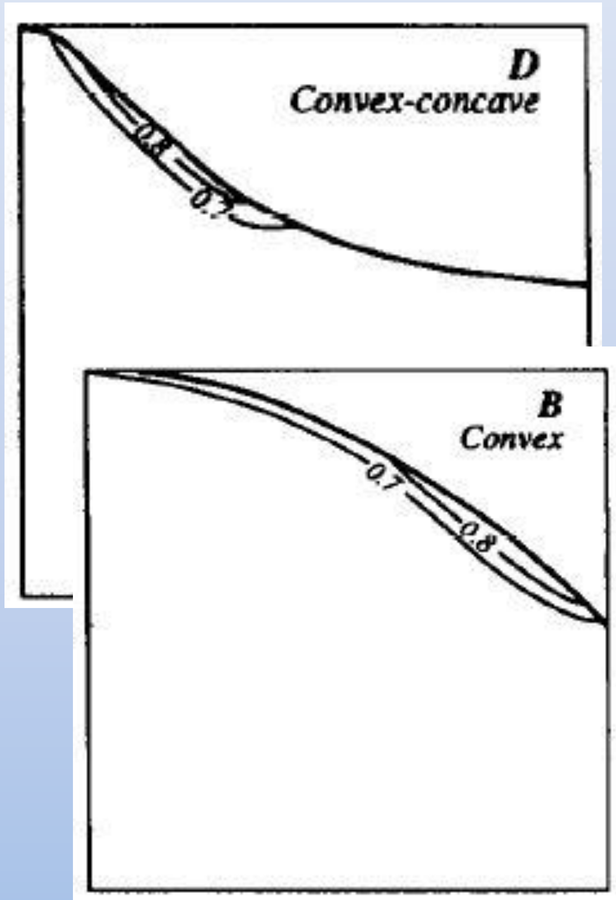
Normalized seepage force vectors and contours of failure potential > 0.7 in saturated hillslopes

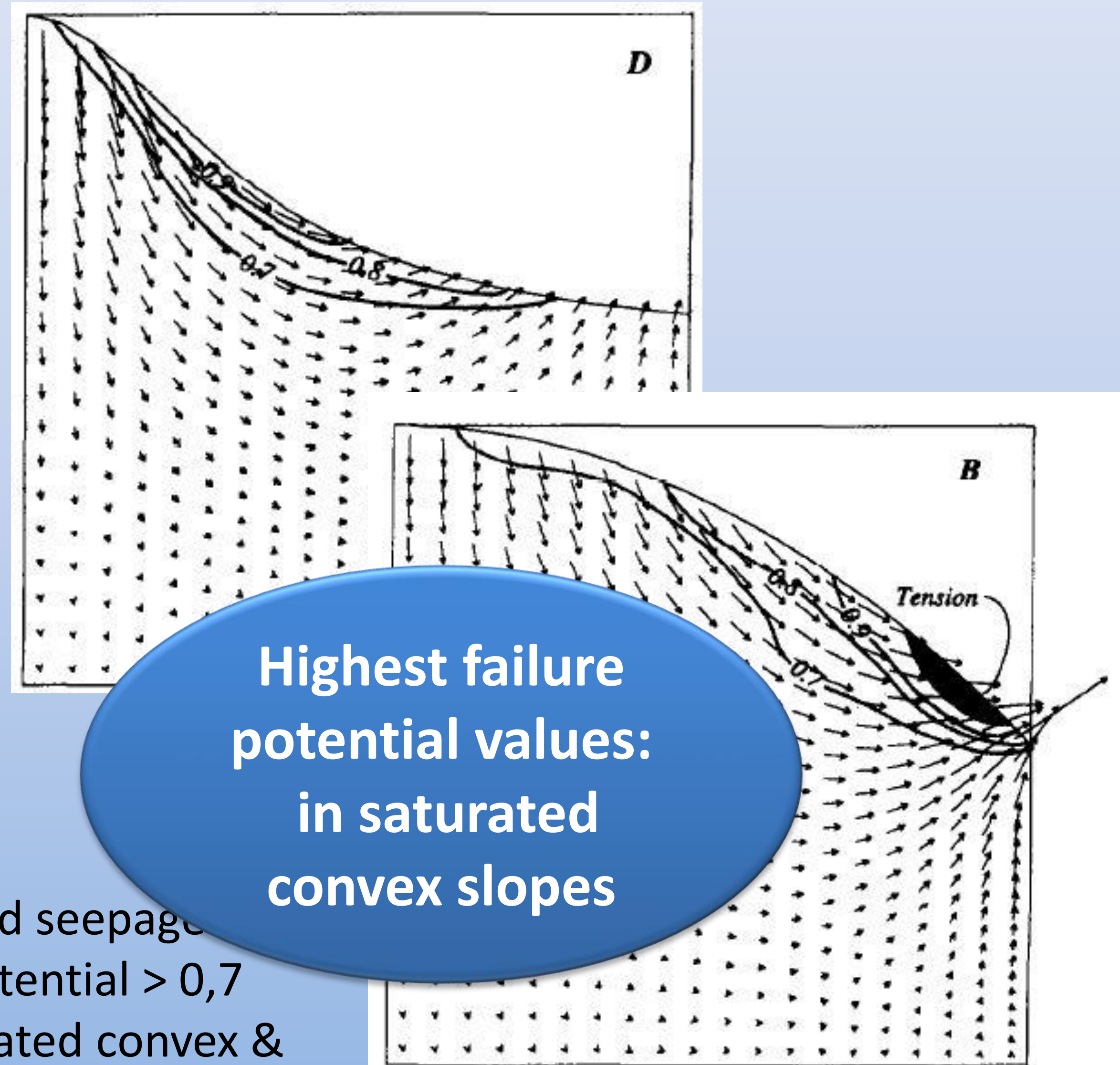




Steeper slopes: near-surface failure potential values increase

Slope morphology





Highest failure potential values: in saturated convex slopes

Contours and normalized seepage vectors of failure potential > 0,7 in case of dry & saturated convex & convex-concave hillslopes

J. A. Coe, 2008:
https://www.researchgate.net/figure/228662529_fig5_Fig-5-Rock-fall-dry-ravel-and-channel-sediments-in-5th-order-main-channel-near-SM3

Landslide in Salvador, Brazil due to heavy rains

http://riotimesonline.com/brazil-news/tag/landslides/#

In Hungary:

Smoother Pannonian sediment layers settled between loess layers,
and seepage from Danube increases failure potential

http://index.hu/tudomany/kornyezet/2011/01/21/miert_indul_meg_a_loszfal/
http://index.hu/belfold/2010/06/16/megint_megmozdult_a_loszfal_dunaszekcson/

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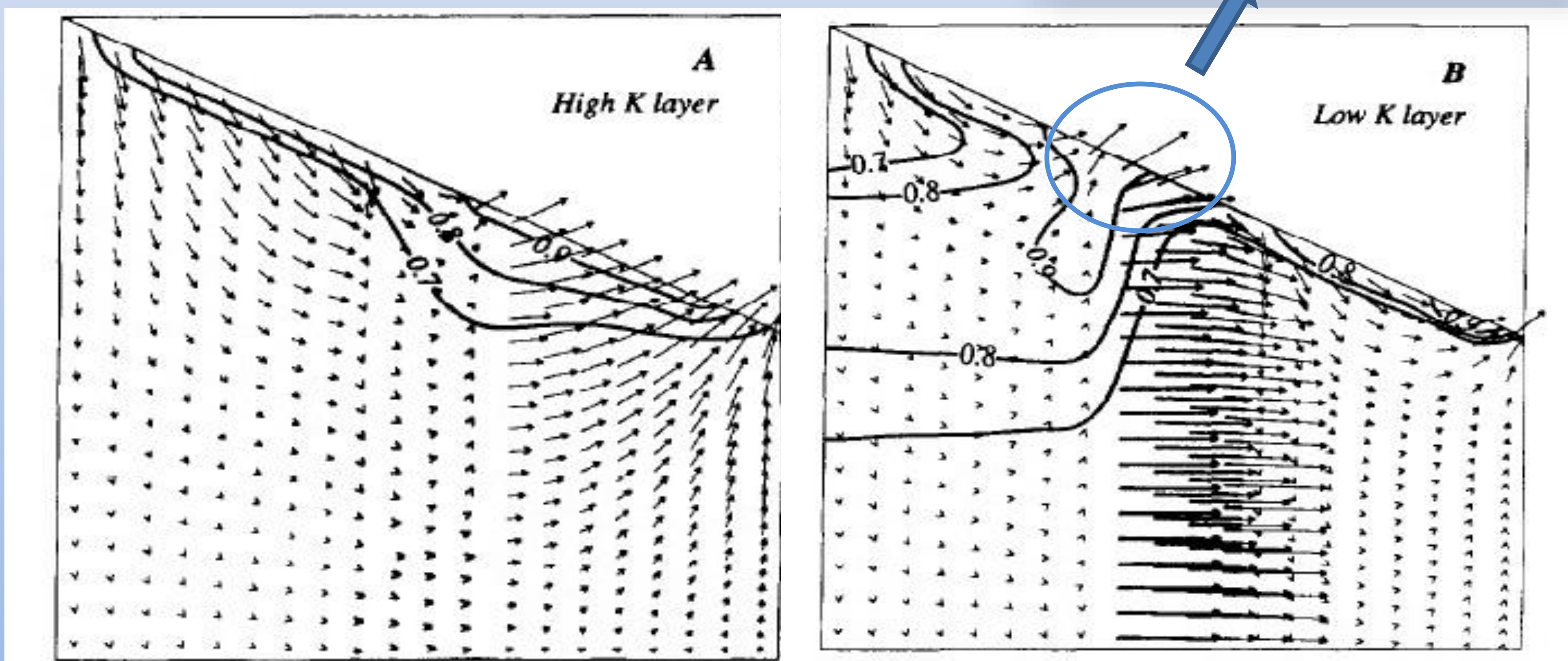
Slope heterogeneity



Normalized seepage vectors in vertical layer, 4 order magnitude lower/higher K

Summary of the Study

- Gravity-driven groundwater flow increases the failure potential in near-surface discharge areas **where seepage forces are directed outward** from the slope

- This may occur
  - *near the toe of the slope*
  - *near a contrasting conductivity interface*

- Influencing factors on the failure potential:

  - **Material properties** /porosity, Poisson's ratio/
  - **Slope morphology** and **hydraulic heterogeneities** have a much larger effect:

Modification of the seepage force field due to gravity-driven groundwater flow

→

Change in the effective stress field

↓

Affect the magnitude and extension of the Coulomb failure potential

Case Study

Campo Vallemaggia
(Alps, Switzerland)

http://www.vallemaggiasecrets.ch/images/slideshow/24_frana.jpg

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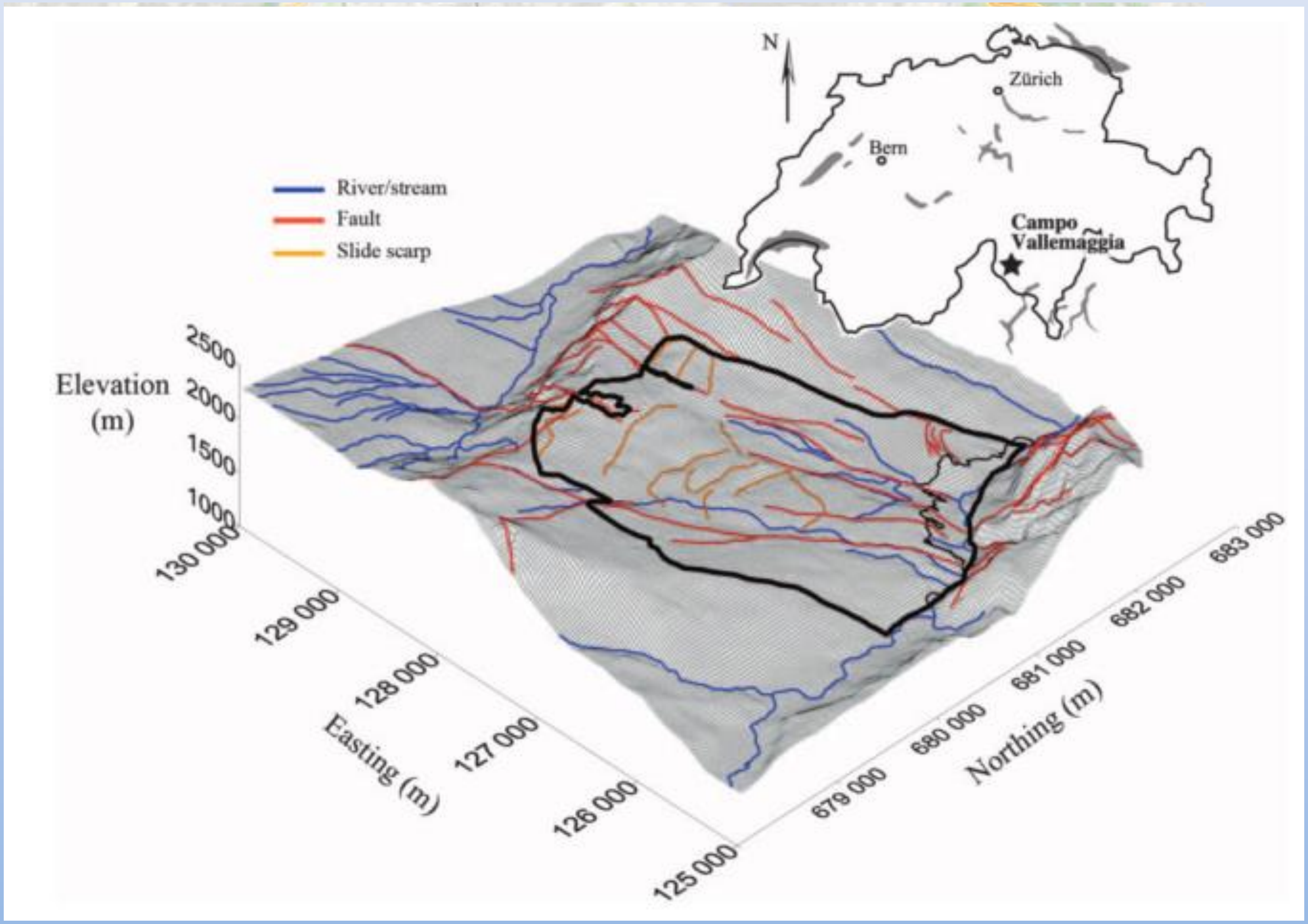
Campo Vallemaggia



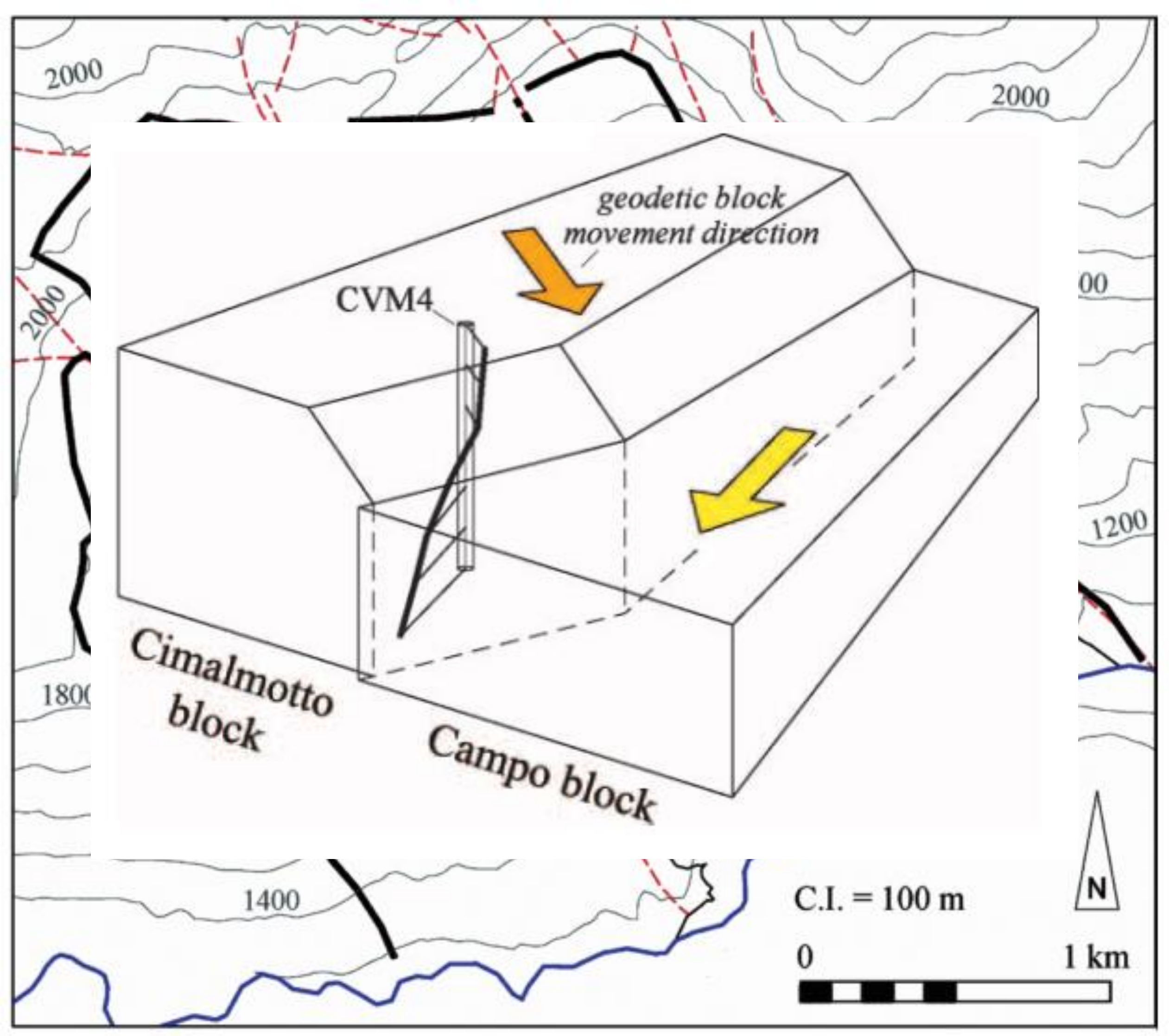
Bonzanigo et al., 2007

Investigations between 1983-1991

- Landslide geology, structure and geomorphology
- Geophysical surveys
- Borehole drilling
- Geodetic measurements
- Geotechnical explorations

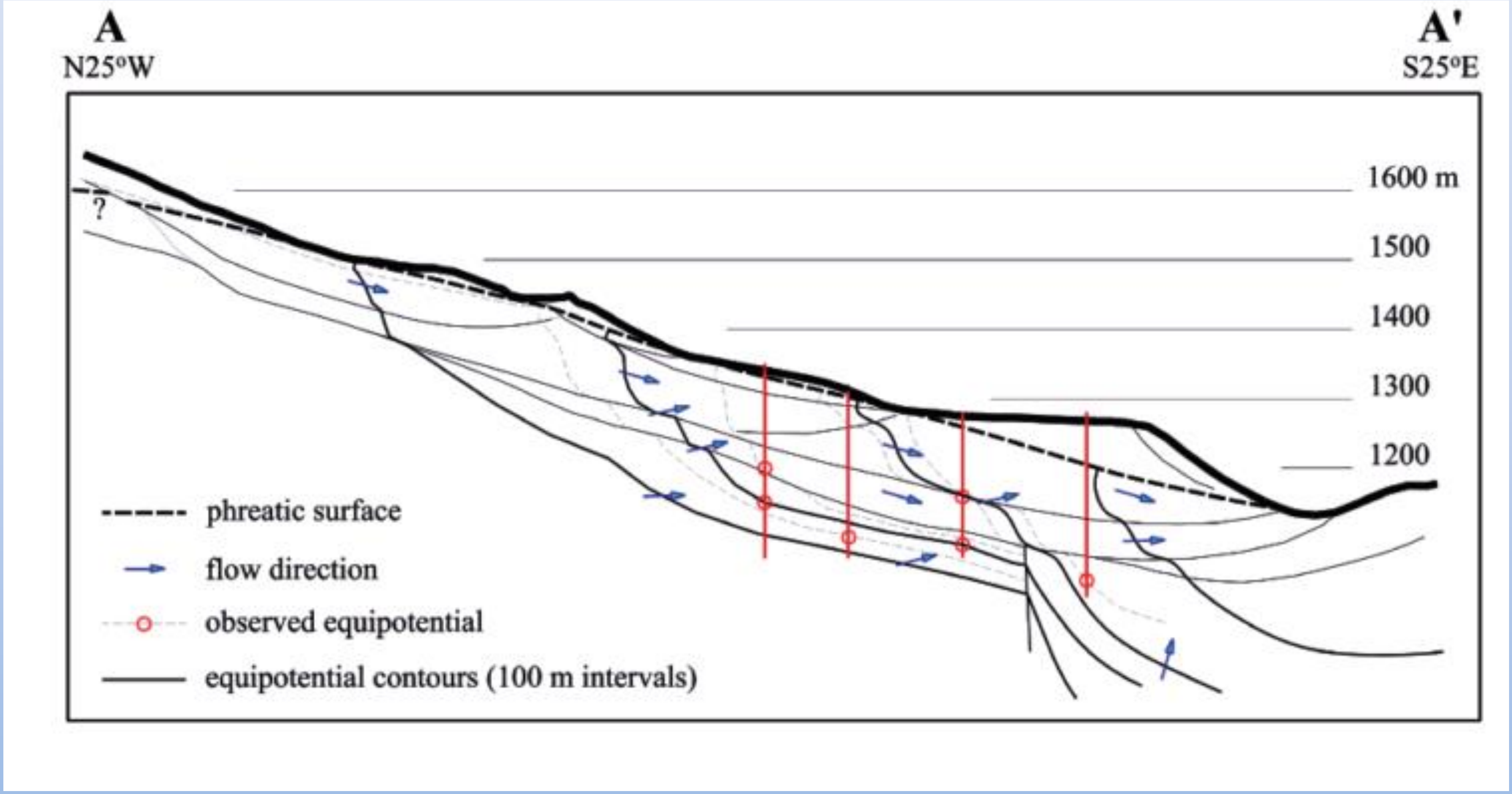
Bonzanigo et al., 2007

3-D block model



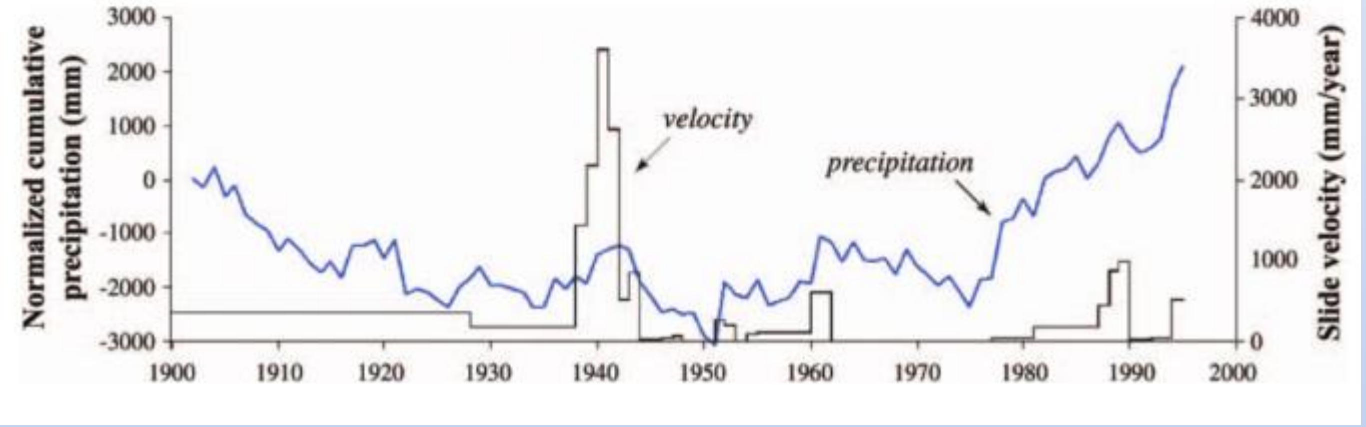
Bonzanigo et al., 2007

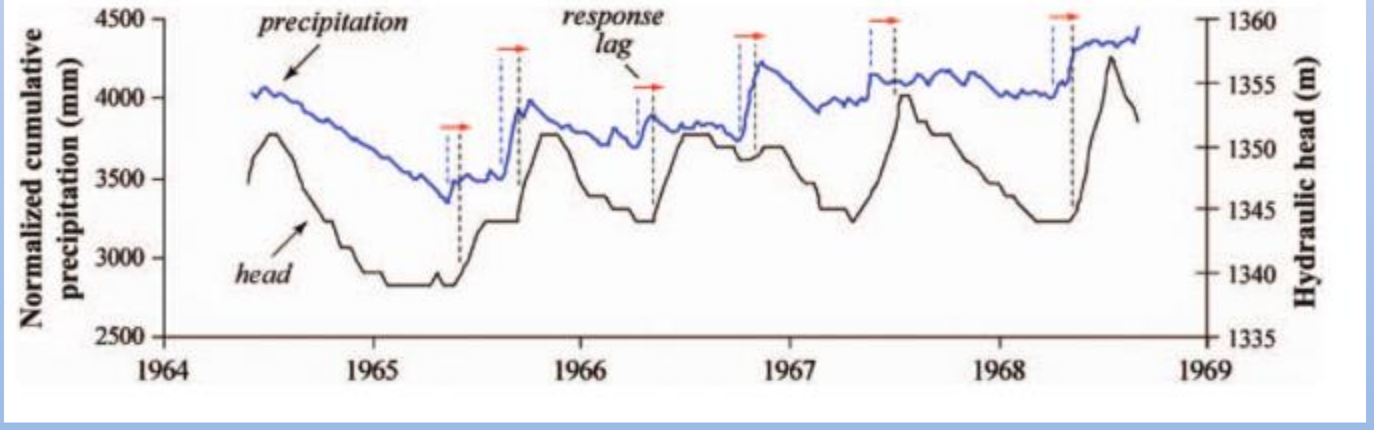
2-D hydrodynamic flow model



Eberhardt et al., 2007

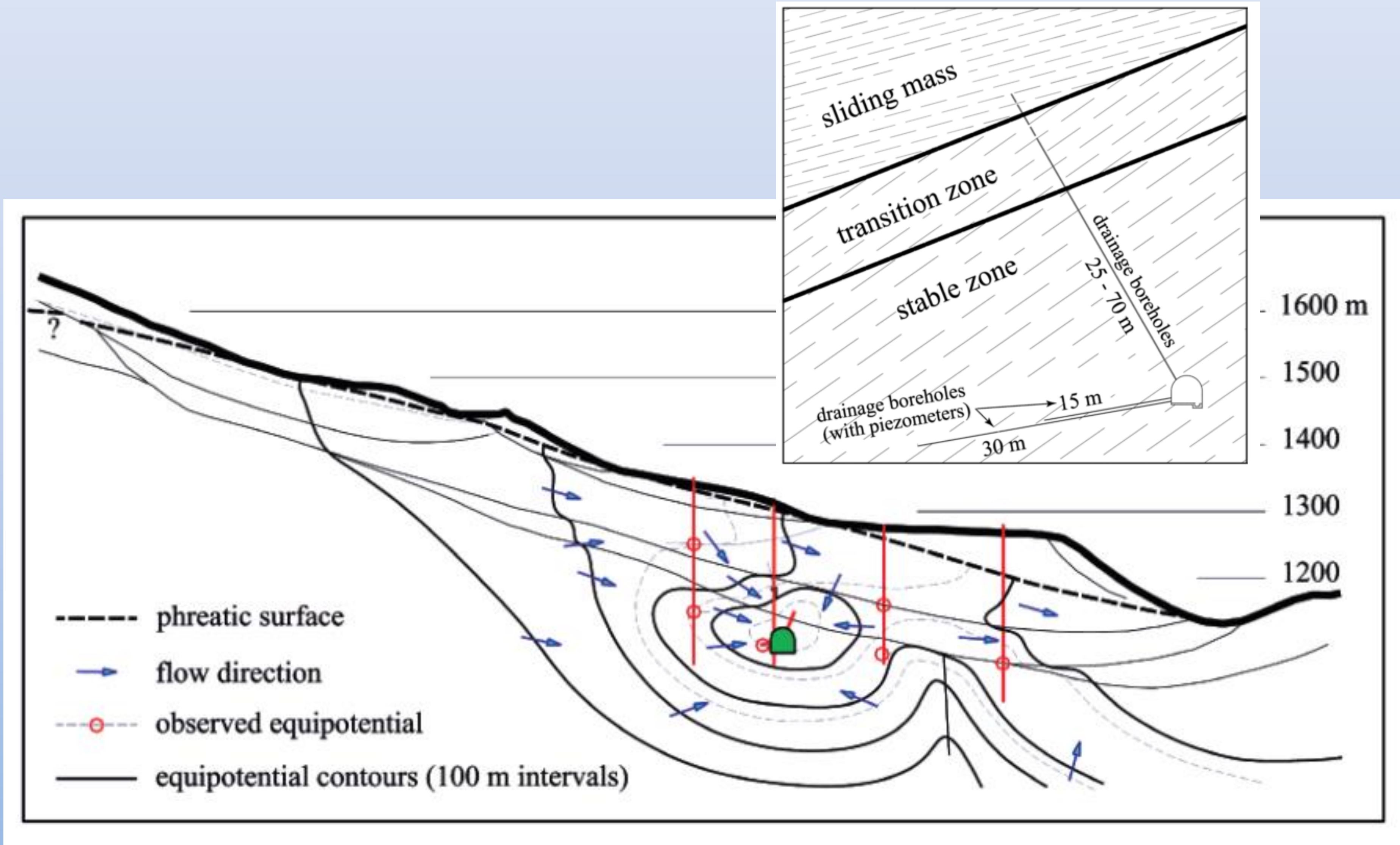
Precipitation and landslide velocity





Bonzanigo et al., 2007

Stabilization of the deep-seated landslide



Eberhardt et al., 2007

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