Addis Ababa University, Ethiopia
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METHODS OF LANDSLIDE INVESTIGATION

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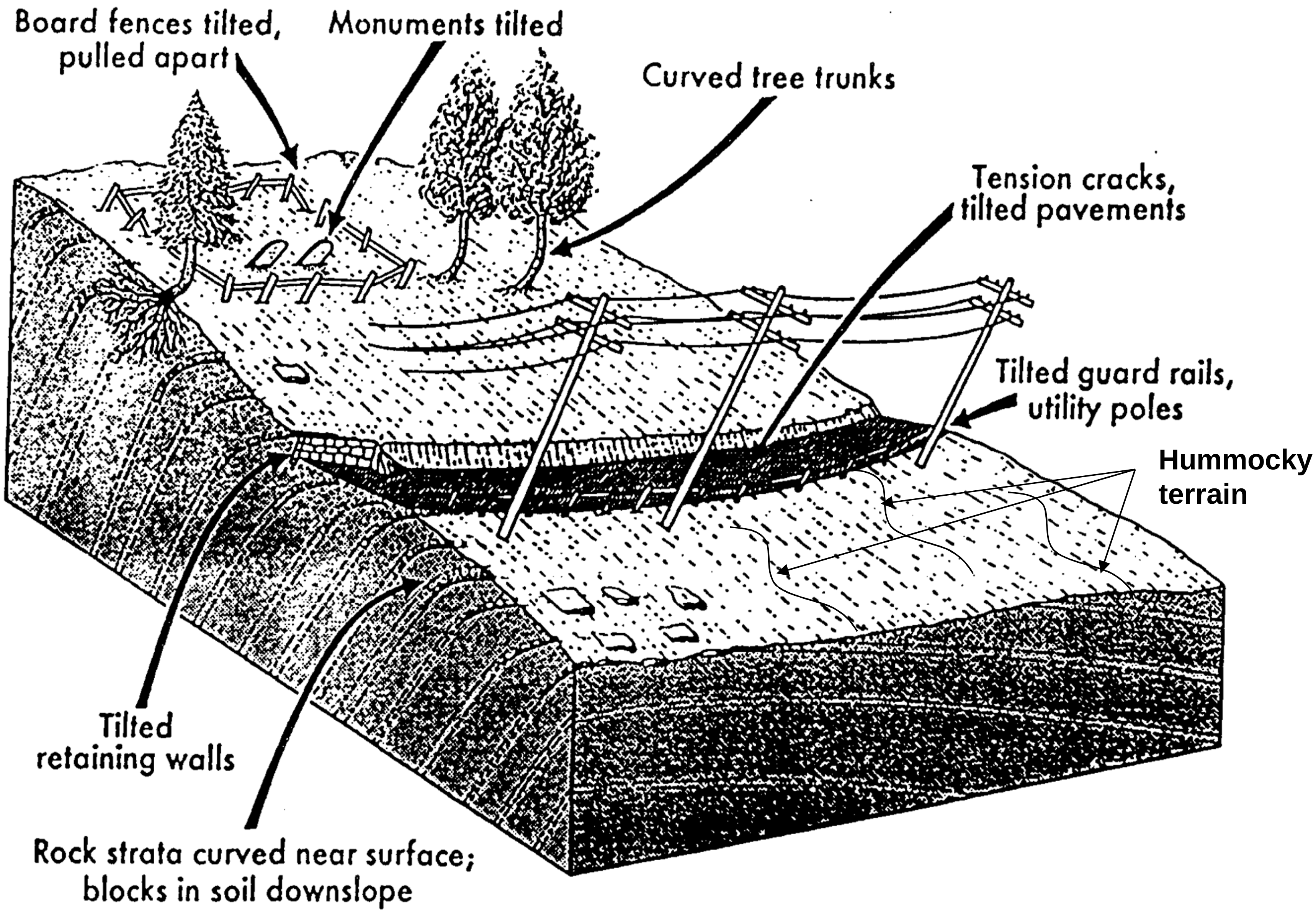
Methods of landslide investigation

1) **Preliminary work**
   - Study of archival materials
   - Terrain reconnaissance
   - Talk to local people
   - Conceptual engineering geological model
2) **Landslide investigation**
   - Engineering geological mapping
   - Longitudinal and cross sections
   - Boreholes, trial pits, rock and soil sampling, field tests, geophysics
   - Laboratory tests
3) **Depth of rupture surface**
4) **Monitoring**
   - Monitoring of deformation
   - Monitoring of hydrogeogical features, GWL and pore pressure fluctuation, spring yield
   - Measurement of stress
   - Indirect methods - geophysics
5) **Methods of prognosis**
   - Spatial prognosis
   - Prognosis of mechanisms and dimension of failure
   - Time prognosis

Methods of landslide investigation



Methods of landslide investigation

Hummocky terrain of landslide with recent movements (locality Germany, *Gradenbach, photo J. Rybář)*

Methods of landslide investigation

Methods of landslide investigation

Hummocky terrain

Carpathian Flysch

Photo J. Rybář, Hervenice, NE from Zázriva

Methods of landslide investigation

Hummocky terrain

Sakhalin, Russia

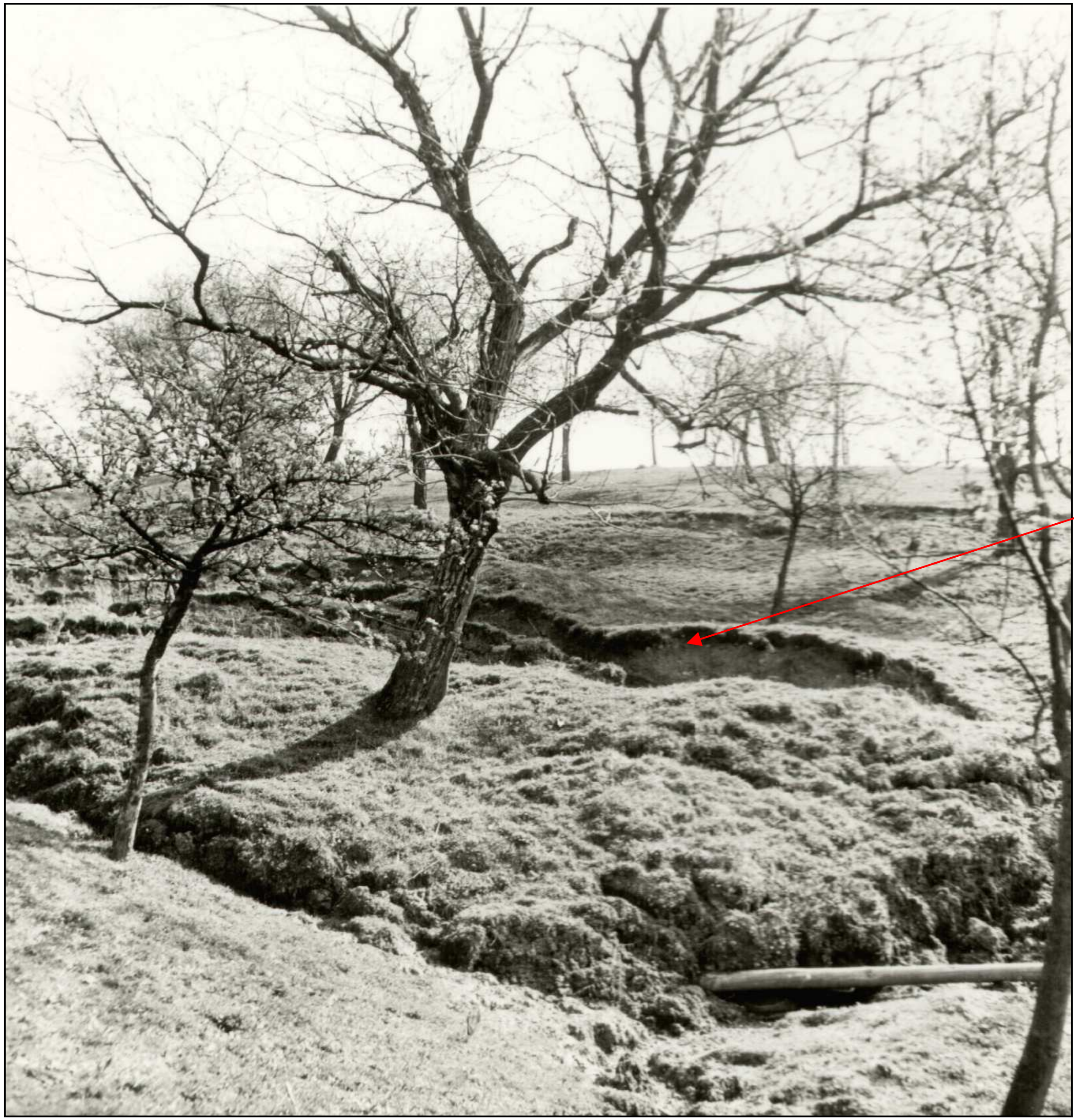
Methods of landslide investigation

Hummocky terrain

Methods of landslide investigation

Hummocky terrain

Methods of landslide investigation



Active landslide morphology
Photo: J. Rybář

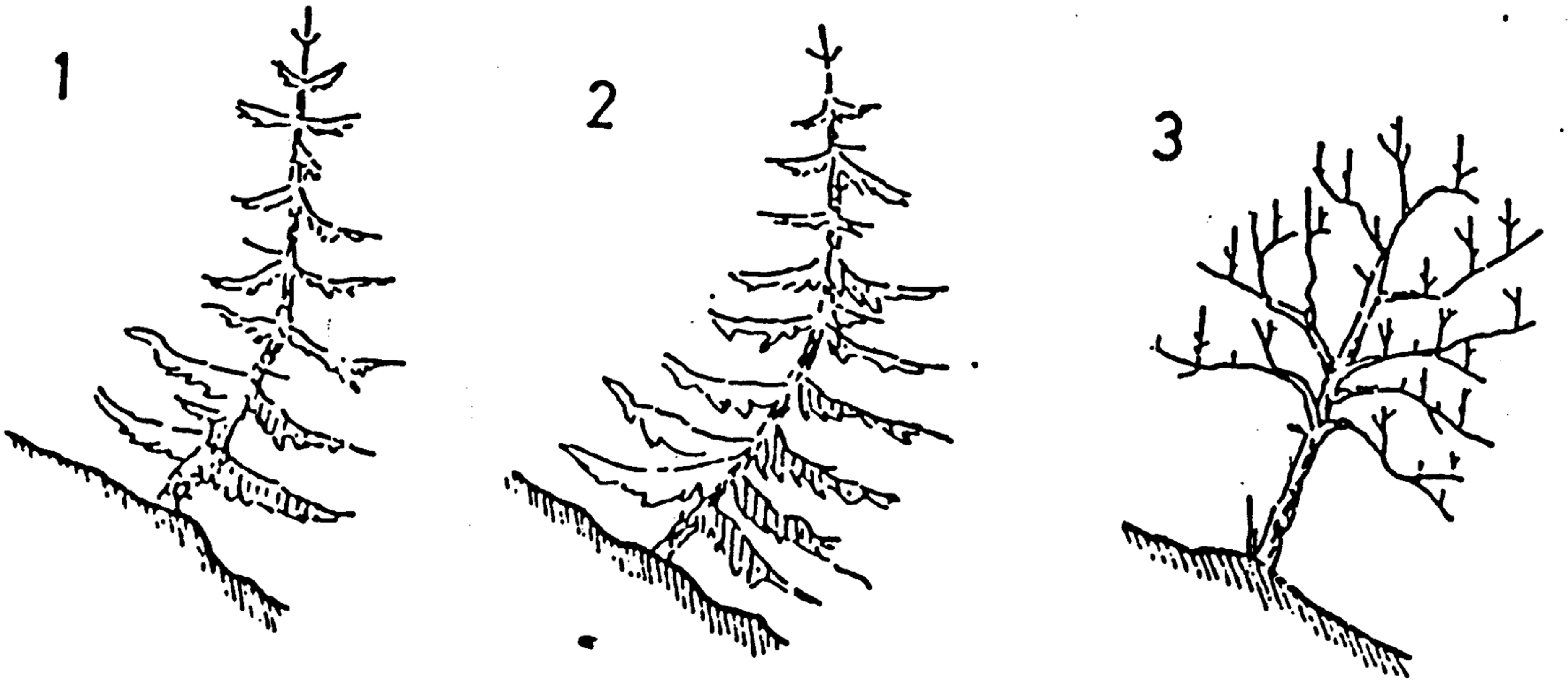
Minor scarp

Methods of landslide investigation

Phase of slope deformation evolution

- *Initial*
- *Developed*
- *Final*

Methods of landslide investigation



Tree bending (Záruba, Mencl)

Methods of landslide investigation

Photo J. Rybář

Dneboh, Czech Republic

Methods of landslide investigation

Bending of trees

Dneboh, Czech Republic

Methods of landslide investigation

Moved gravestones by creep movements
Photo: J. Rybář

Methods of landslide investigation

Moved gravestones by creep movements
Photo: J. Rybář

Moved grave monuments by creep movements, Photo: J. Rybář

In winter periods frozen water from springs can be observed in landslide areas, Photo: J. Zvelebil

Methods of landslide investigation

Road deformed by long-term movements
Photo:
J. Rybář

Methods of landslide investigation

Main
scarp
of
a flow

Methods of landslide investigation

Main scarp

Methods of landslide investigation

Slickensided surface on surface of rupture

Ústí nad Labem, Motorway D8, Czech Republic

Methods of landslide investigation

Slickensided surface on surface of rupture

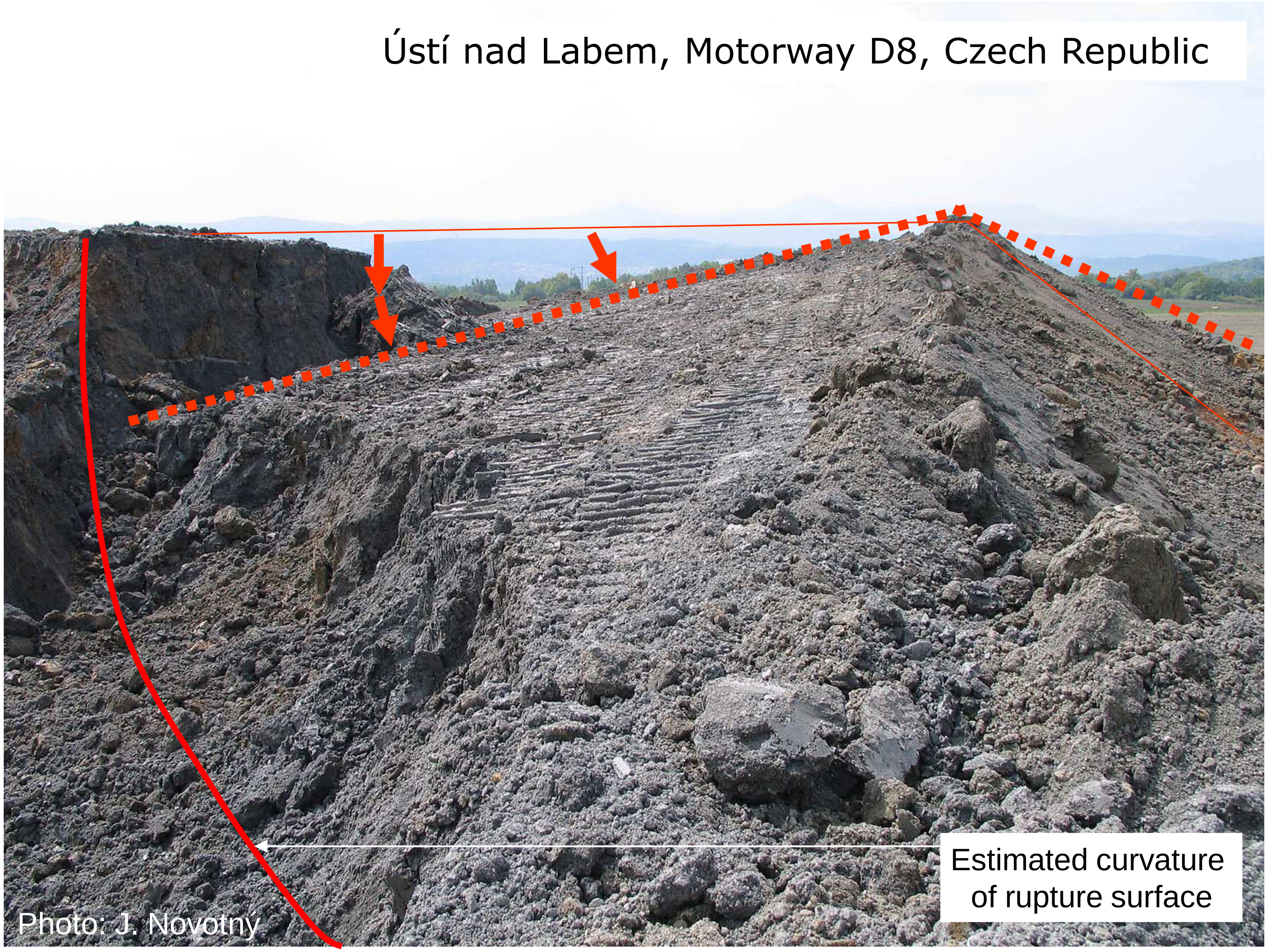
Photo: J. Rybář

Methods of landslide investigation

Rotation in head area

Ústí nad Labem, Motorway D8, Czech Republic

Rotation in head area



Open tension crack, without rotation in head area

Methods of landslide investigation

Surface of rupture

Methods of landslide investigation

Frank Slide (Canada)

Photo: P. Olišar

Open crack

Photo: J. Novotný

Methods of landslide investigation

Frank Slide (Canada)

Photo: J. Novotný

Methods of landslide investigation

Open cracks, ditches, grabens

Photo J. Rybář

Methods of landslide investigation

Open cracks, ditches, grabens

Beskydy, Lukšinec, Czech Republic

Photo: J. Novotný

Methods of landslide investigation

Open cracks, ditches, grabens

Potvorov, Czech Republic

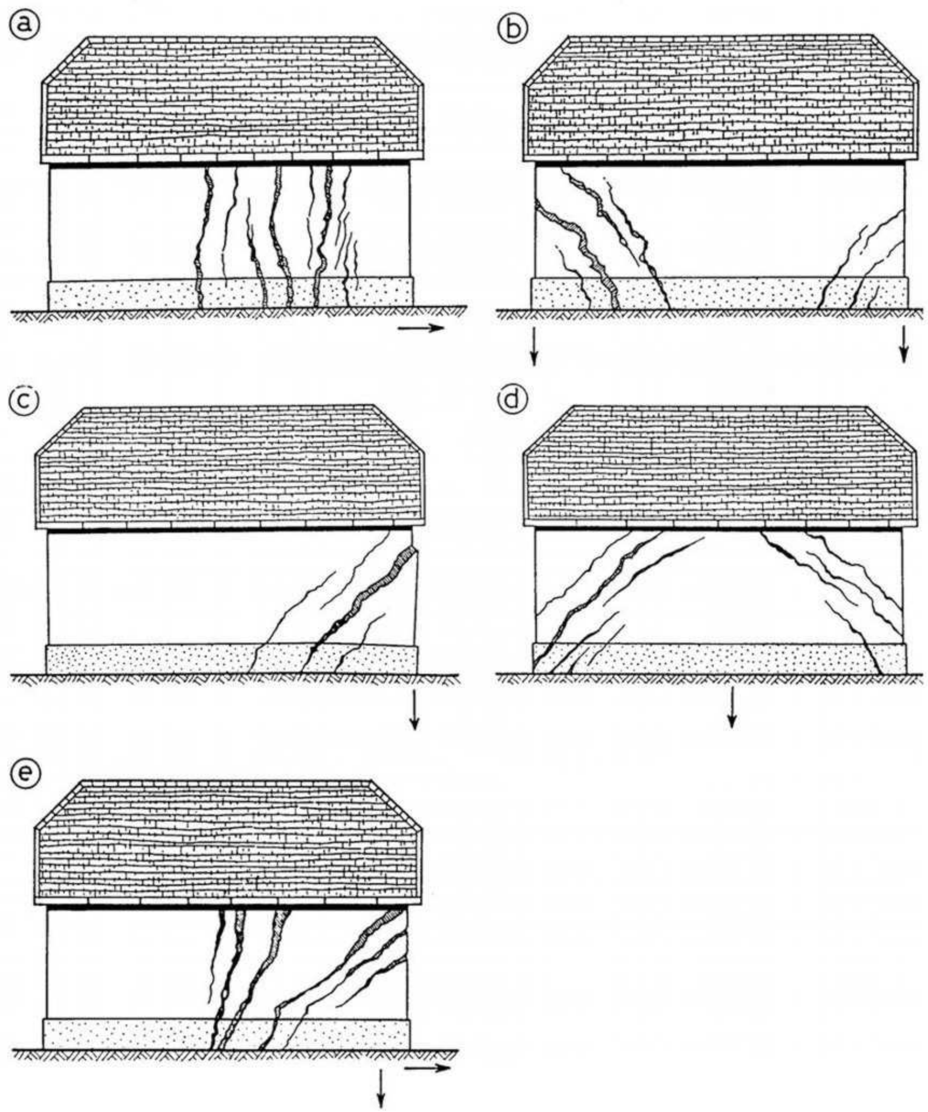
Photo: J. Novotný

Methods of landslide investigation

Stretched tree roots in fissures indicate active movement

Photo: J. Rybář

Methods of landslide investigation



Cracks in buildings
can be caused by:

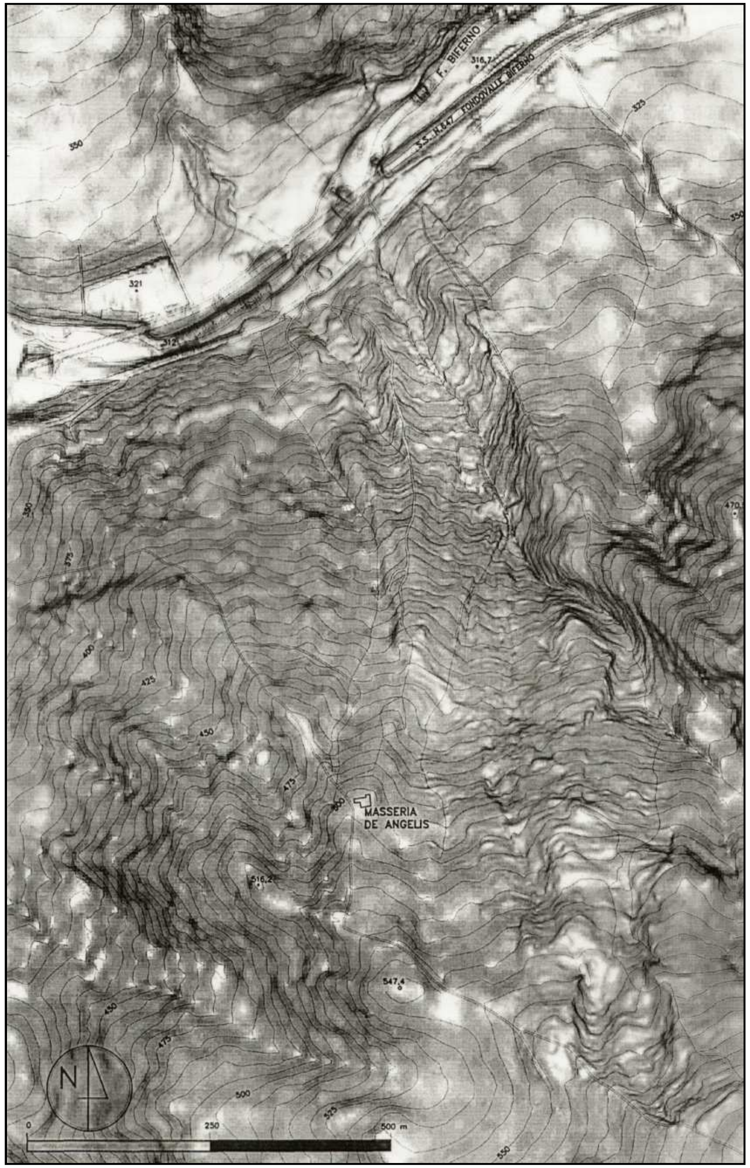
a, c, e – slope movements

b – shrinkage of clayey soils

d - undermining

before

Aerial photography



after

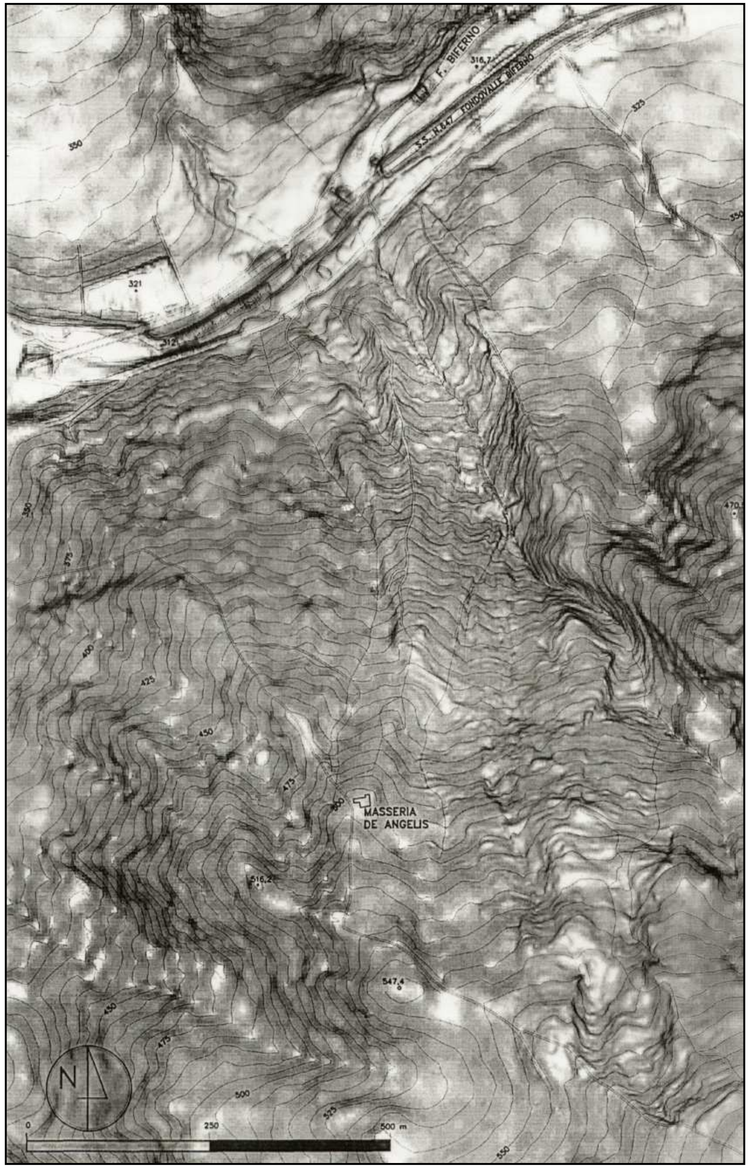
Aerial photography

Methods of landslide investigation

after

Aerial photography

before



Methods of landslide investigation

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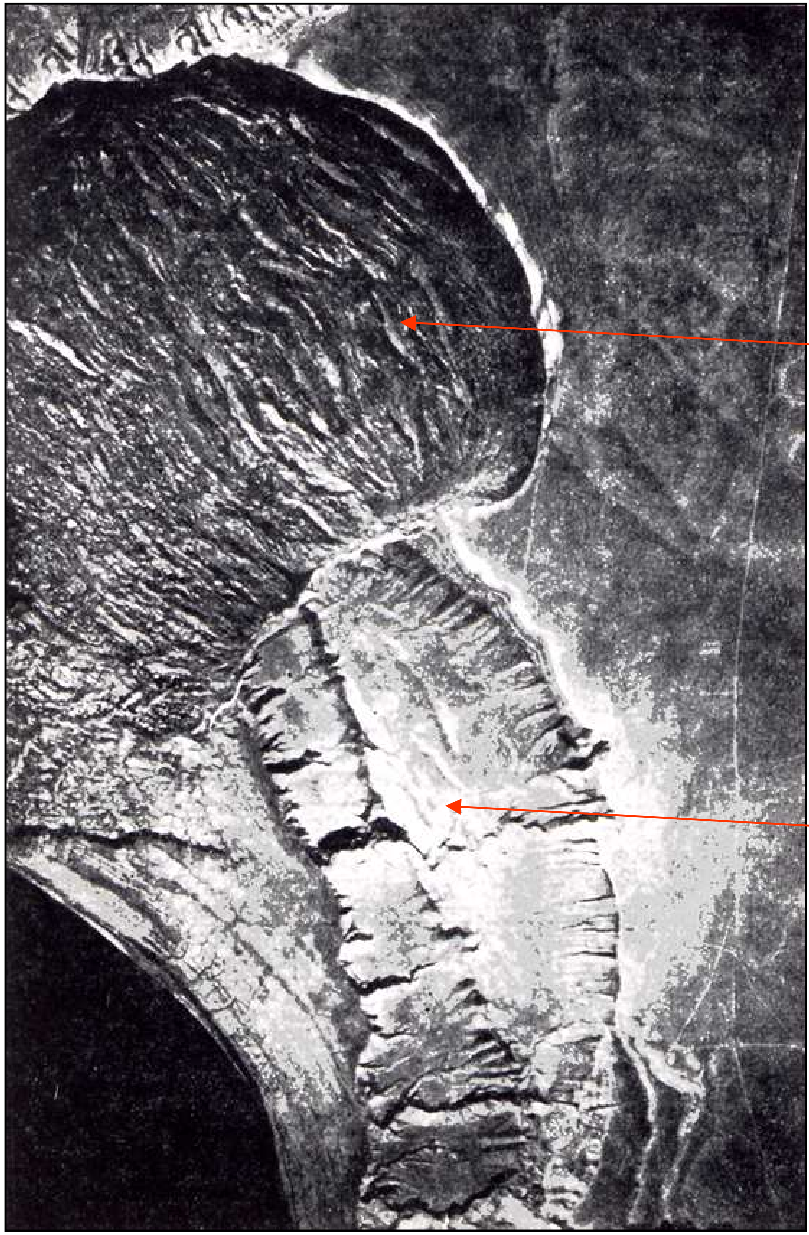
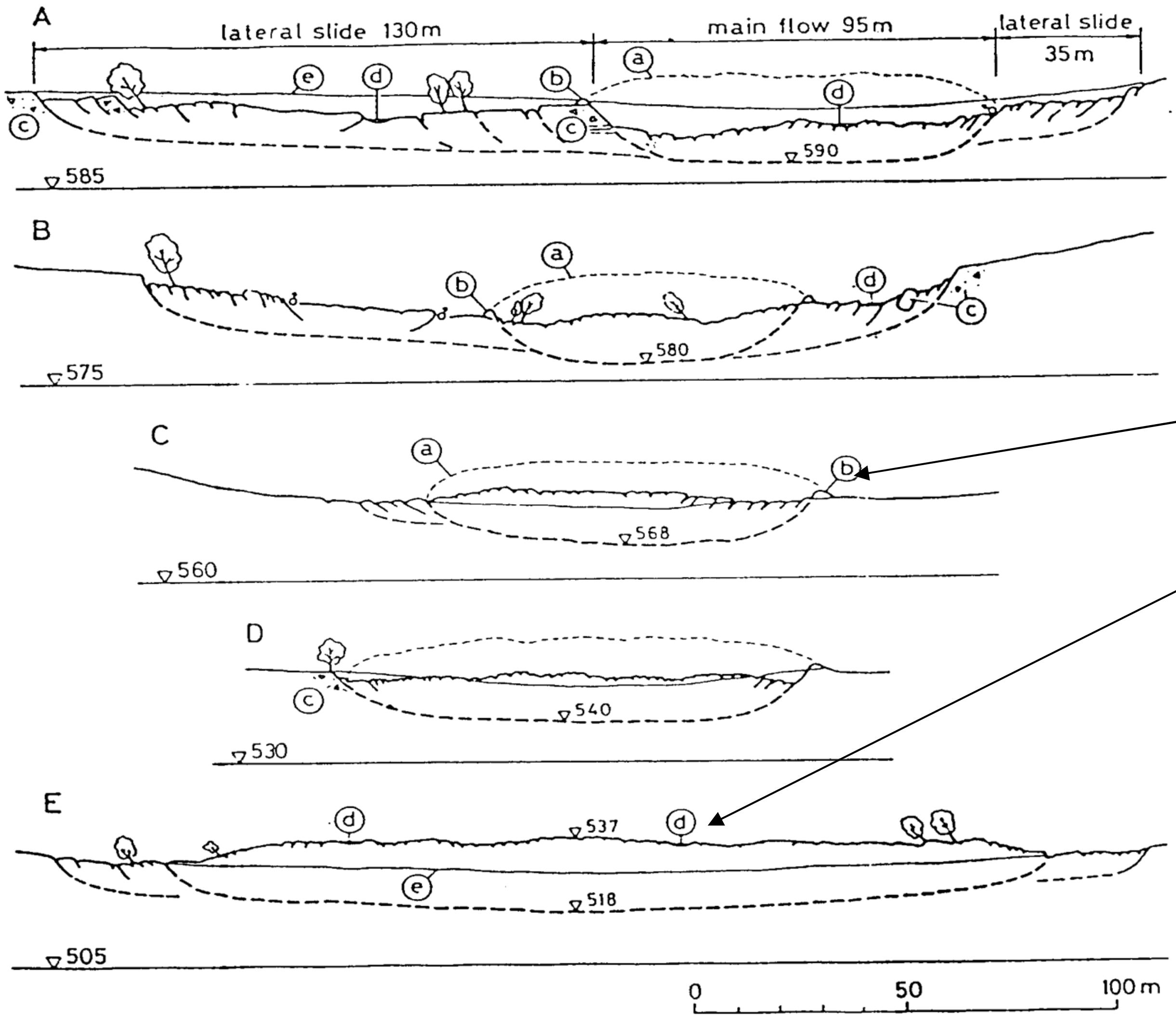


new landslide cutting through an old landslide

old landslide

Longitudinal profile



Cross sections

of earth flow near Handlová, Slovak Republic

b – squeezed lateral ridges

d – lake in the depression of the surface

Methods of landslide investigation

Rupture surface

Photo: J. Rybář

Methods of landslide investigation

Rupture surface

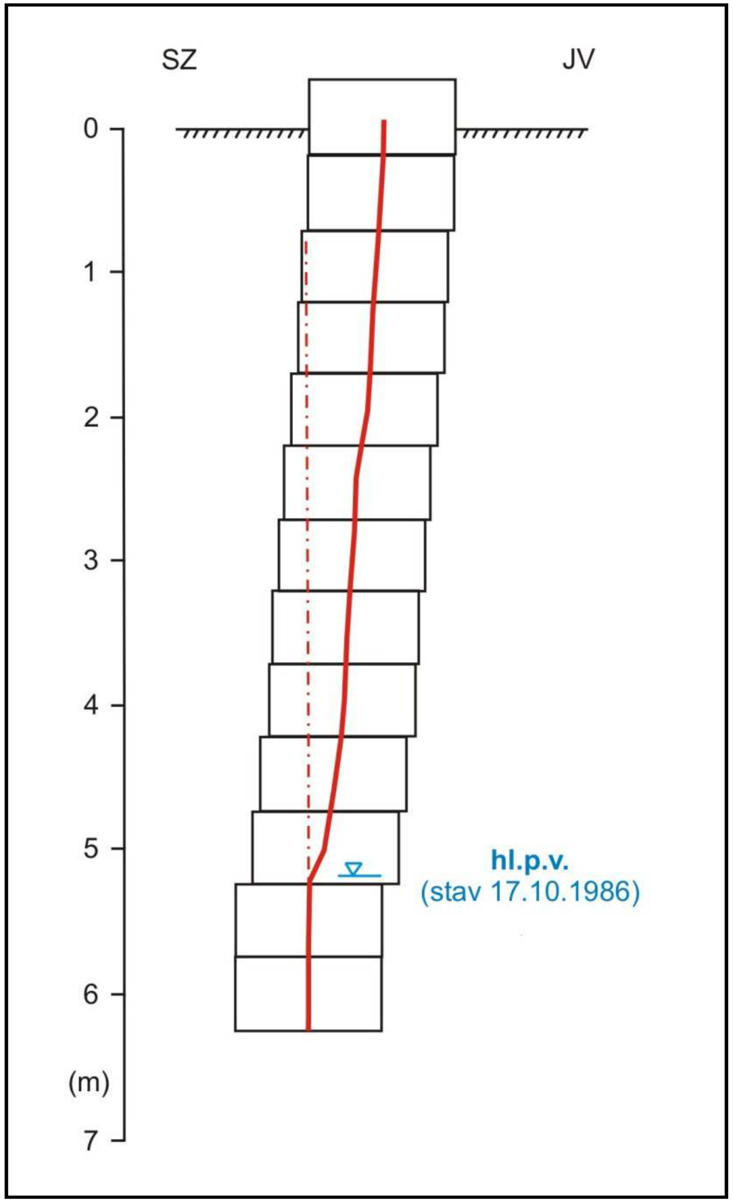
Photo: J. Novotný

Methods of landslide investigation

Rupture surface

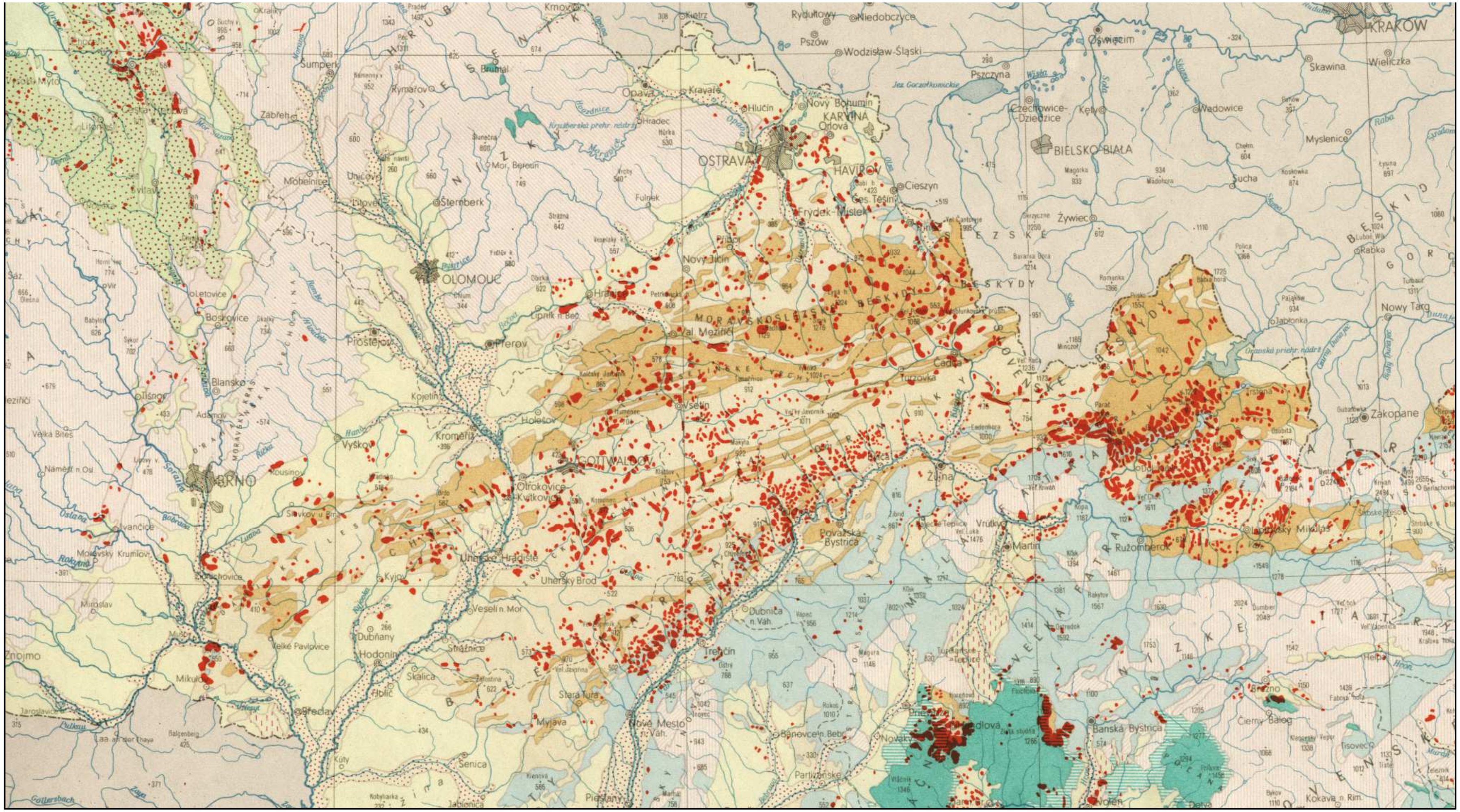
Photo: J. Novotný

Methods of landslide investigation



Measurements of movements in a well

Landslides mapping



Part of Map of landslides in Czechoslovakia
in the scale 1 : 1 000 000

Landslides mapping

Use of colors

Fossil landslide and potential landslide – black line (difference in sign)

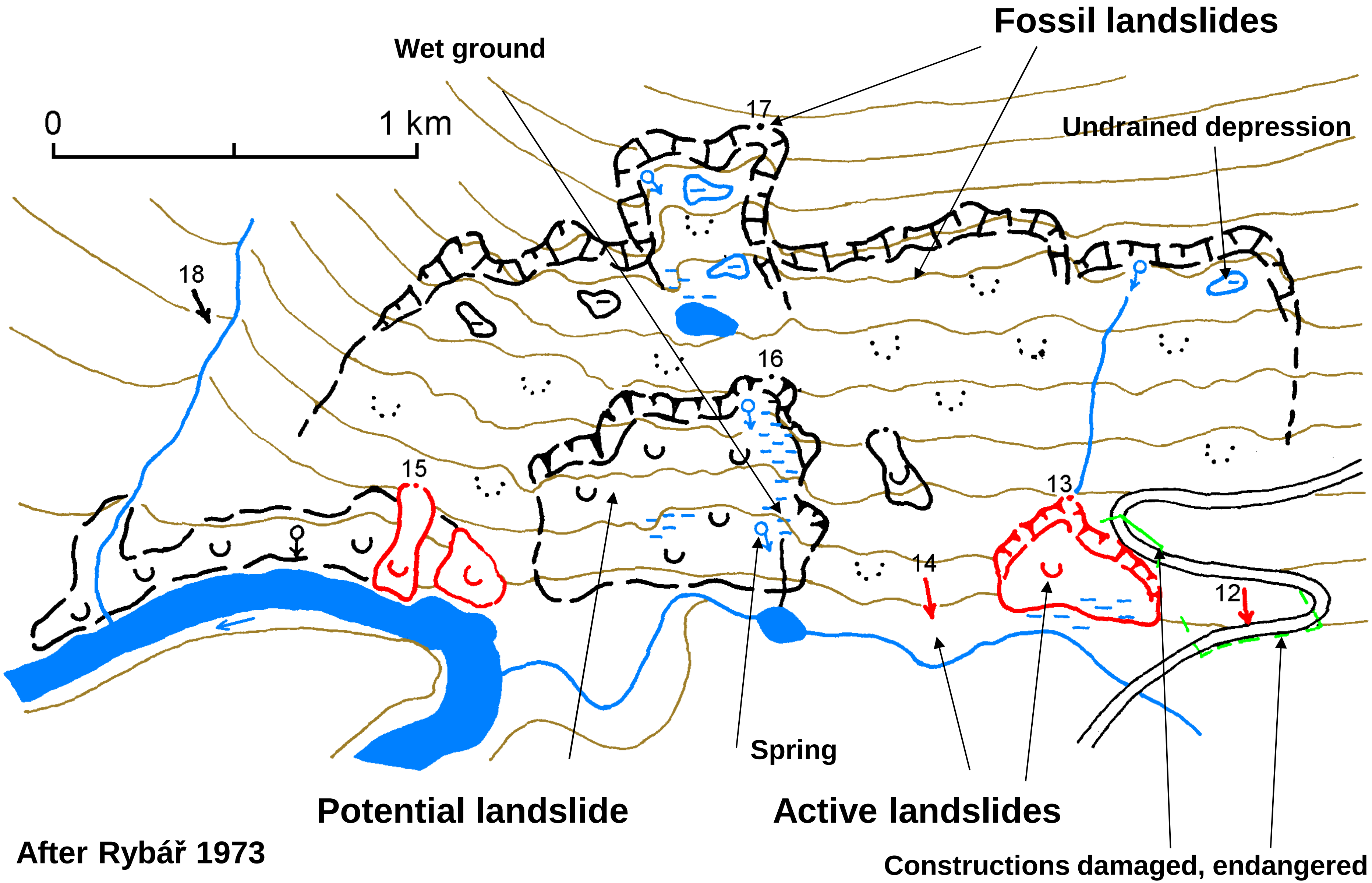
Active landslide – red line

Hydrogeological features – blue line, areas

Man-made construction – green line

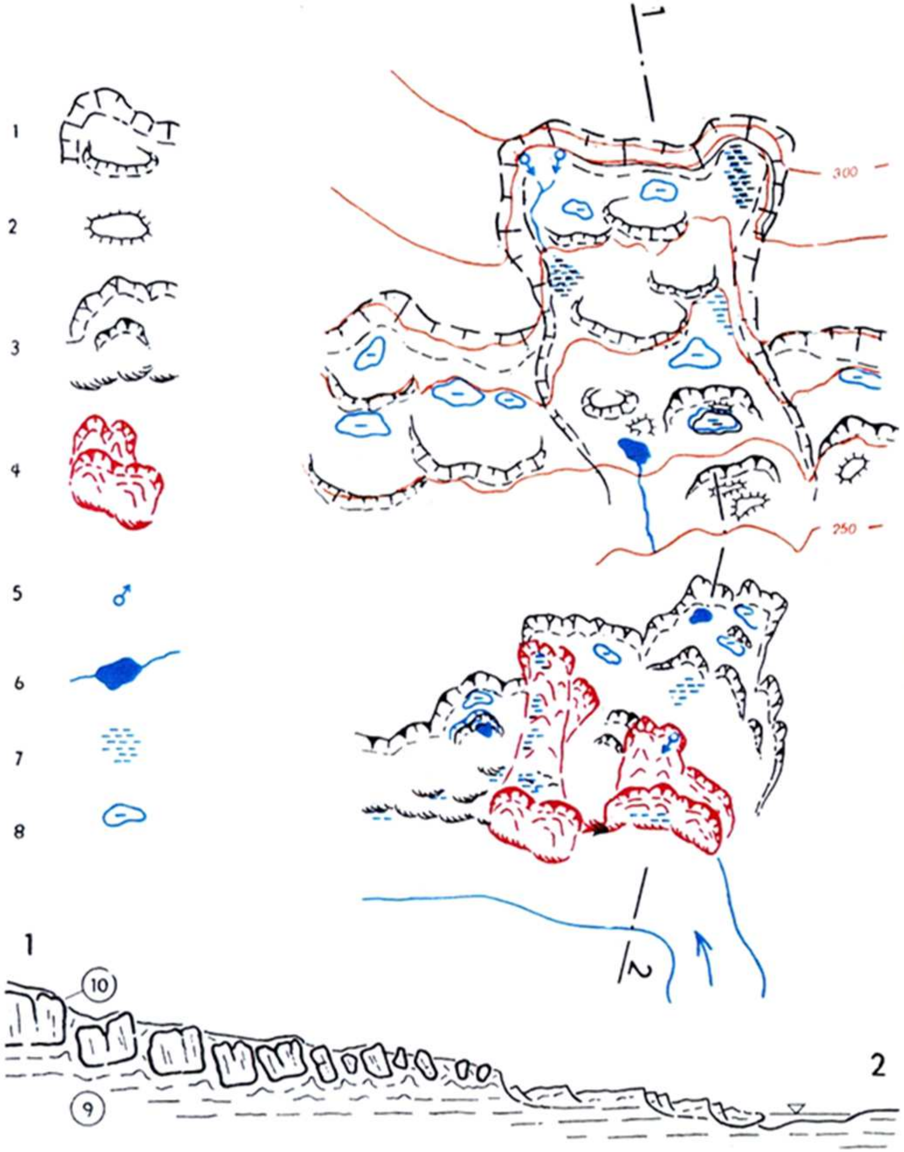
Methods of landslide investigation

Landslides in maps 1 : 25 000



After Rybář 1973

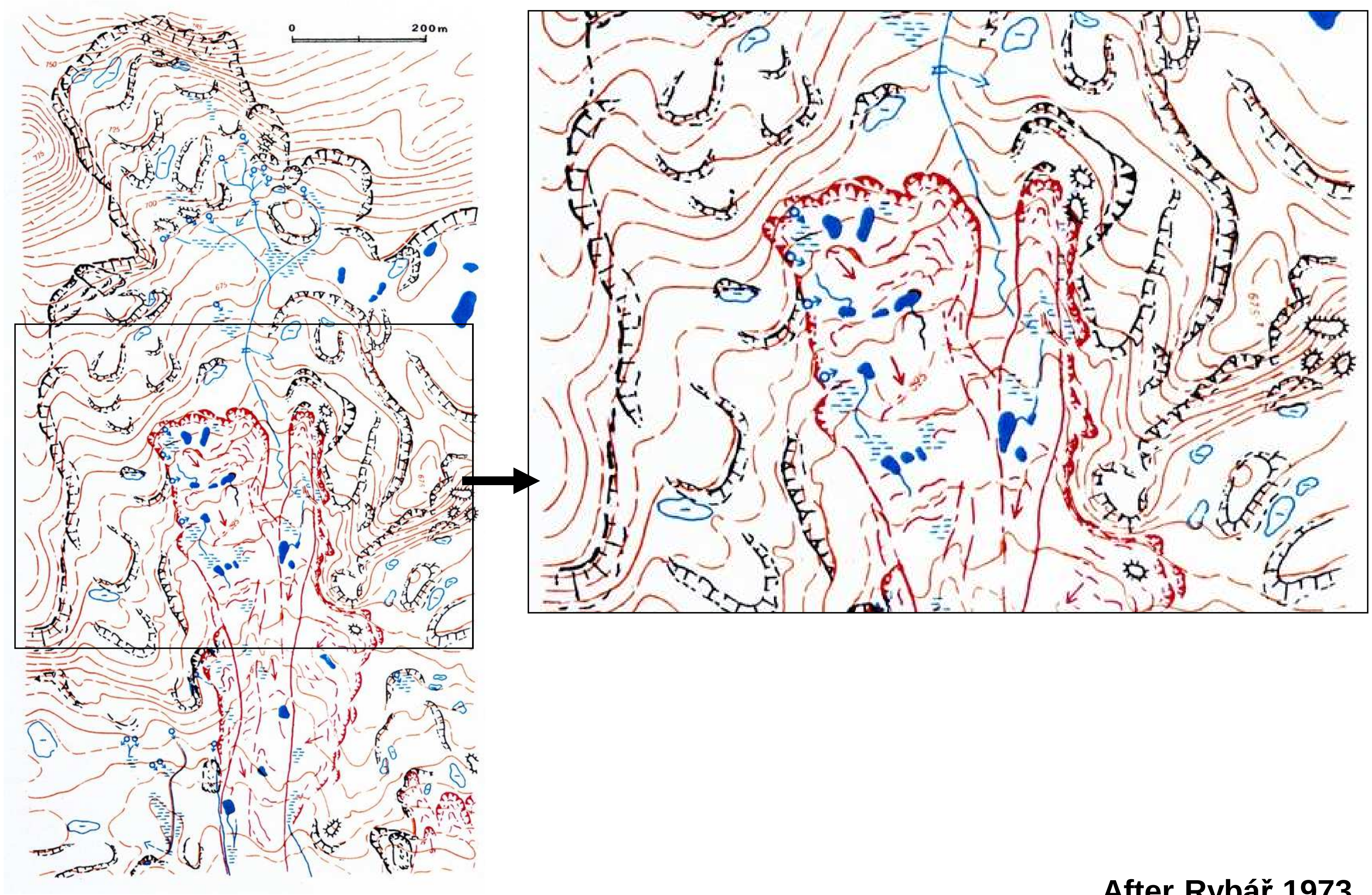
Landslides – mapping in to scale 1 : 5 - 10 000



Example of landslide representation on the scale 1:5-10,000 with schematic profile 1-2 of the sliding area.
1—scarp and outcropping edges of buried slide block (fossil landslide); 2—outlines of emerging blocks; 3—scarps and accumulation ramparts of two generations of potential landslides; 4—recent active landslides representing two developmental stages, with main joints; 5—springs; 6—water-courses and lakes; 7—wet ground; 8—undrained depressions; 9—plastic clayey rocks; 10—solid rocks.

After Rybář 1973

Methods of landslide investigation



After Rybář 1973

Methods of landslide investigation

Landslides – mapping in to scale 1 : 5-10 000

Photo J.Rybář

Photo J.Rybář

Landslides – mapping in to scale 1 : 5 - 10 000

DOMOUSNICE, November 1981, after J.RYBÁŘ

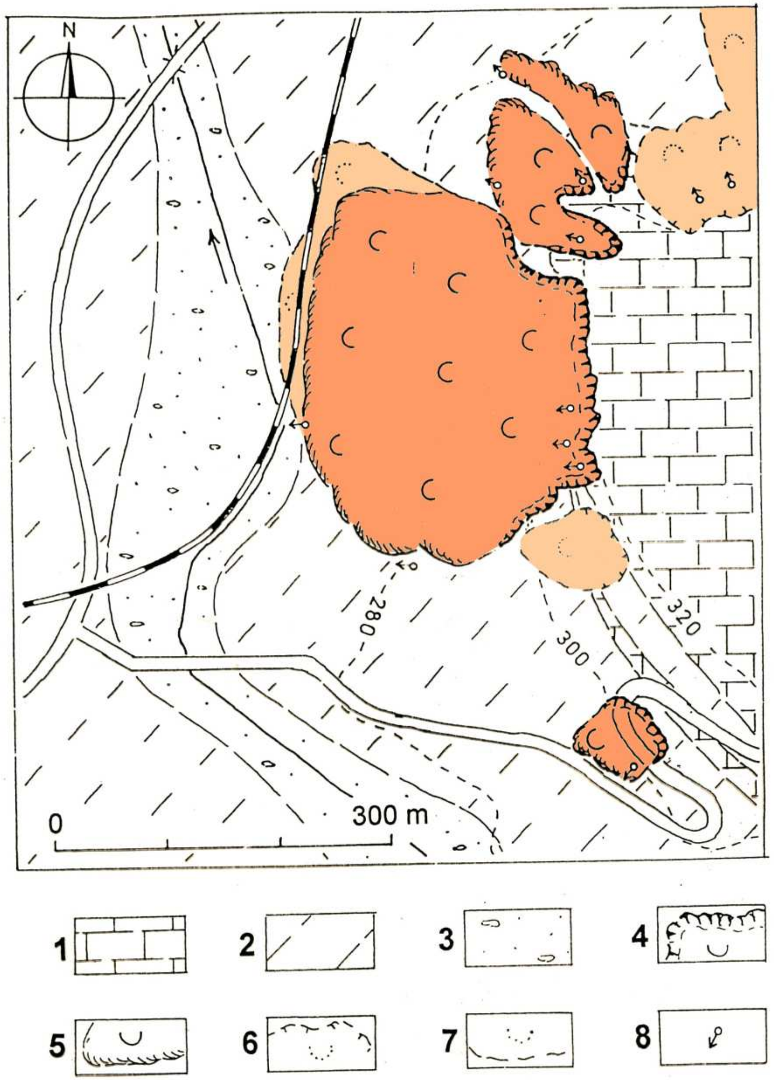
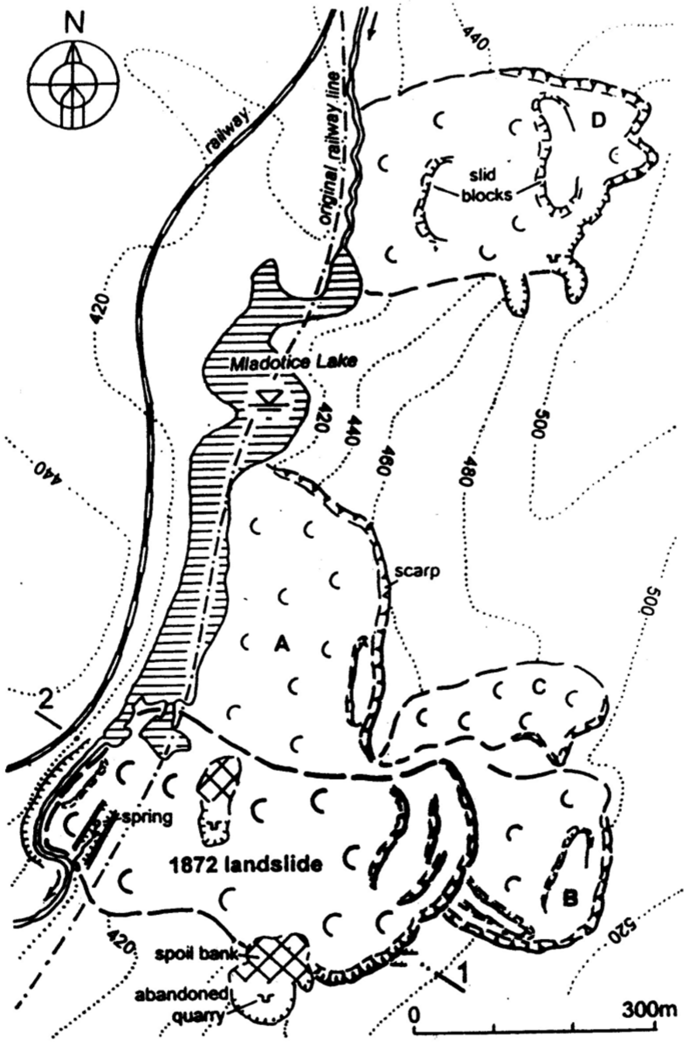


Photo: J.Rybář

Landslides – mapping in to scale 1 : 5 - 10 000

POTVOROV 1872



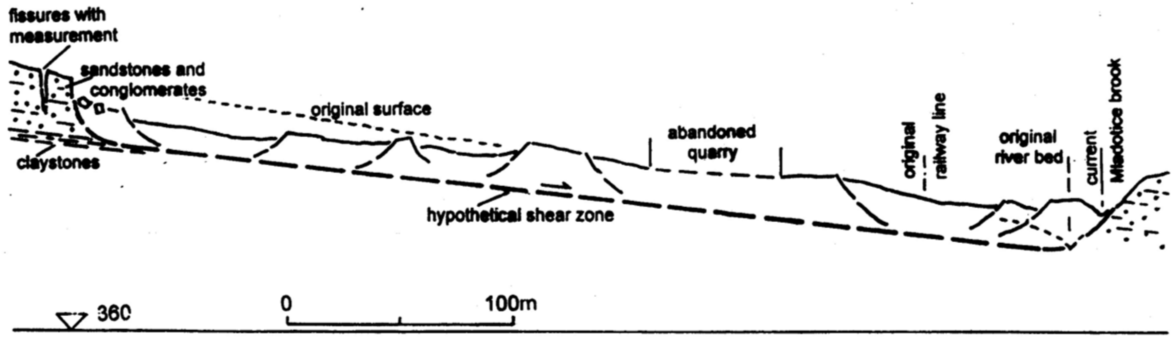
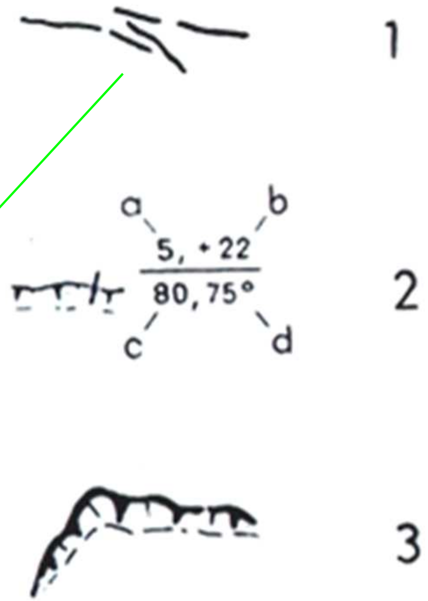


Photo J.Rybář

Landslides – detailed mapping

Upper part of the slide



1–tension joints; 2a–width of gaping joint in cm; 2b–subsidence of lower block along joint in cm; 2c–depth of gaping joint; 2d–inclination of joint in degrees; 3–tension joint with expressive subsidence (uncovered sliding plane); 4–shear joint with indicated direction of movement; 5, 6, 7–different types of failures in the toe of the slide, with exaggeration in cm; 8–undrained depressions; 9–wet ground; 10–contours and gradient hatchings underlining the bulges.

After Rybář 1973

Methods of landslide investigation

Landslides – detailed mapping

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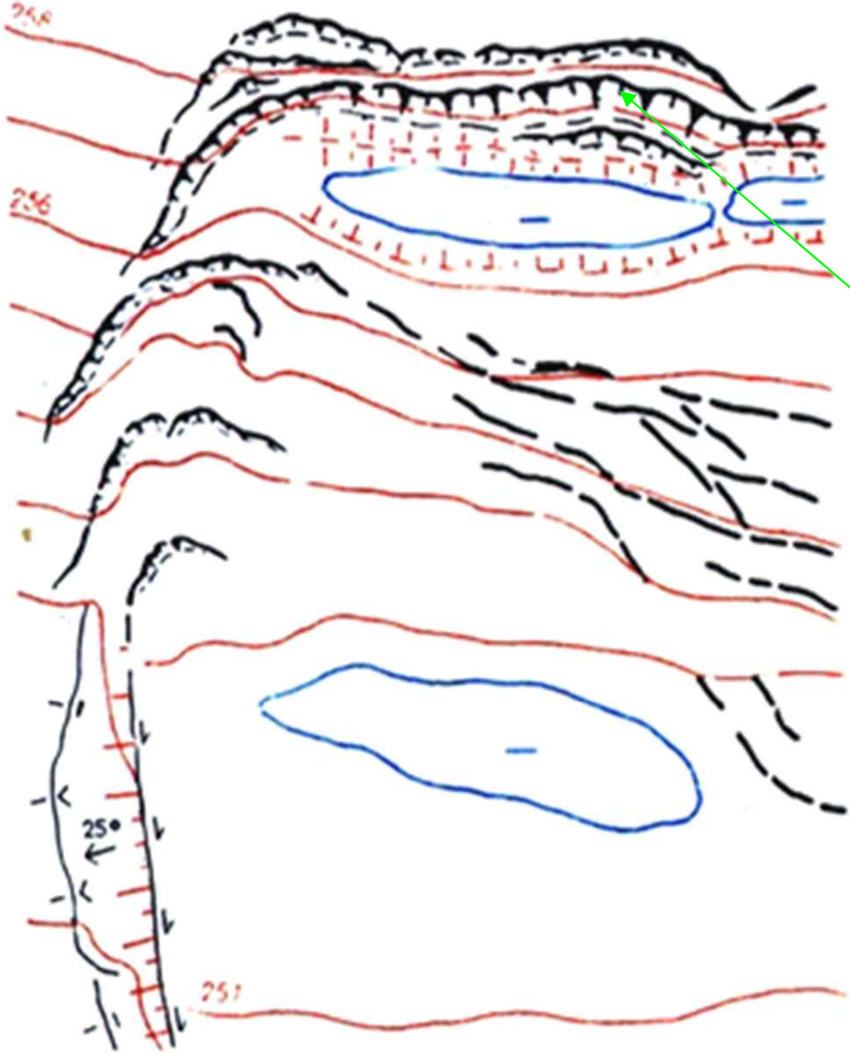

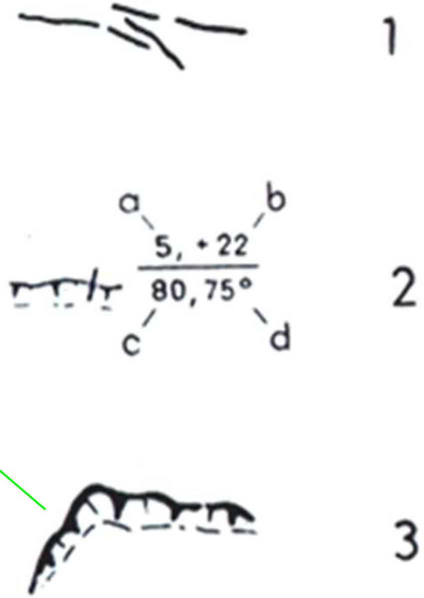

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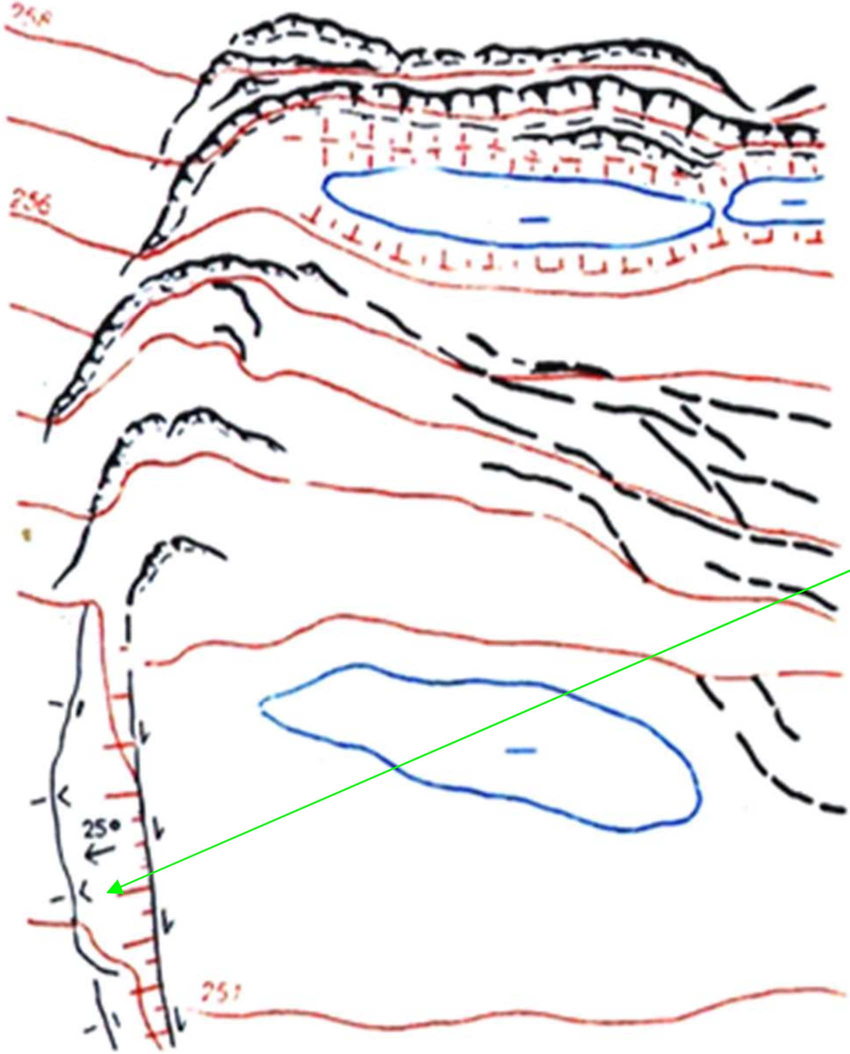

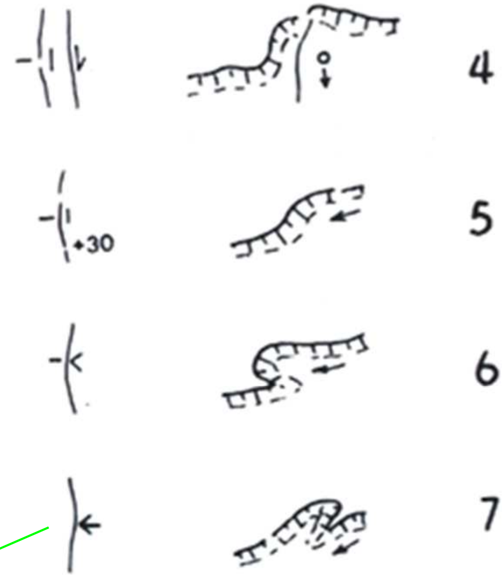

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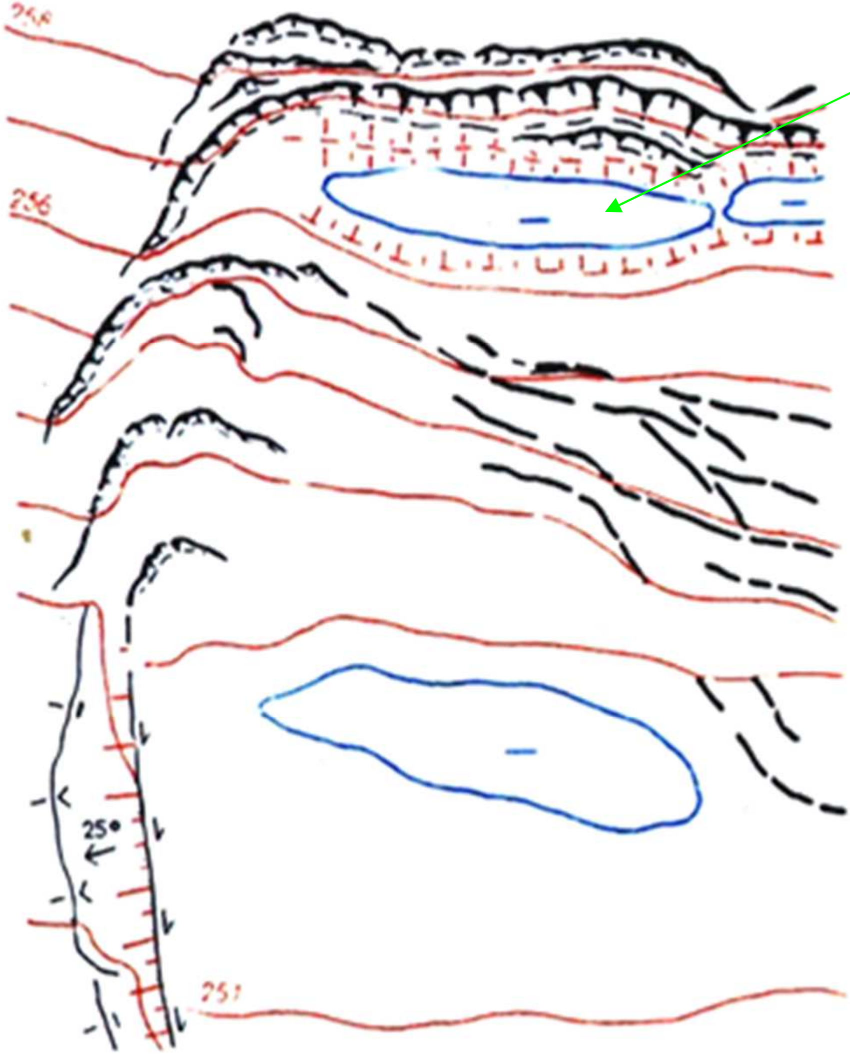

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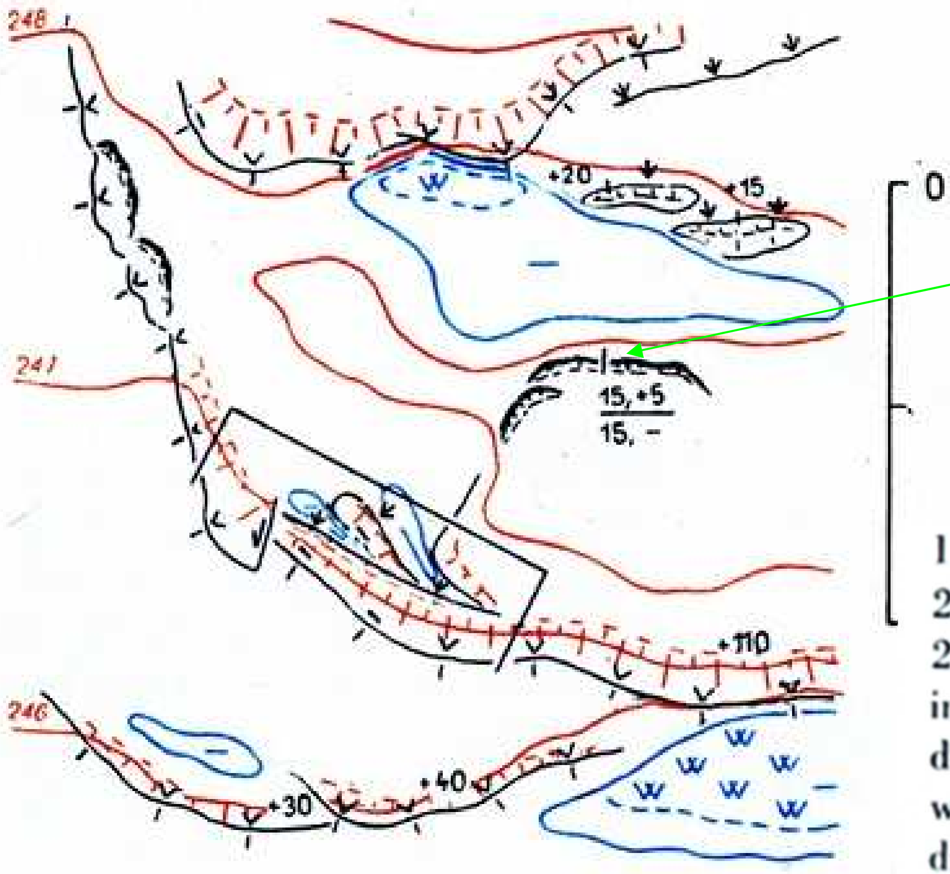
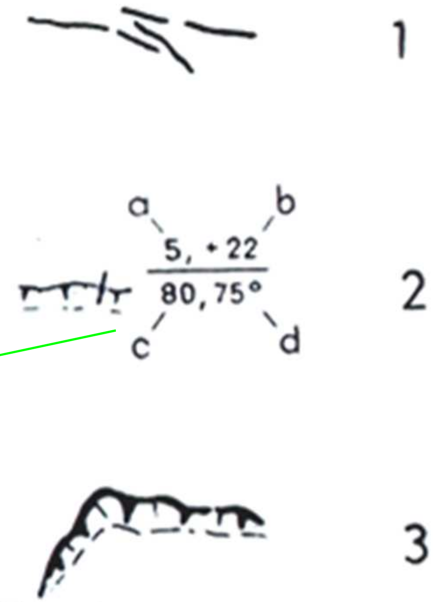
After Rybář 1973

Methods of landslide investigation

Landslides – detailed mapping

Toe of the slide





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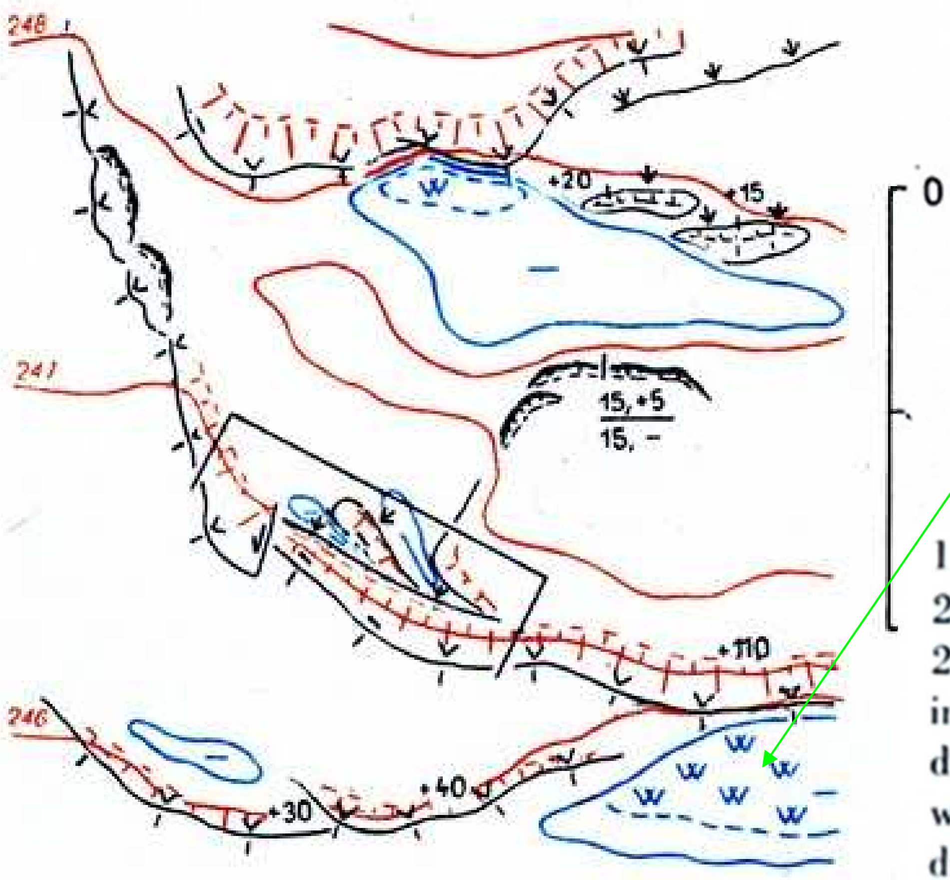
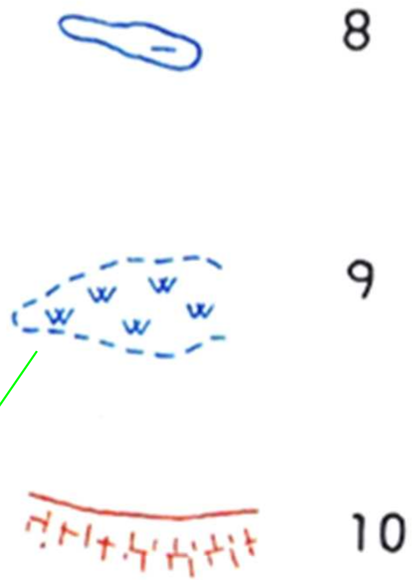
After Rybář 1973

Landslides – detailed mapping

Toe of the slide





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After Rybář 1973

Landslides – detailed mapping

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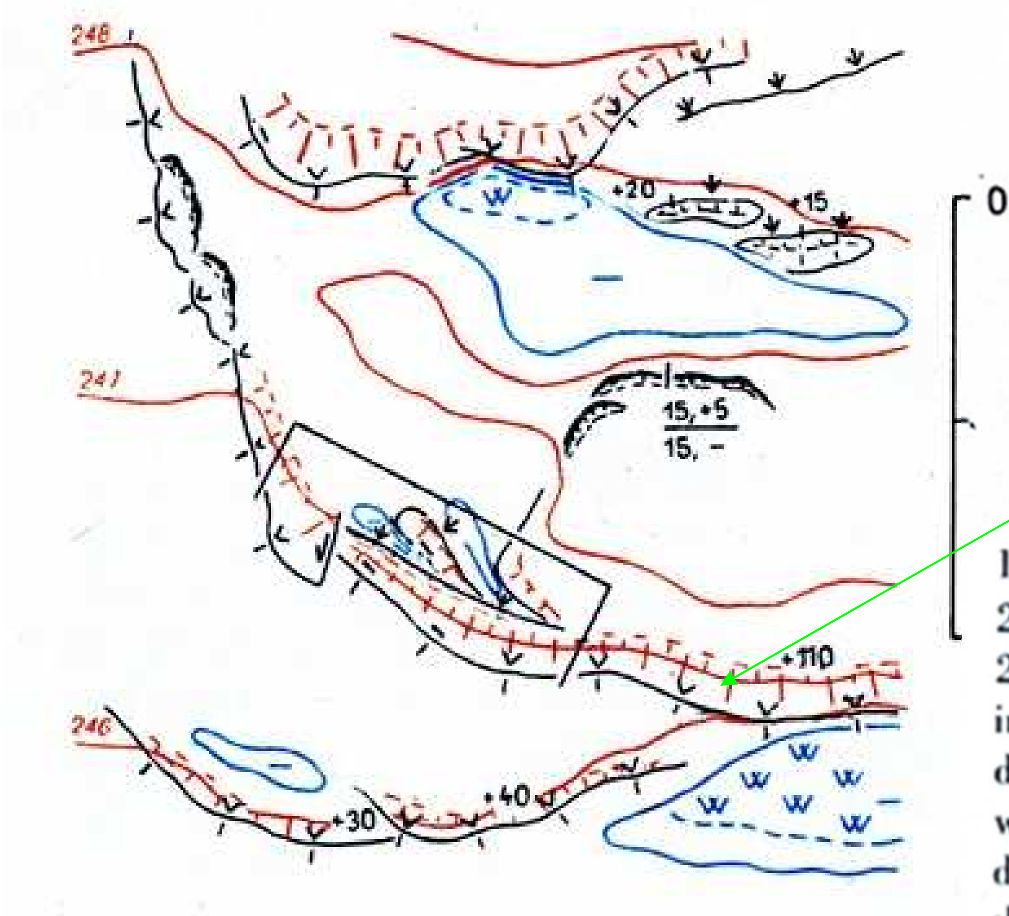

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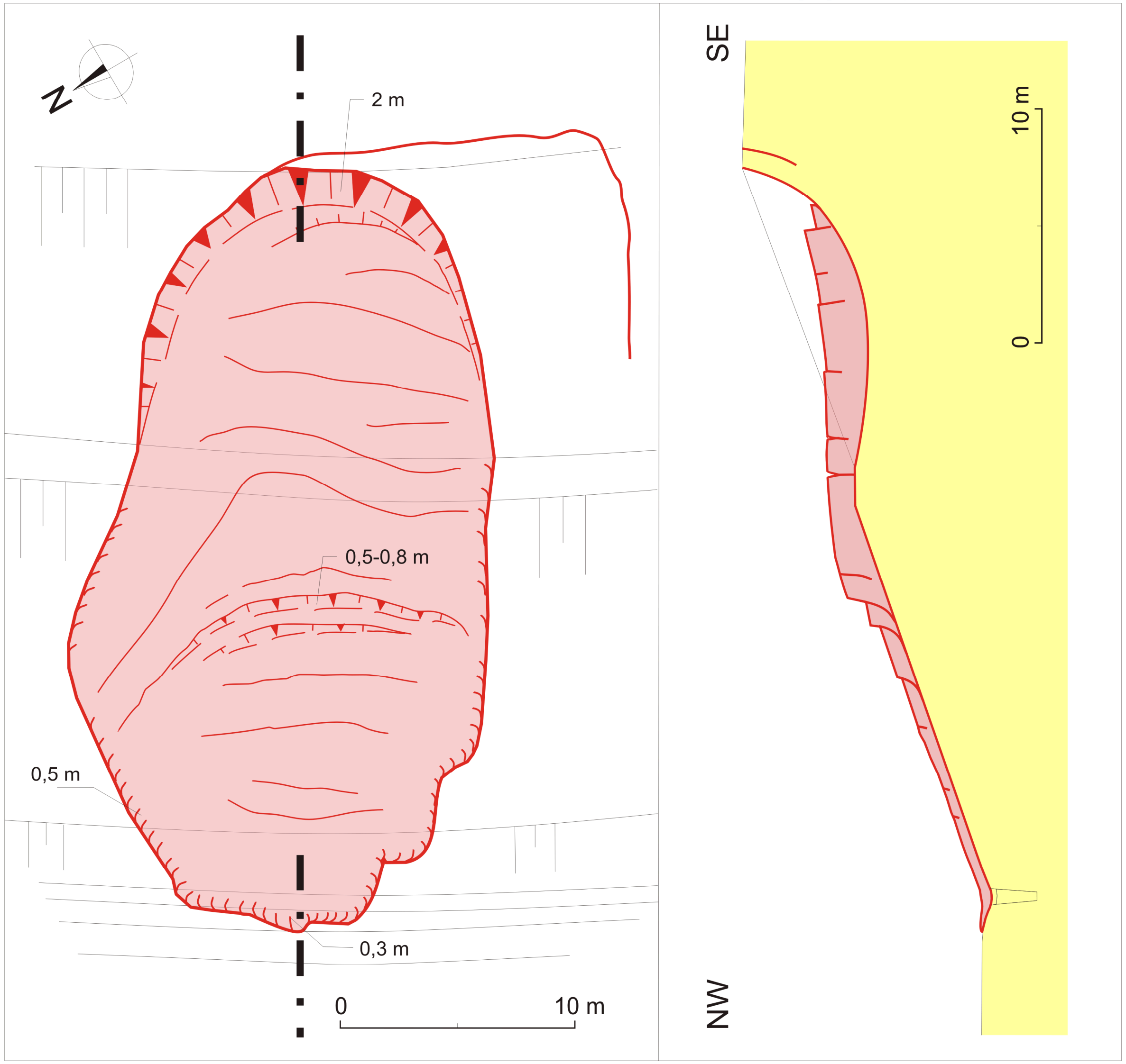
After Rybář 1973

Landslides – detailed mapping

Photo: J. Novotný

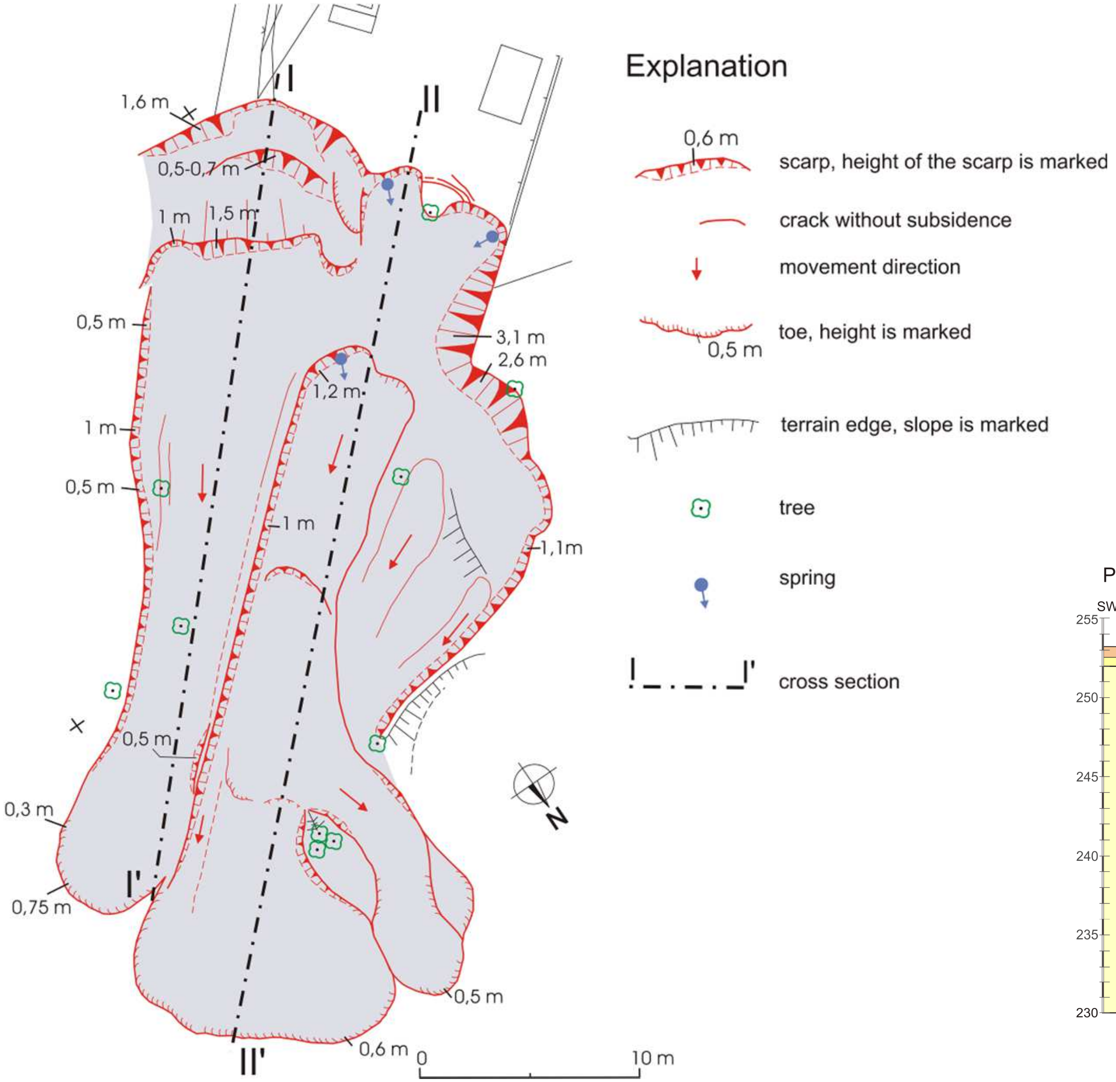
Landslides – detailed mapping

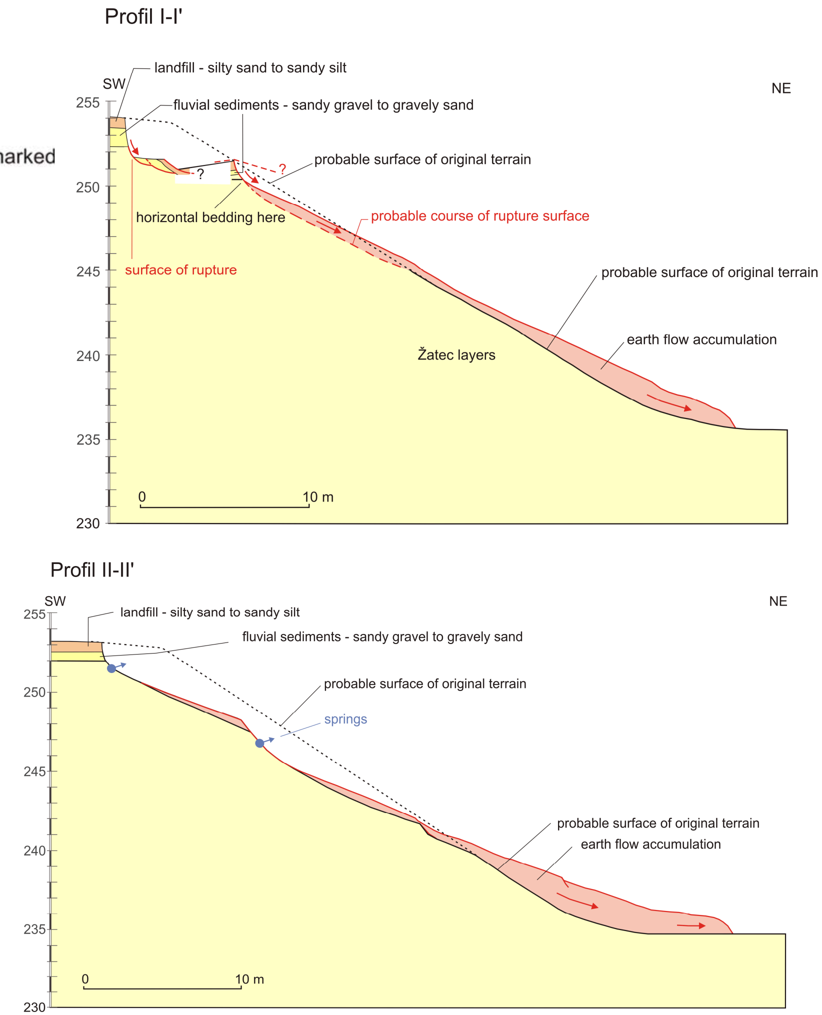


After J. Novotný

Methods of landslide investigation

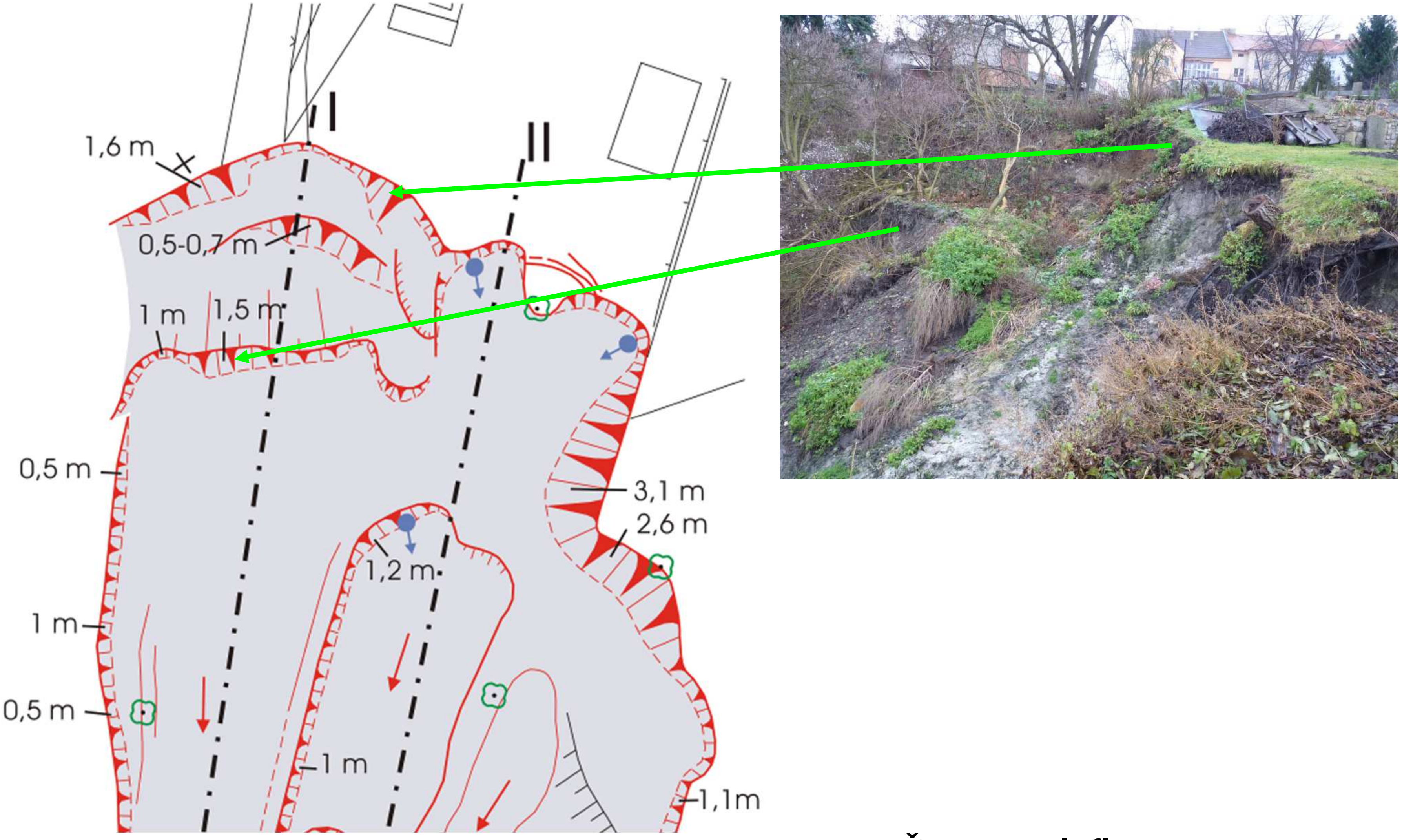
Landslides – detailed mapping





Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

Landslides – detailed mapping



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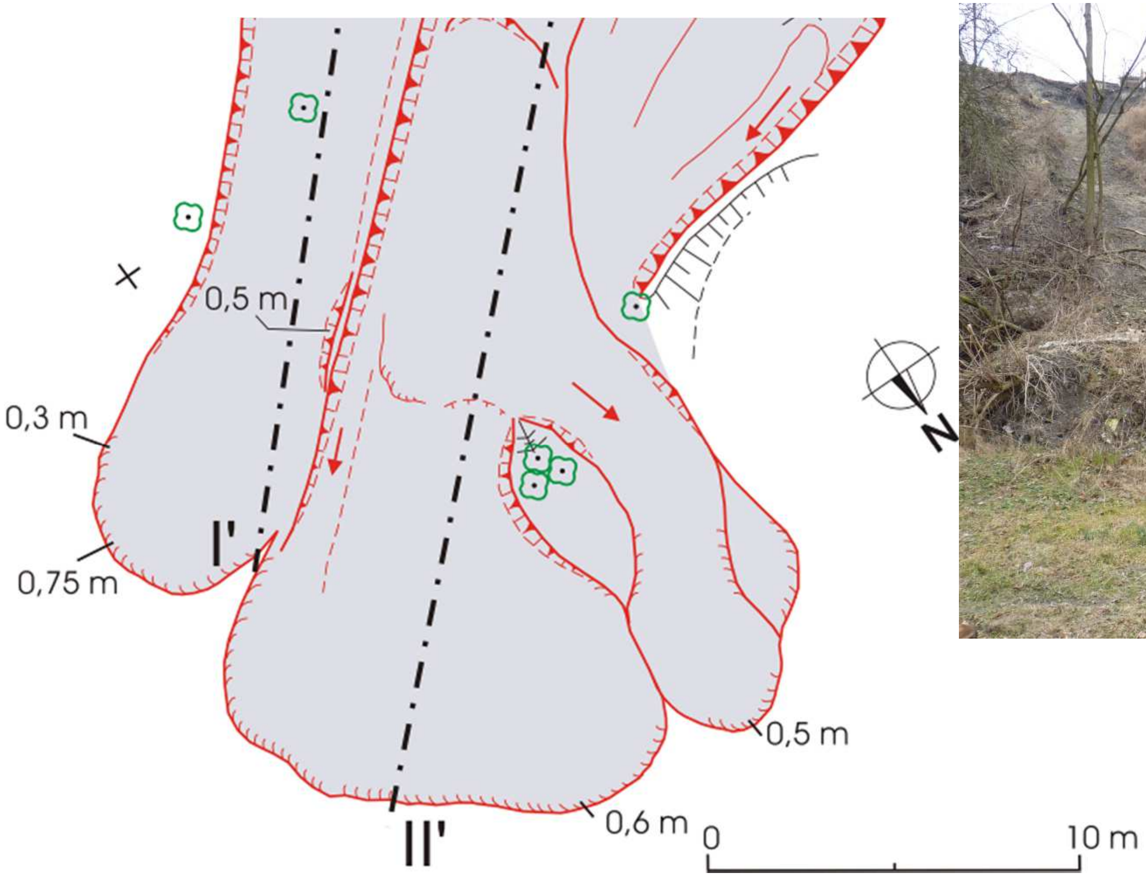
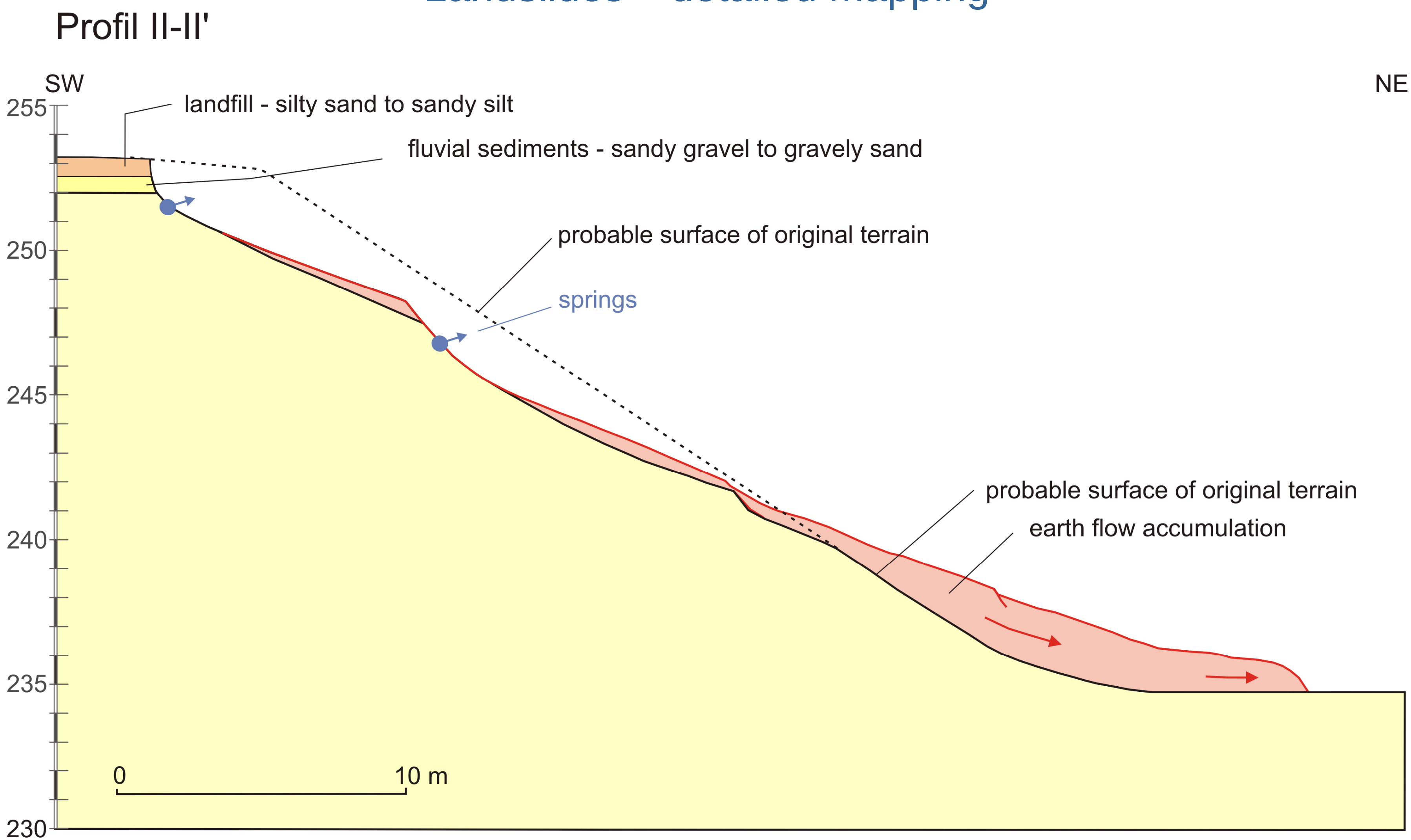


toe

tip

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

Landslides – detailed mapping



Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

Landslides – detailed mapping

rotated block

main scarp

minor scarp

Head

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

Landslides – detailed mapping

rotated block

minor scarp

main scarp

Head

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

Methods of landslide investigation

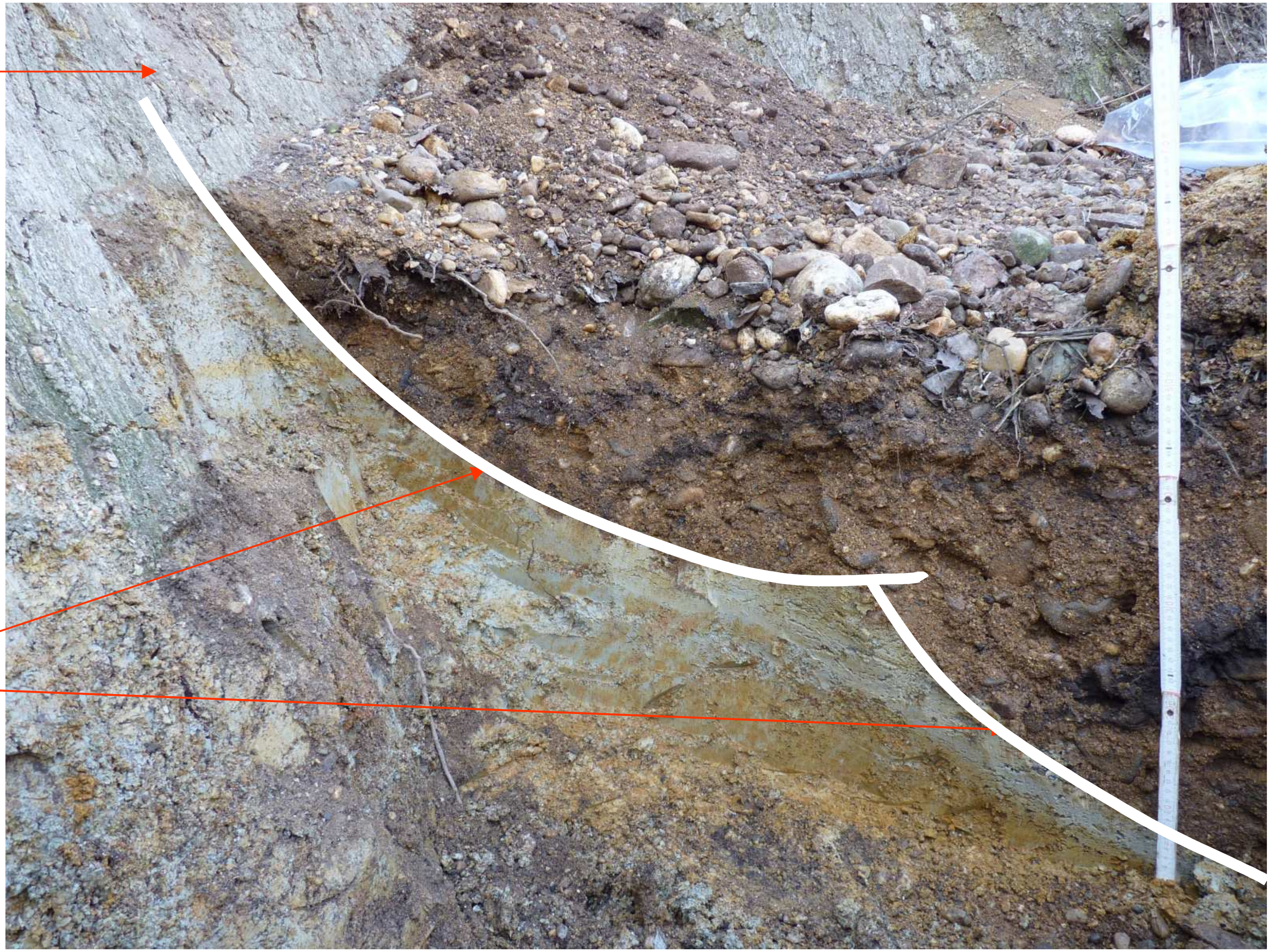
Landslides – detailed mapping

main scarp

Rupture surface covered by sandy gravel to gravely sand during the movement

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

Landslides – detailed mapping



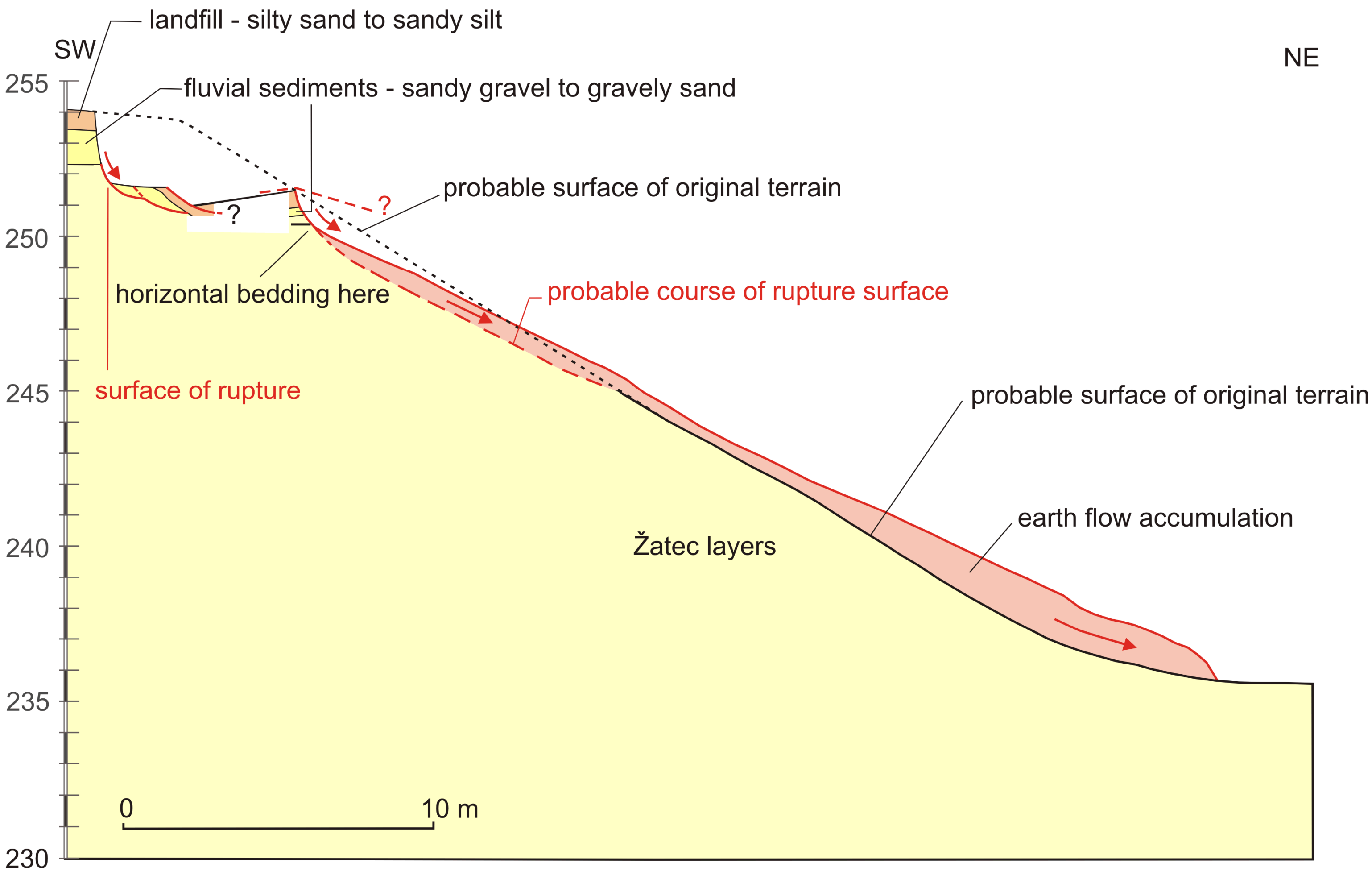
main scarp

Rupture surface covered by sandy gravel to gravely sand during the movement

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

Landslides – detailed mapping

Profil I-I'

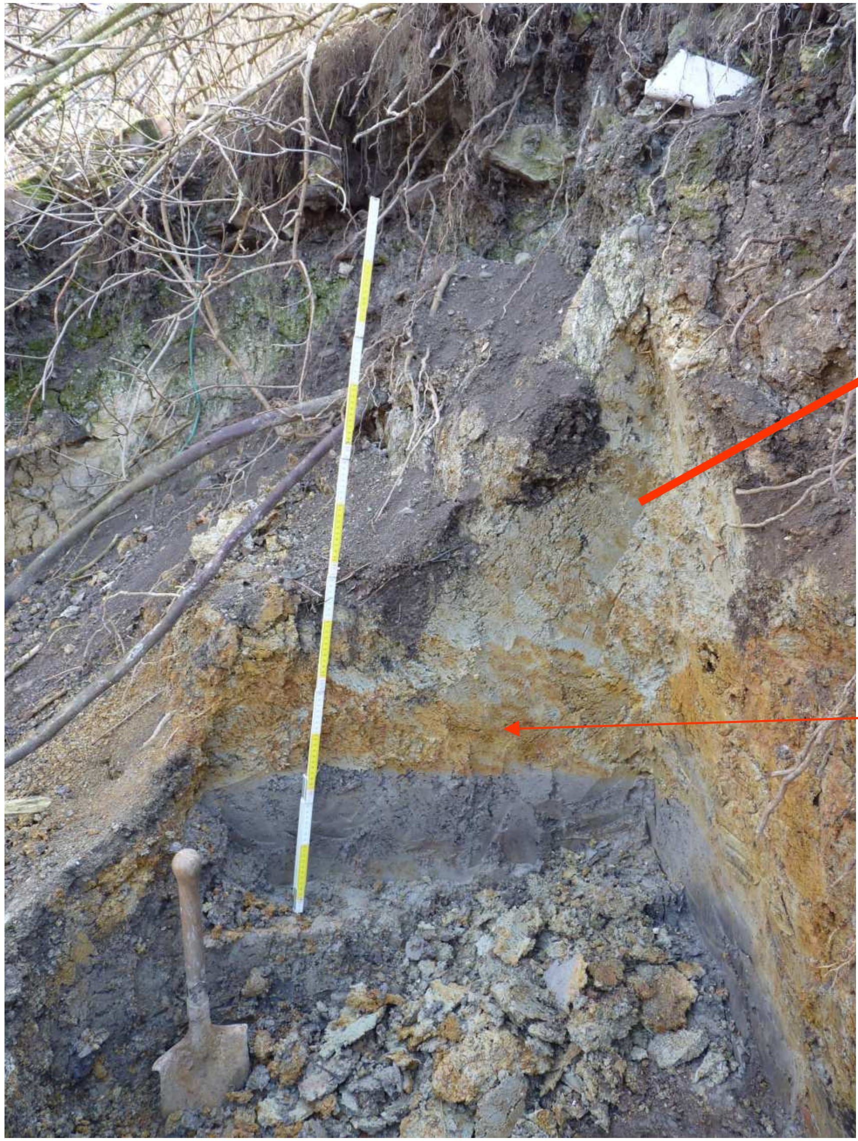


Žatec earth flow

After J. Novotný, T, Šmejkalová, J. Rybář

Methods of landslide investigation

Landslides – detailed mapping



horizontal bedding

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

Methods of landslide investigation

Landslides – detailed mapping

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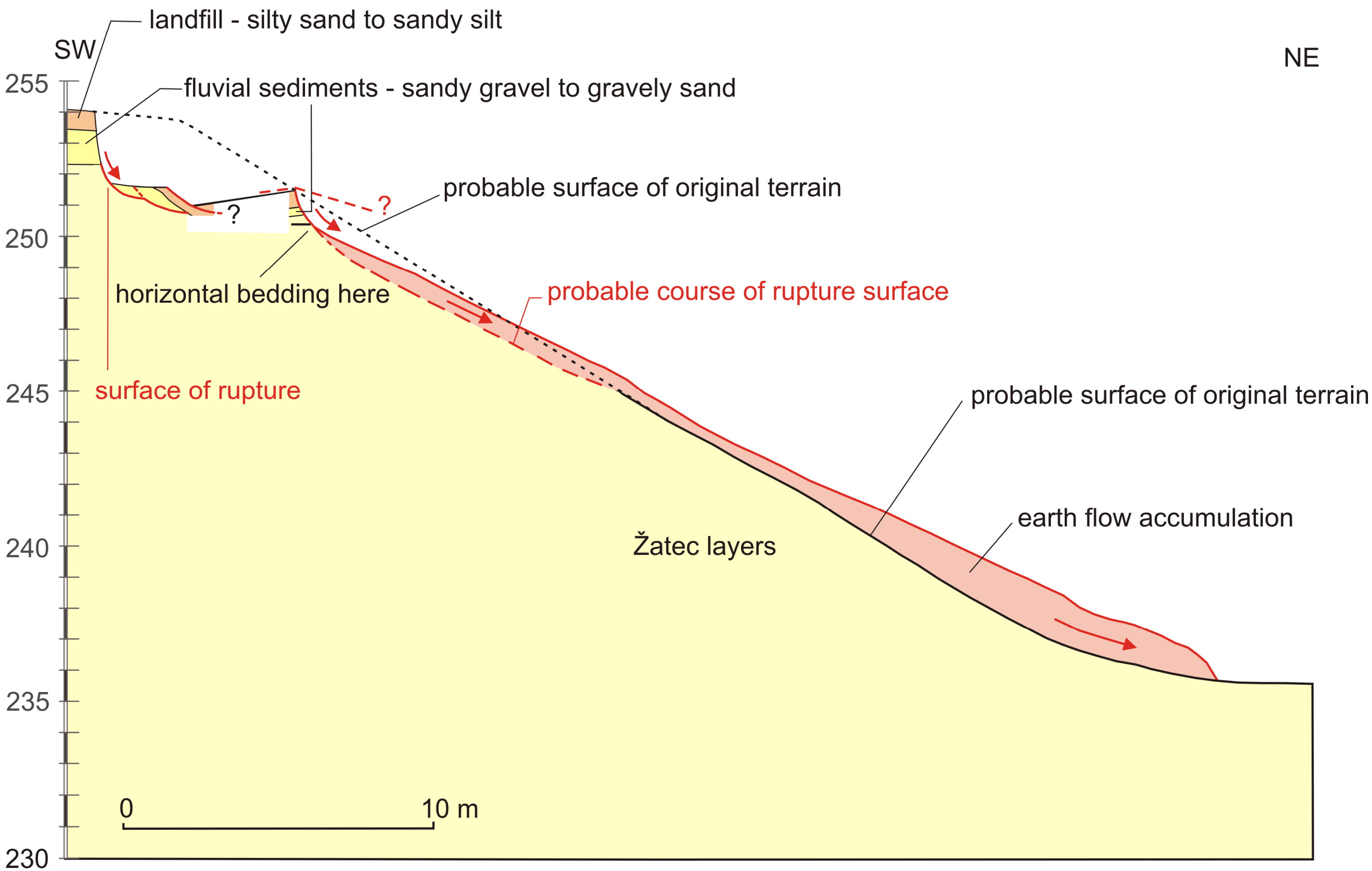


Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

Slope Deformation Field Checklist

1	**Number of slope deformation**	*Unique number for each slope deformation*
2	**Map number**	*Map number where is marked slope deformation*
3	**Near town, village**	*Near town or village*
4	**Coordinates (GPS)**	*Is related to the highest point of slope deformation in main scarp*
5	**Author of documentation and institution**	Name of geologist who is documenting slope deformation and his affiliation
6	**Date of documentation**	Day / month / year:
7	**Slope deformation**	☐ Single ☐ Complex ☐ Part of complex
8	**Type of slope deformation**	Classification (Varnes 1978) ☐ Falls ☐ Topples ☐ Slides ☐ Lateral spreads ☐ Flows ☐ Complex

9	**Total length (m)**	*the minimum from the tip of the landslide to the crown*
10	**Width of displaced mass (m)**	*the maximum breadth of the displaced mass perpendicular to the length of the displaced mass*
11	**Width of rupture surface (m)**	*the maximum width between the flanks of the landslide*
12	**Slope deformation according affected depth**	*Based on estimated vertical distance between surface and base of slope deformation:* ☐ Shallow (1-5 m) ☐ Medium deep (5 -50 m) ☐ Very deep (more than 50 m) ☐ Unknown
13	**Slope inclination**	*Average slope inclination of not affected original slope – estimation*
14	**Rock / soil type**	

15	**Hydrogeology**	Surface state: ☐ Dry ☐ Locally wet ☐ Springs ☐ Lakes, undrained depressions ☐ Brook / river
16	**Phase of slope deformation evolution**	☐ Initial (main movement is being expected) ☐ Developed ☐ Final (there is not space for next movement) ☐ Unknown
17	**Degree of activity**	☐ Active ☐ Dormant ☐ Stabilized
18	**Main scarp**	Height:
19	**Accumulation**	Height:
20	**Cracks**	☐ Yes ➢ width: ➢ estimated depth: ☐ No

21	**Triggering factors**	☐ Precipitation / water saturation ☐ Seismic activity / tectonic activity ☐ Change of slope geometry ➢ natural ➢ anthropogenic ☐ Human activity ☐ Unknown
22	**Remedy measures**	▪ Performed: ▪ Proposed:
23	**Land use**	☐ Forest ☐ Bush ☐ Meadow, pasture ☐ Field ☐ Urbanized area (settlements) ☐ Other

24	**Endangered objects:**	
25	**Remarks, recommendations, (sketch of slope deformation):**	

Monitoring of landslides

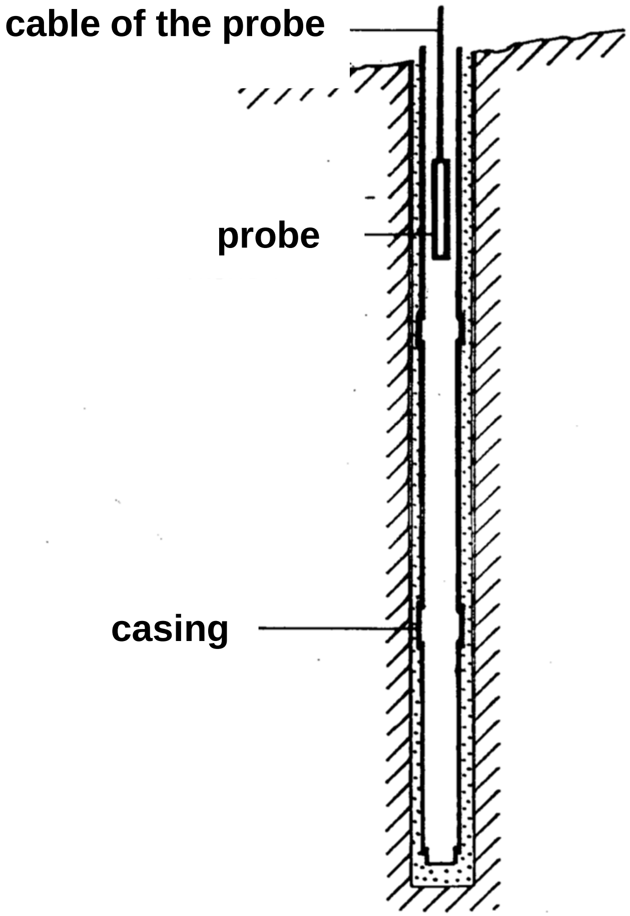
A) Measurement of deformations
- geodesy
- extensometry
- inclinometry
- dilatometry

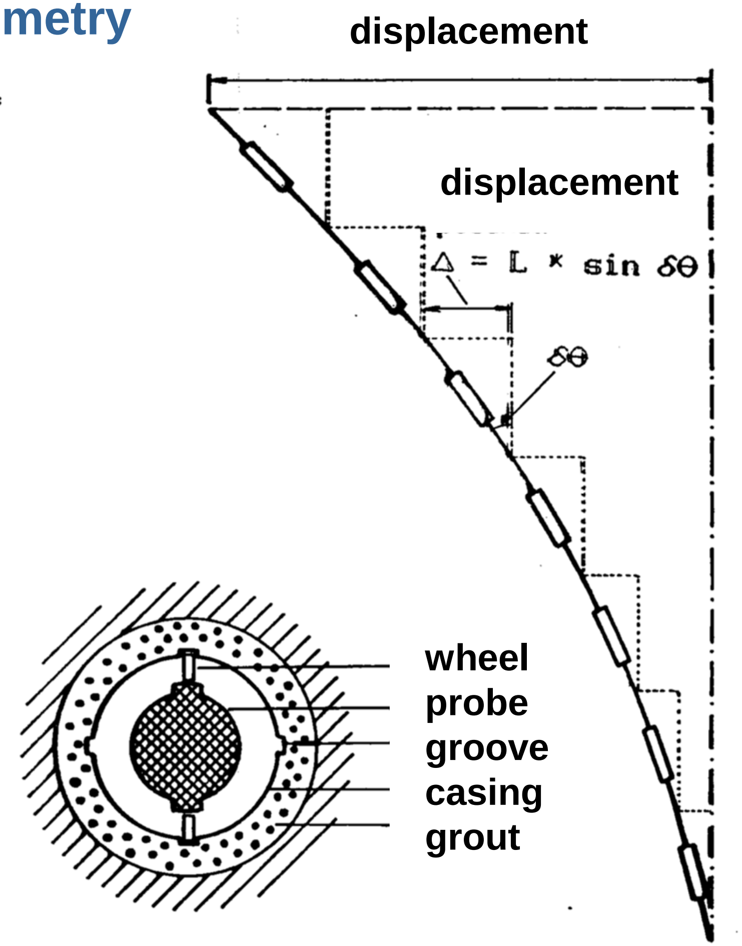
B) Monitoring of water state within landslide body
- ground water level and pore pressure observation
- measurement of spring yield

C) Measurement of stress
- stress in anchors

D) Indirect methods
- geophysics

Inclinometry





Methods of landslide investigation

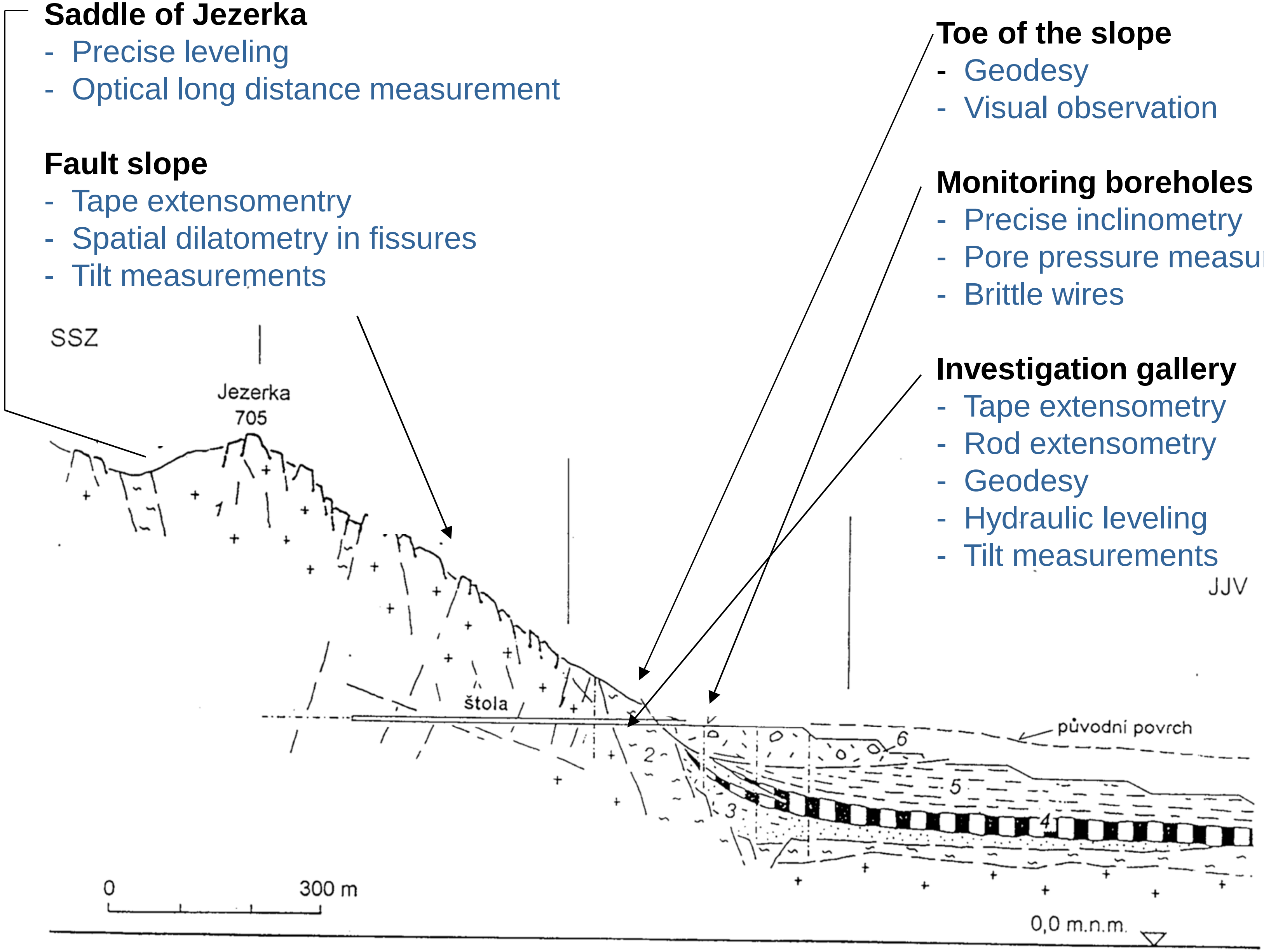
Saddle of Jezerka
- Precise leveling
- Optical long distance measurement

Fault slope
- Tape extensometry
- Spatial dilatometry in fissures
- Tilt measurements

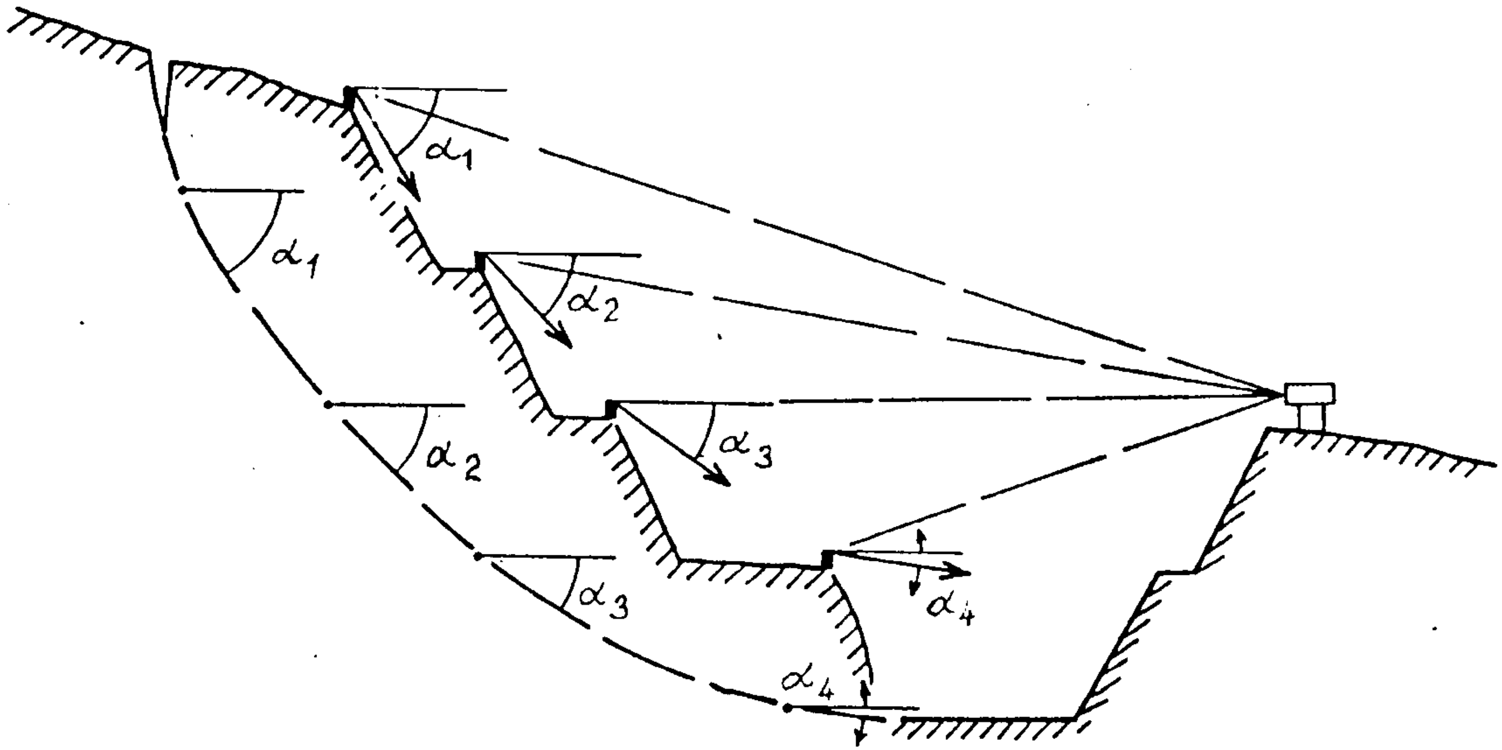
Toe of the slope
- Geodesy
- Visual observation

Monitoring boreholes
- Precise inclinometry
- Pore pressure measurement
- Brittle wires

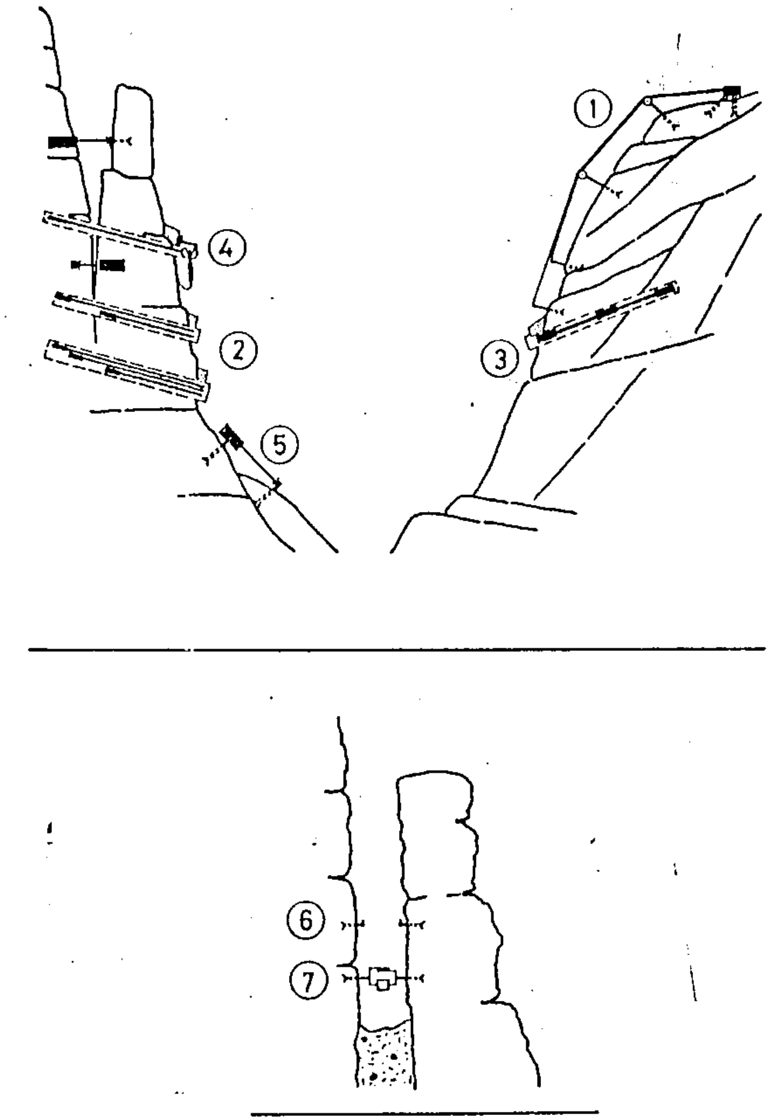
Investigation gallery
- Tape extensometry
- Rod extensometry
- Geodesy
- Hydraulic leveling
- Tilt measurements



Methods of landslide investigation



Scheme of reconstruction of rupture surface course based on vector measurement by optical long distance measurements



Selected types of gauges for monitoring of displacements on rock slopes:

1 – wire extensometer

2 – rod extensometer

3 – deflectometer

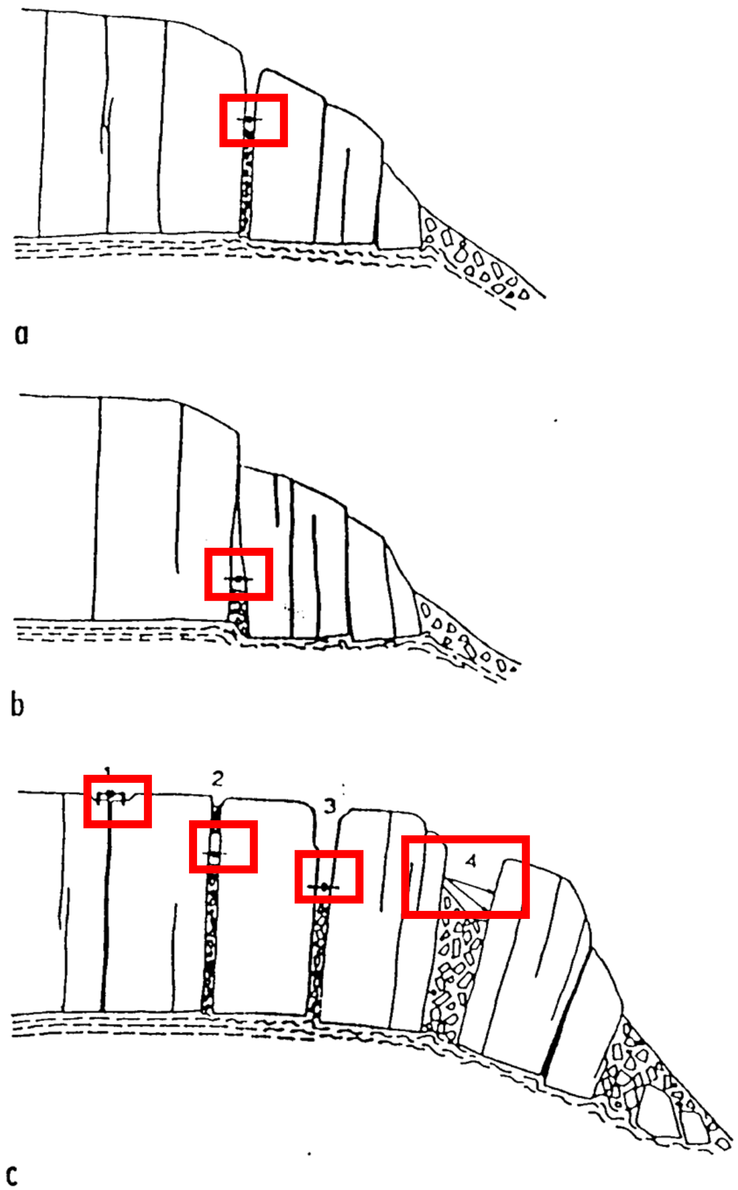
4 – rod extensometer with mechanical warning apparatus

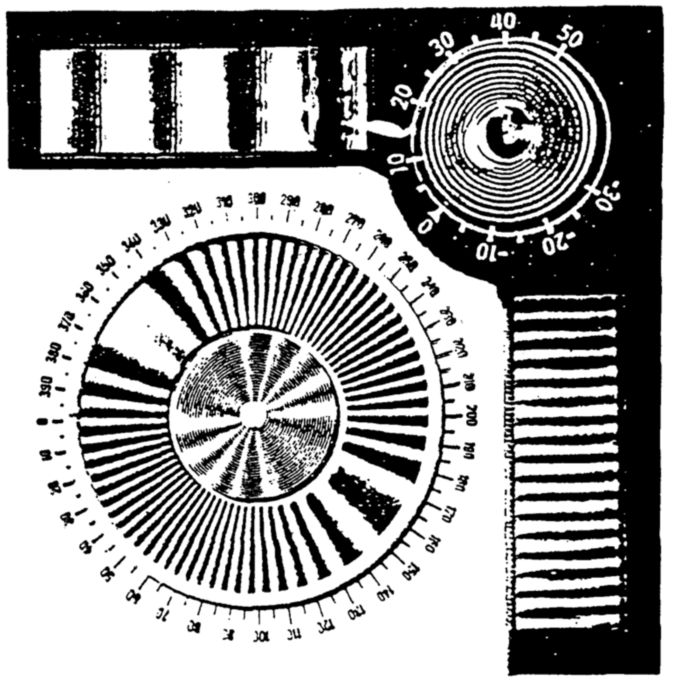
5 – portable rod dilatometer

6 – points for portable rod dilatometry

7 – dilatometric gauge TM-71

Methods of landslide investigation

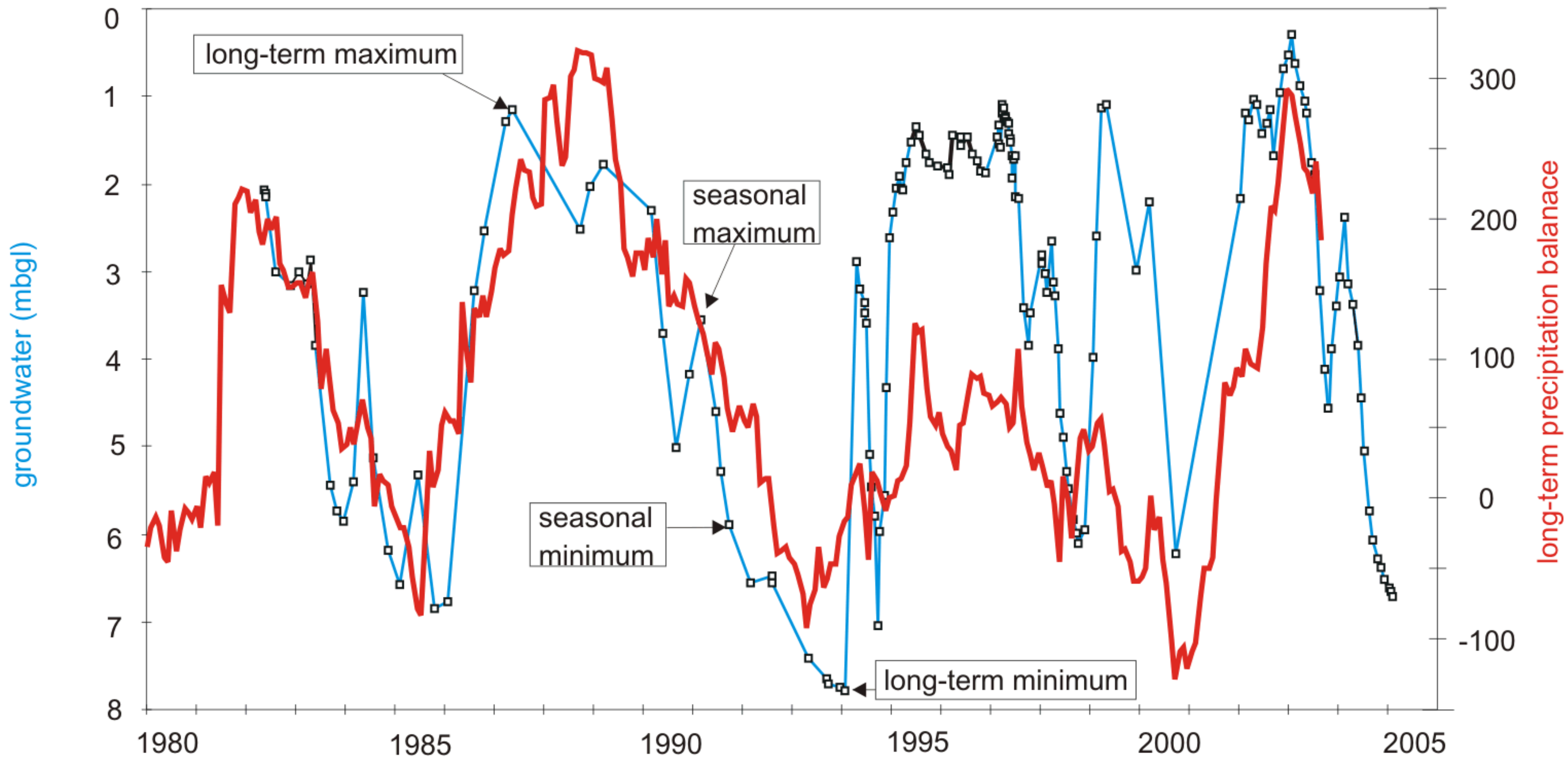




„TM 71“ interference system used for crack monitoring in all spatial components (Košťák 1991)

Long-term monitoring of groundwater level changes and long-term precipitation balance

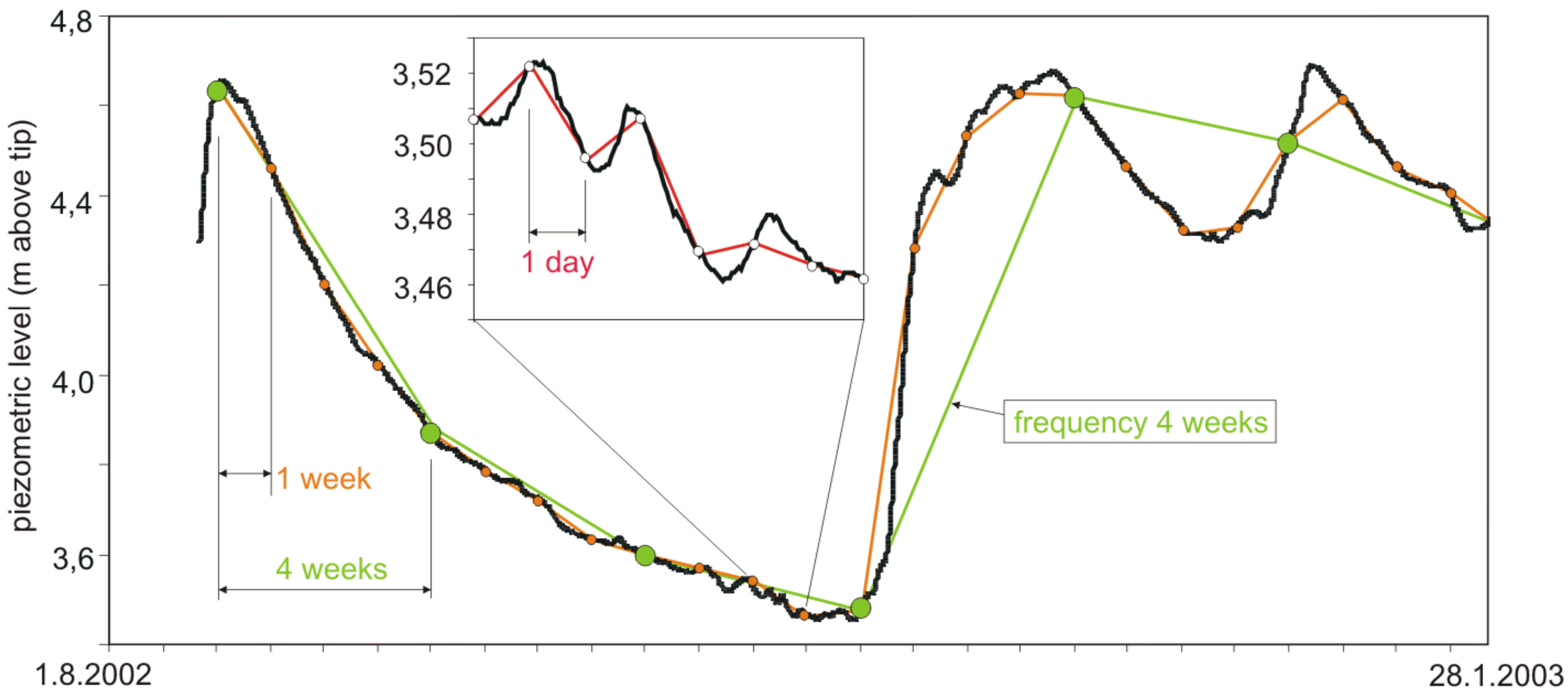
Třebenice landslide (Cretaceous claystones)



After J. Novotný 2005

Comparison of frequency of regime monitoring with quasicontinual monitoring

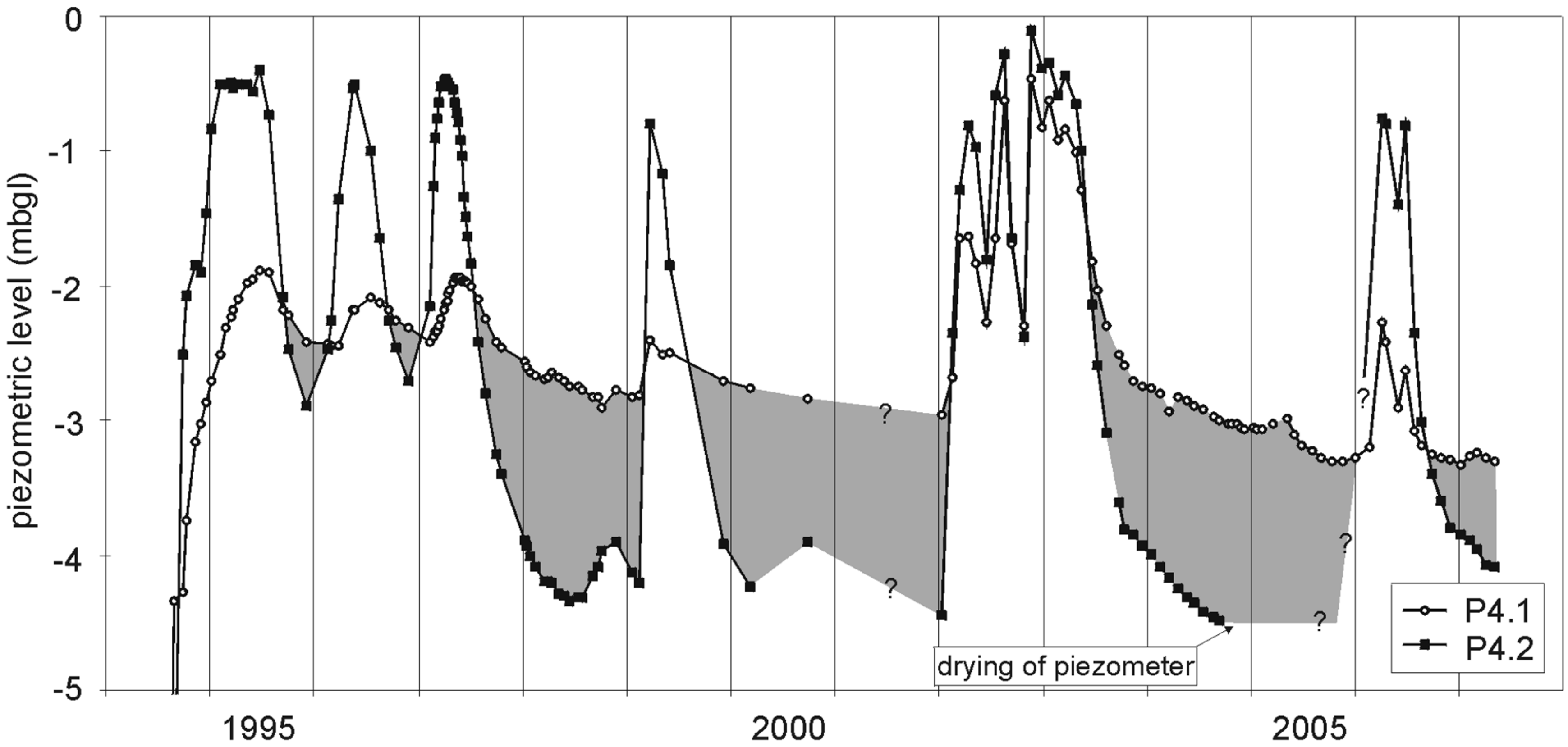
Třebenice landslide (Cretaceous claystones)



After J. Novotný 2005

Fluctuation of piezometric level in the P4.1 borehole (tip 9,5 m under the terrain) and the piezometric level in the P4.2 borehole (tip 4,5 m under the terrain). Grey areas represent time period with upward groundwater flow

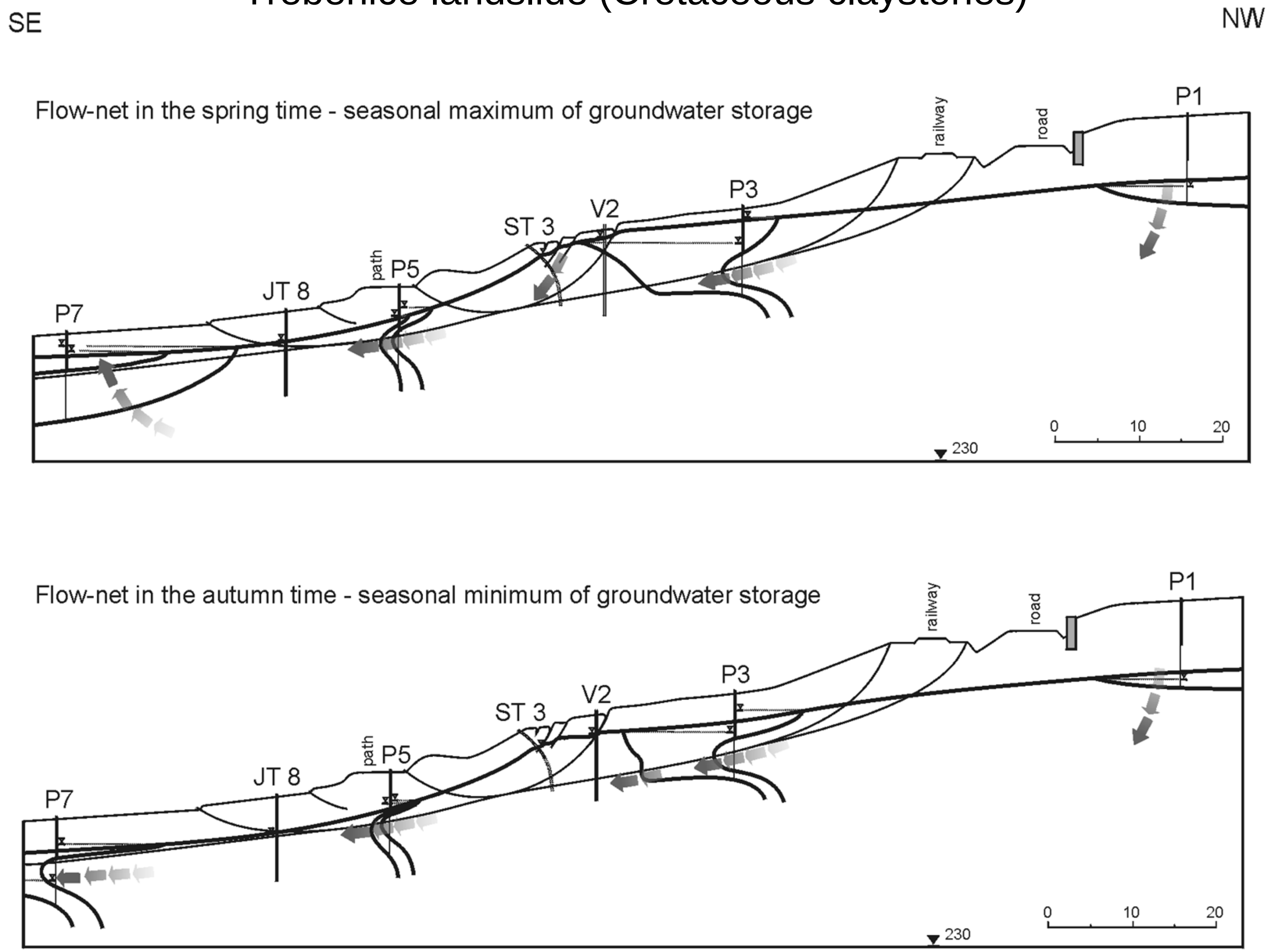
Třebenice landslide (Cretaceous claystones)



After J.Novotný and M.Kobr 2009

Schematic flow net for the period of seasonal culmination (above) and seasonal minimum (below) in the ground water storage

Třebenice landslide (Cretaceous claystones)



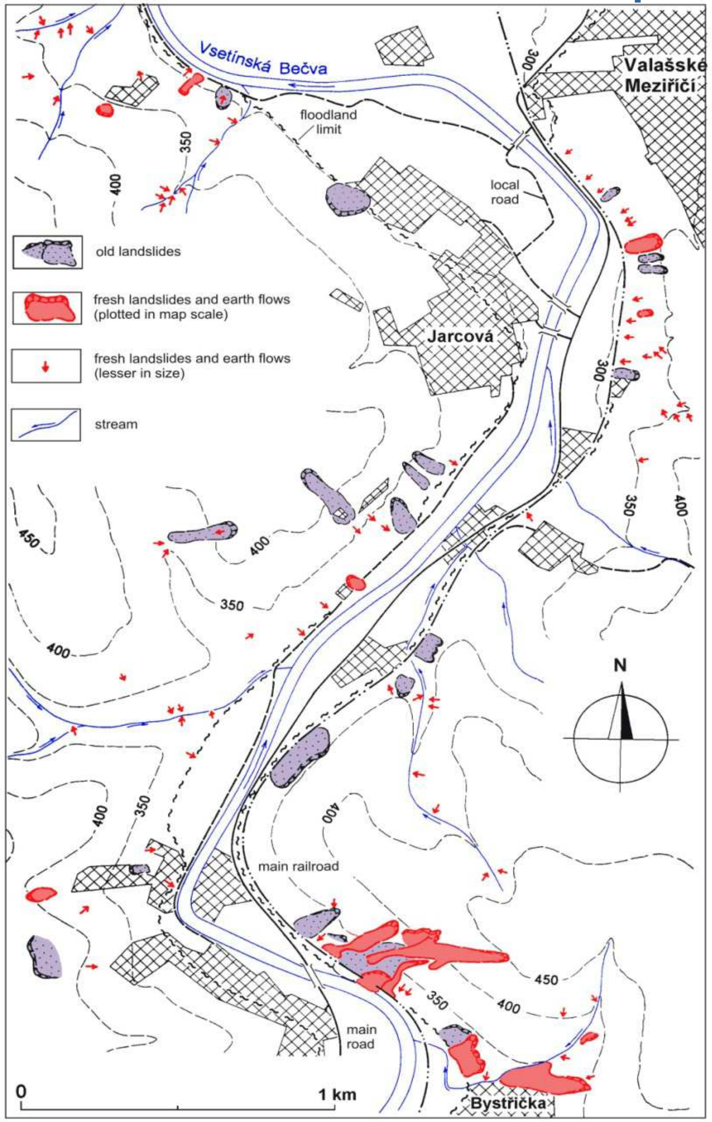
After J.Novotný and M.Kobr 2009

Methods of prognosis

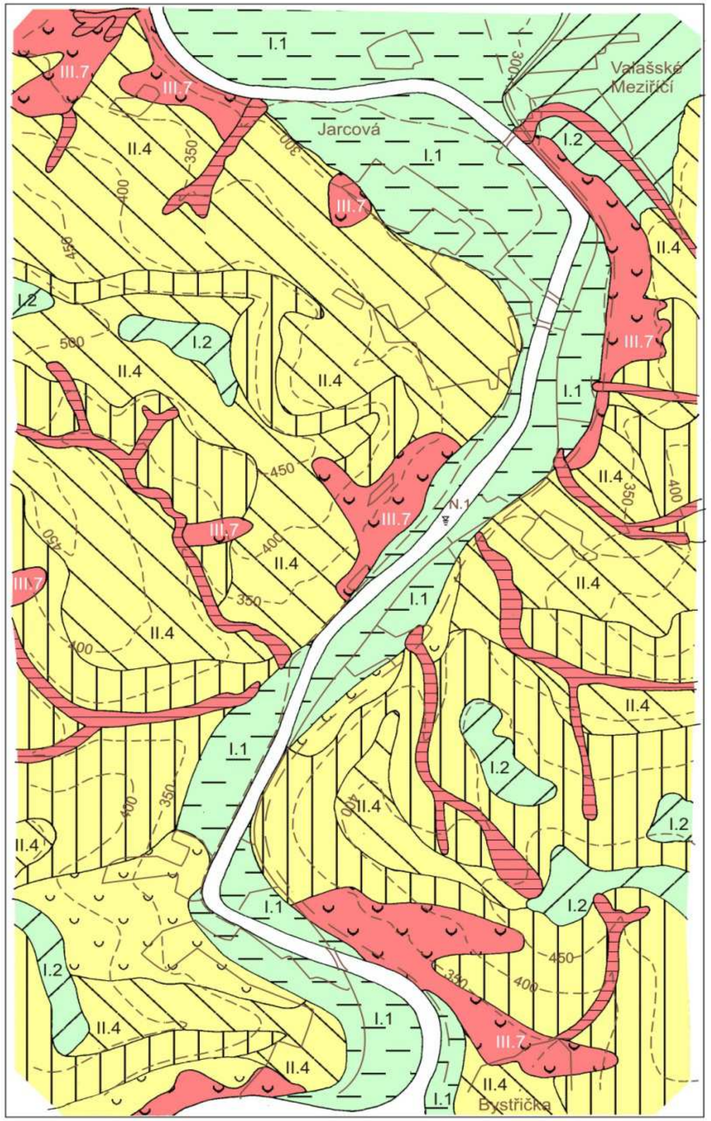
- Spatial prognosis
- Prognosis of mechanism and dimensions of failure
- Time prognosis

Methods of landslide investigation

Spatial prognosis



Landslide distribution map at 1: 10 000 scale
Vsetínská Bečva River site, northern of the town Vsetín (E Moravia)



Landslide susceptibility map at 1: 10 000 scale
Vsetínská Bečva River site

After J. Rybář

Methods of landslide investigation

zone	characteristic of the area regarding stability conditions	conditions for the area to be used as construction site of			
		residental and industruial buildings	roads	pipelines	light recreational buildings
I.	*stable areas*	*usable areas*			
I.1	flat flood plains	foundation conditions suitable for not sophisticated structures (exceptionally even for more sophisticated ones) under specific conditions	roads to be built on an embankment or a bridge, the structure must not reduce flood passage	without limitation	unsuitable area, although cottage building is presently frequent, flood risk is high
I.2	permanently stable slopes with very moderate gradient and flat areas above valleys	simple foundation conditions usually suitable even for more sophisticated structures	the area usually accessible only with difficulties; connections to main roads in valleys difficult	without limitation, connection to main network difficult	without limitation
II.	*area where slope instability cannot be excluded*	*conditionally usable areas*			
II.3	moderate slopes without verified sings of more serious failure	suitable for not sophisticated structures, stability failures due to improperly designed earthwork are not excluded (cuttings, cut-offs, embankments, water leakage etc.)	lay-out of the line, as well as earthwork is to be designed with respect to slope stability	slope stability must not be inflicted with deep furrows excavated for long-distance lines	without limitation
II.4	steep slopes without sings of deeper failure	unusable for ordinary building, otherwise enormous expenditures must be accepted	suitable only for local roads (e.g. forest roads)	if the lay-out cannot be changed then increased expenditures are to be accepted	without limitation
II.5	slopes deformed by superficial creep movements	if chosen as construction site increased expenditures for preventive remedy measures must be considered (e.g. for superficial or deep drainage in the area)	suitable only for local roads, othrewise increased expenditures for preventive remedy measures	lay-out of long-distance lines along the dip	unsuitable area
II.6	slope deformed by landslides and block-type movements in the past time	unusuitable for building, acceptable only with enormous expenditures for survey, monitoring and remedy measures	construction possible only with enormously increased expenditures	unsuitable area, in case of absolute necessity lay-out along the dip	unsuitable area
III.	*unstable areas*	*unsuitable areas*			
III.7	slope deformed by present active or dormant deformations, as well as by earthflows	construction has to be avoided unless stabilisation measures carried out beforhand with successful results proved by monitoring	construction possible with enormously increased expenditures for preventive remedy measures and monitoring	entirely unsuitable area	unsuitable area
III.8	erosion gullies of occasional as well as of permanent small flows	entirely unsuitable area	unsuitable area that can be passed by abridge	unsuitable area	unsuitable area, although cottage building, is presently frequent; risk due to floods, spates and earthflows is high
III.9	steep rock slopes and their toes where rockfalls may occur	unsuitable area	change of the lay-out is recommended, preventive remedy measures would be too expensive	without limitation under the condition of keeping the lines underground in the area of accumulation	entirely unsuitable area, although cottage building is presently frequent
N.	*areas unusable regarding other than stability reasons*				
N.1	large water plains				
N.2	quarries, dump sites, protected areas, etc.				

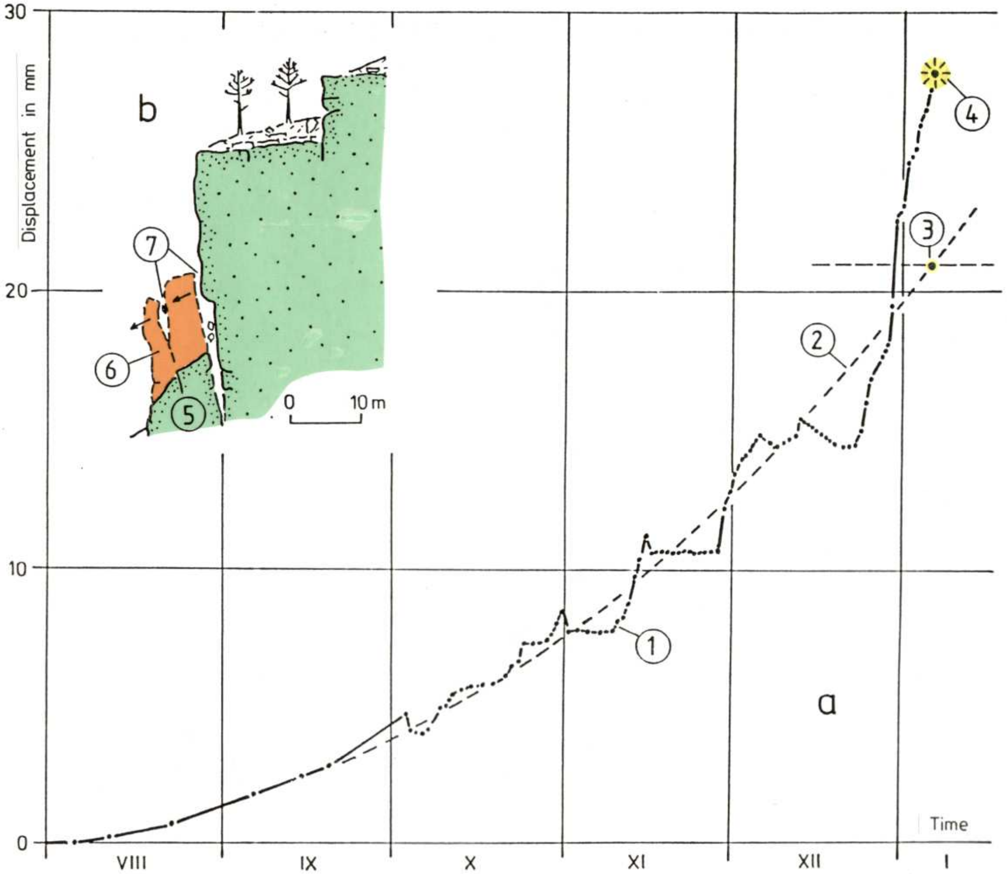
Explanations to landslide susceptibility maps

After J. Rybář 2003

Methods of landslide investigation

Time prognosis

Rock fall in Hřensko, Czech Republic, March 1978

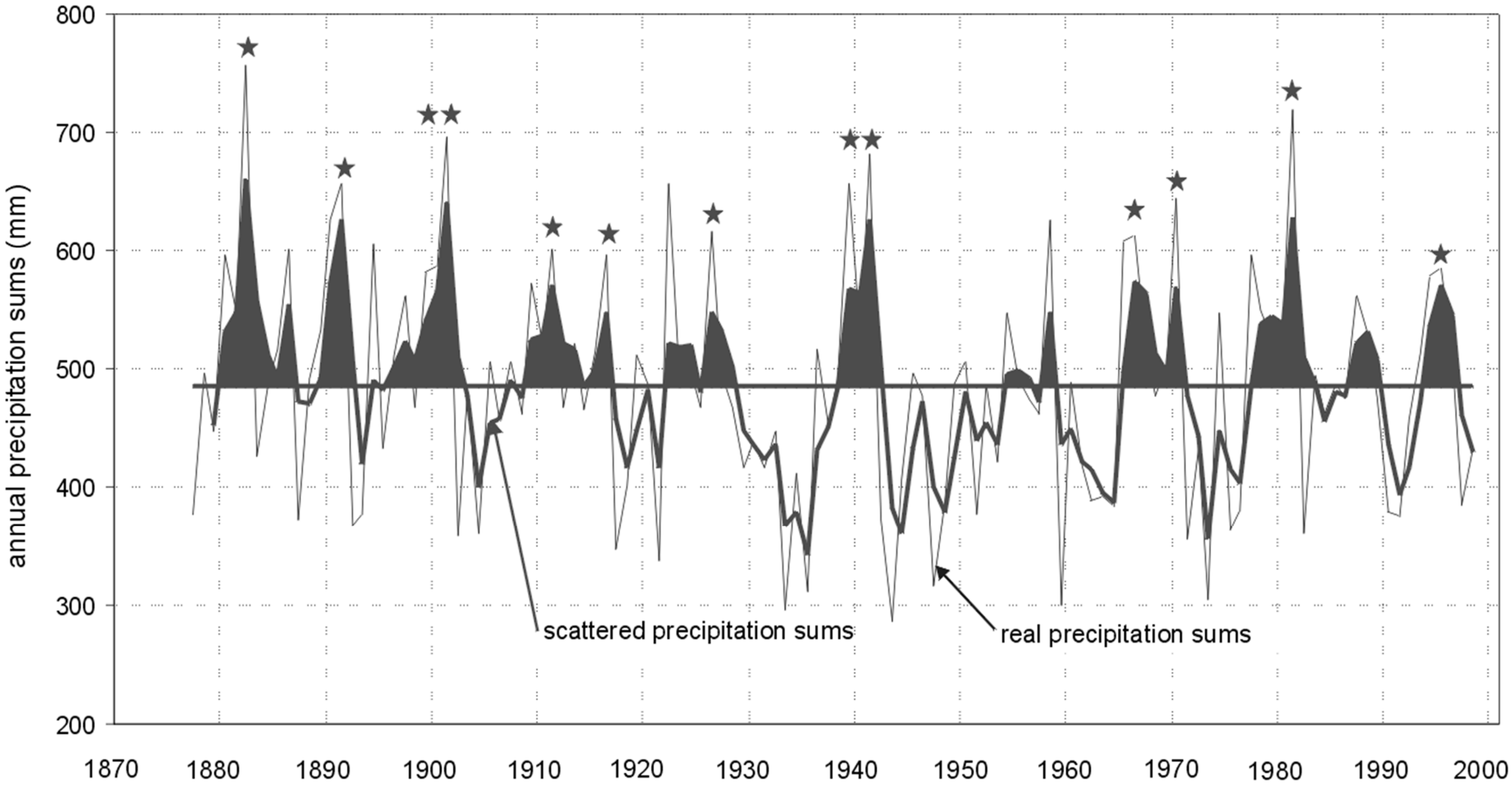


Time prognosis for the outset of a rockfall (a) in the profile (b) near Hřensko in Czech-Saxonian Sandstones (Zvelebil)

Photo J. Rybář

After J. Zvelebil 1984

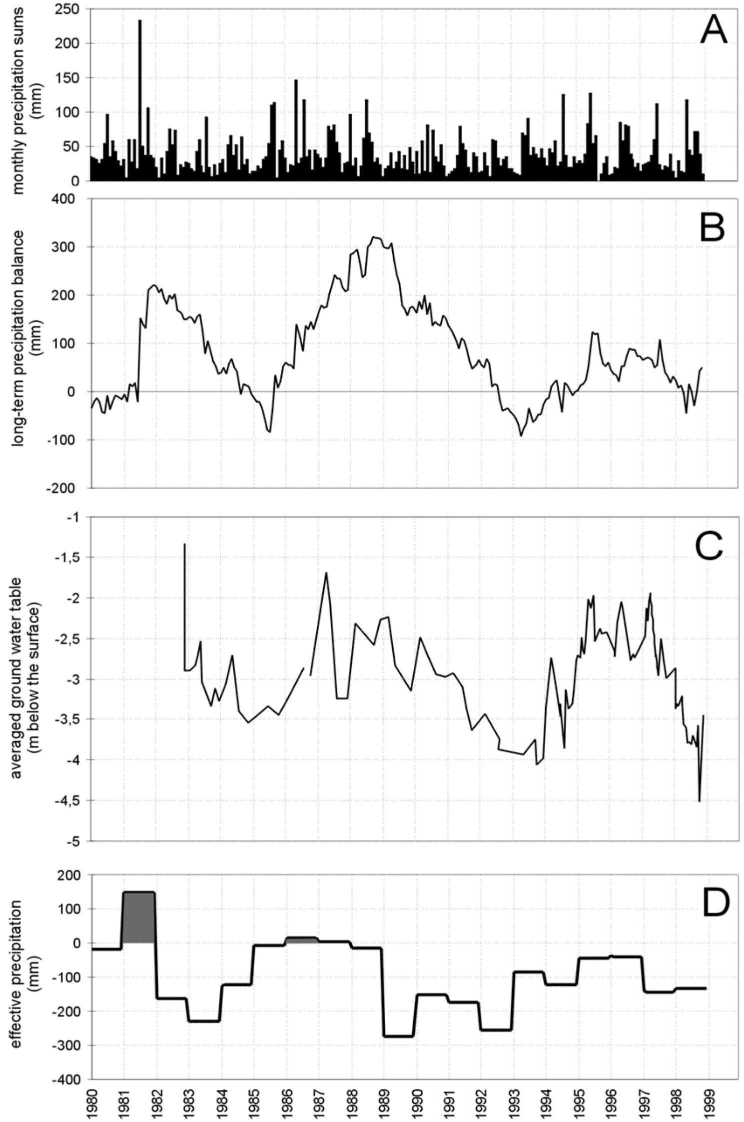
Real and three year gradually dispersed annual precipitation total from Louny hydrometeorological station, periods of sliding activity are marked by asterisks



After Novotný 2000

Methods of landslide investigation

The effect of precipitation and evapotranspiration on fluctuation of groundwater level for Třebenice landslide



After Novotný 2000

Correlation between climate, piezometric levels and movement for Třebenice landslide