

# Systematic mapping and hazard and risk classification of unstable rock slopes with a potential of forming displacement waves in Norway

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## Content

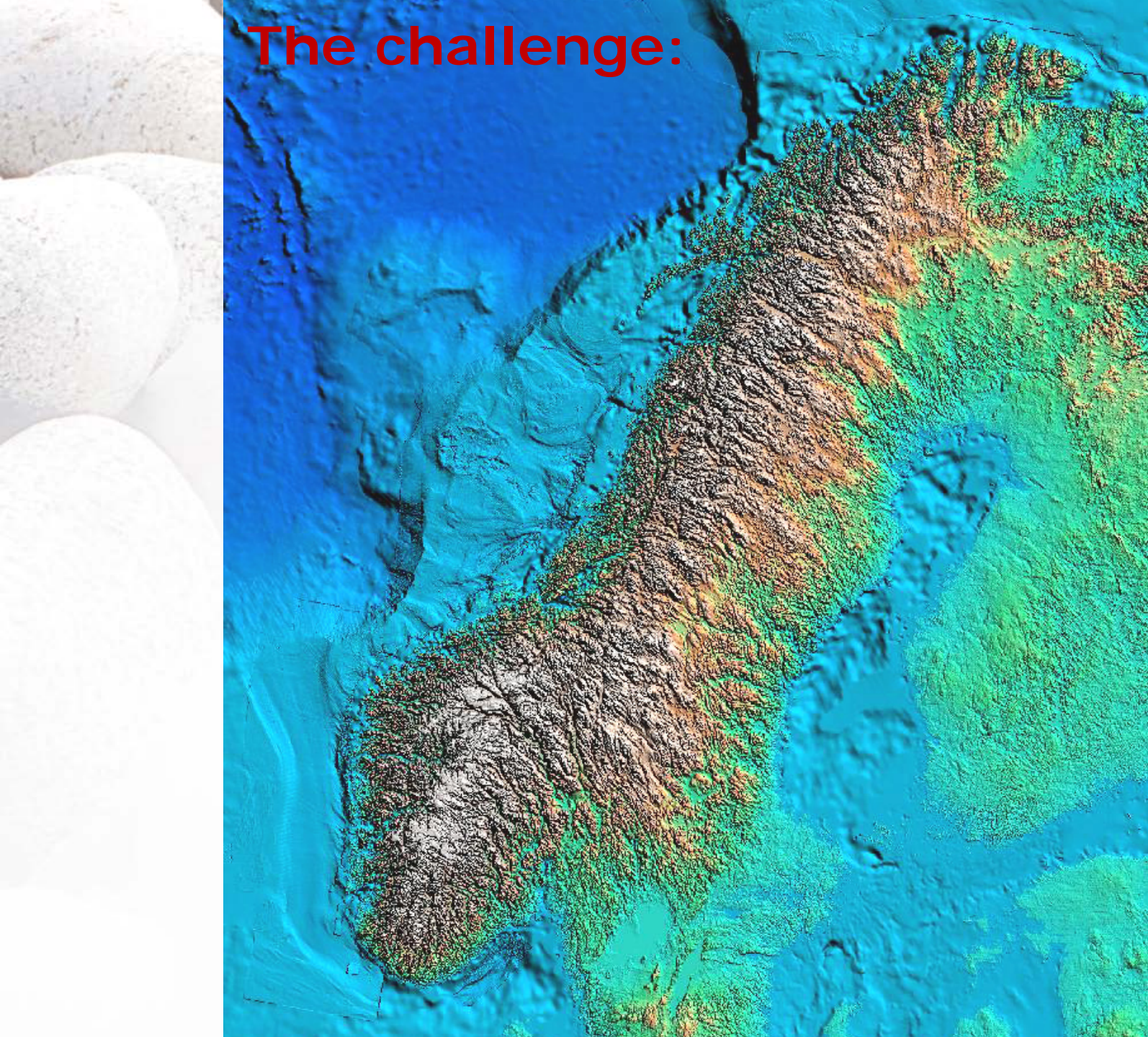
- Historic rock slope failures in Norway triggering displacement waves
- Hazard and risk classification
- Mapping methodology for unstable rock slopes







**The challenge:**





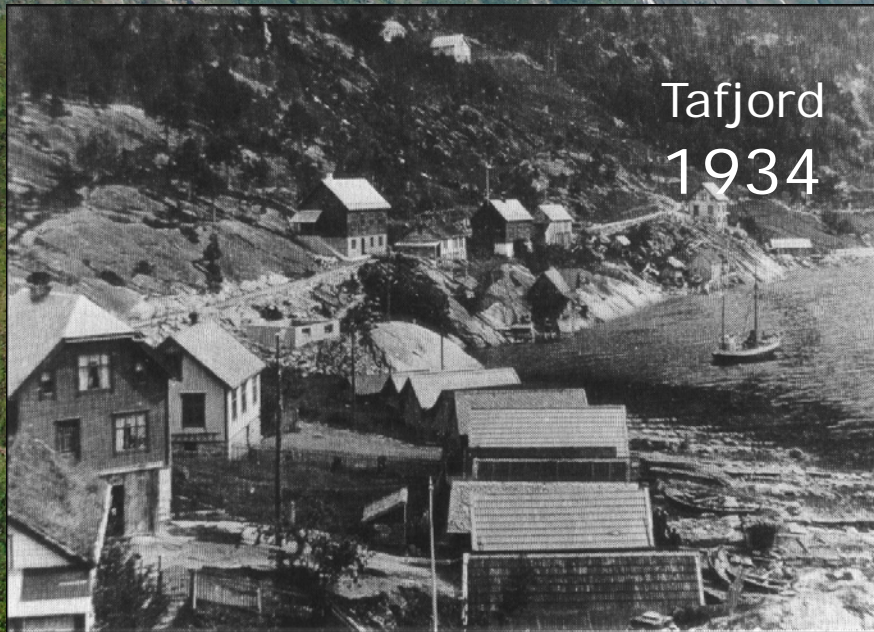
# Norway

- 68. largest country on earth
- 7. longest coast line
- coast line > 100.000 km long + lakes





# Historic rockslide disasters in Norway





Certain fjellskred events						
Name	County	Municipality	Year	Volume [Mm³]	Lives	Displacement wave
Tjelle	Møre og Romsdal	Nesset	1756	15.0	32	Yes
Tafjordulykka	Møre og Romsdal	Norddal	1934	3.0	40	Yes
Skafjellet	Møre og Romsdal	Stranda	1731	6.0	17	Yes
Lausneset	Møre og Romsdal	Stranda	1300	-	0	Yes
Loenulykke 1	Sogn og Fjordane	Stryn	1905	0.4	61	Yes
Loenulykke 3	Sogn og Fjordane	Stryn	1936	1.0	74	Yes
Pollfjellet	Troms	Lyngen	1810	-	14	Yes
Uncertain fjellskred events						
Name	County	Municipality	Year	Volume [Mm³]	Lives	Displacement wave
Storefonna	Møre og Romsdal	Sande	1700	-	0	Yes
Geirangerfjorden	Møre og Romsdal	Stranda	1749	0.1	0	Yes
Skafjellet	Møre og Romsdal	Stranda	1938	0.4	0	Yes
Arnafjord	Sogn og Fjordane	Norddal	1811	-	45	Yes
Hestadfjorden	Sogn og Fjordane	Gaular	1786	-	0	Yes
Årdalsfjorden	Sogn og Fjordane	Årdal	1983	0.2	0	Yes

151 km

© 2011 Europa Technologies  
© 2011 Geocentre Consulting  
© 2011 Google  
© 2011 Tele Atlas

61°55'58.57" N 8°08'38.54" E elev 575 m

©2010 Google

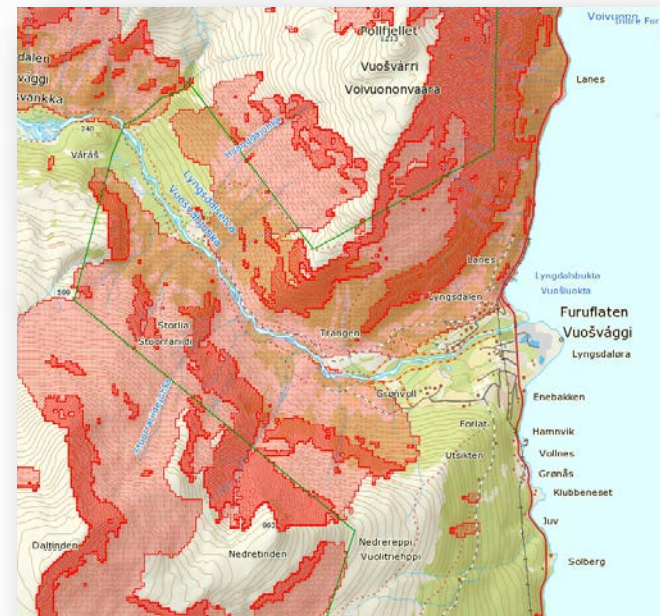
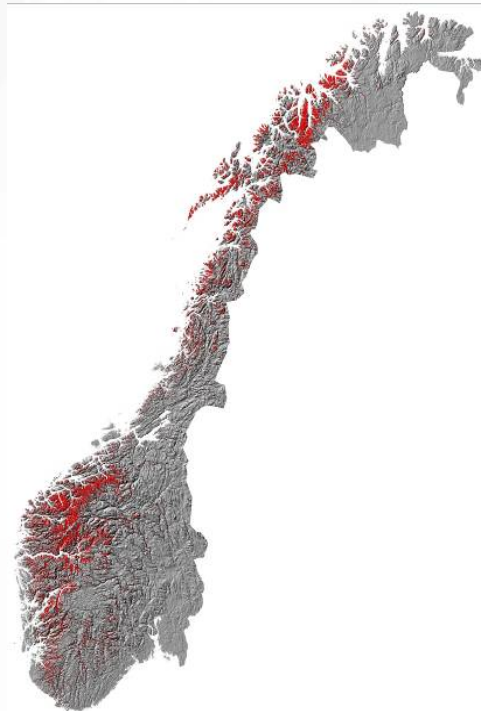
Eye alt 499.03 km



# Mapping of unstable rock slopes in Norway

## The vision:

- to characterize all unstable rock slopes which can cause effects in a distance larger than the shadow angle of rock falls
- 0 loss of life due to large rock slope failures in the next centuries



<http://www.skrednett.no/>





# Mapping of unstable rock slopes in Norway

Tafjord 1984

## **Assumption:**

- Slow deformation indicating slope instability
- Acceleration phase prior to collapse





# Hazard and risk classification of unstable rock slopes

**” As the likelihood of failure cannot be given quantitatively in hundreds or thousands of years with today's scientific knowledge, the risk analysis is built on a qualitative hazard analysis and a quantitative consequence analysis. ”**

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HALGEIR DAHLE (\*\*\*\*), GRAZIELLA DEVOLI (\*\*\*\*\*), LUZIA FISCHER (\*),  
MICHEL JABOYEDOFF (\*\*\*\*\*), SIMON LOEW (\*\*\*\*\*), STINE SÆTRE (\*\*\*\*\*),  
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(\*\*\*\*\*) University of Lausanne, Switzerland

(\*\*\*\*\*) ETH Zurich, Switzerland

(\*\*\*\*\*) The county of Møre og Romsdal, Norway





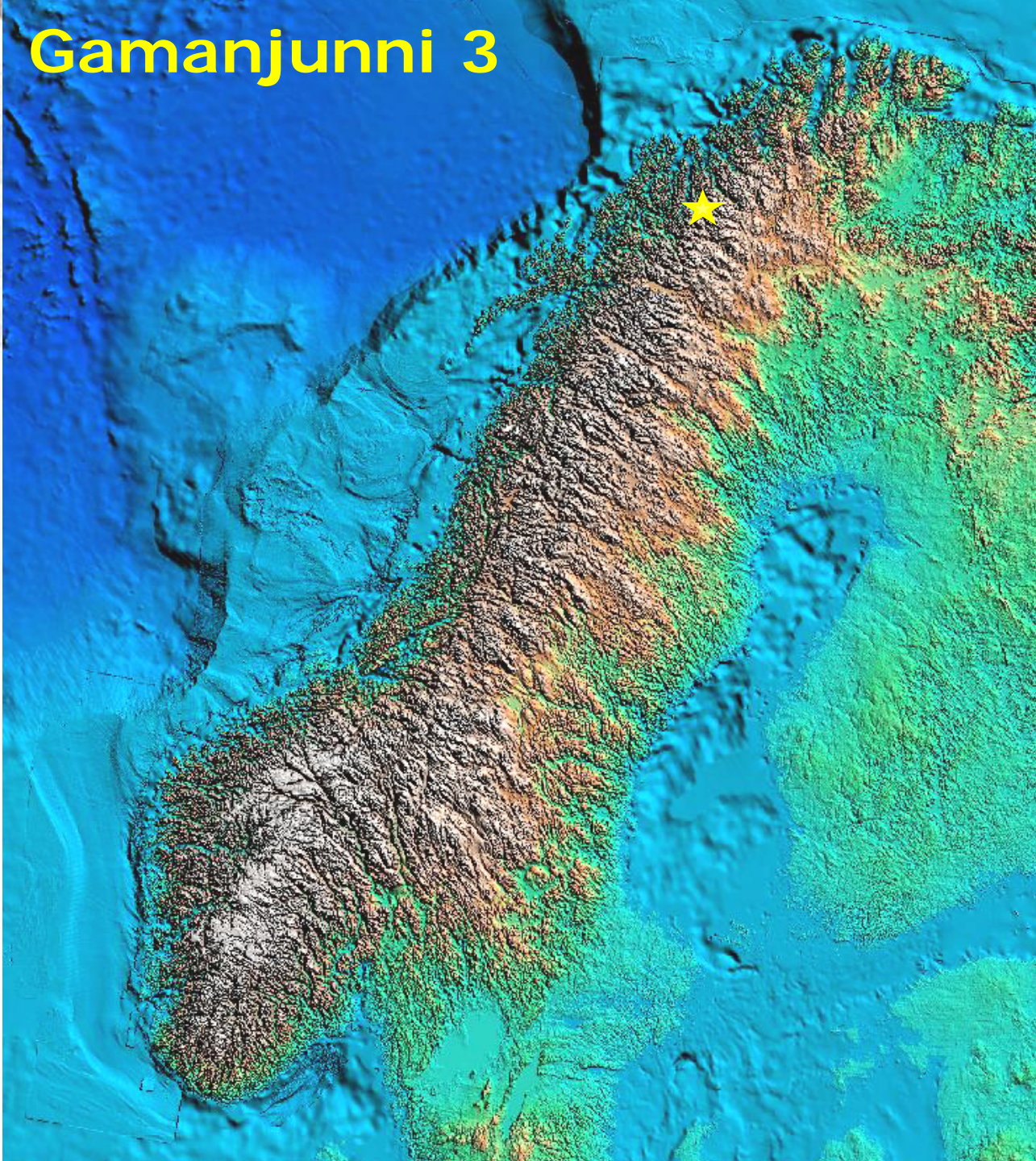
# Hazard and risk classification of unstable rock slopes

<b>1. Back-scarp</b>	<b>Score</b>	<b>Rel. prob.</b>	<b>Norm. prob.</b>
Not developed	0	0	0.0%
Partly open over length of slide body (few cm to m)	0.5	20	20.0%
Fully open over length of slide body (few cm to m)	1	80	80.0%
<b>2. Potential sliding structures</b>	<b>Score</b>	<b>Rel. prob.</b>	<b>Norm. prob.</b>
No penetrative structures dip out of the slope	0	10	10.0%
Penetrative structures dip on average < 20 degree or steeper than the slope	0.5	80	80.0%
Penetrative structures dip on average > 20 degree and daylight with the slope	1	10	10.0%
<b>3. Lateral release surfaces</b>	<b>Score</b>	<b>Rel. prob.</b>	<b>Norm. prob.</b>
Not developed	0	0	0.0%
Partly developed on 1 side	0.25	0	0.0%
Fully developed or free slope on 1 side or partly developed on 2 sides	0.5	0	0.0%
Fully developed or free slope on 1 side and partly developed on 1 side	0.75	100	100.0%
Fully developed or free slope on 2 sides	1	0	0.0%
<b>4. Kinematic feasibility test</b>	<b>Score</b>	<b>Rel. prob.</b>	<b>Norm. prob.</b>
Kinematik feasibility test does not allow for planar, wedge sliding or toppling	0	0	0.0%
Failure is partly kinematically possible (movement direction is more than $\pm 30^\circ$ to slope orientation)	0.5	100	100.0%
Failure is partly kinematically possible (movement direction is more than $\pm 30^\circ$ to slope orientation)	0.75	0	0.0%
Failure is partly kinematically possible on persistent discontinuities (movement direction is more than $\pm 30^\circ$ to slope orientation)	0.75	0	0.0%
Failure is kinematically possible on persistent discontinuities (movement direction is less than $\pm 30^\circ$ to slope orientation)	1	0	0.0%
<b>5. Morphologic expression of the rupture surface</b>	<b>Score</b>	<b>Rel. prob.</b>	<b>Norm. prob.</b>
No indication on slope morphology	0	75	75.0%
Slope morphology suggests formation of a rupture surface (bulging, concavity-convexity, springs)	0.5	25	25.0%
Continuous rupture surface is suggested by slope morphology and can be mapped out	1	0	0.0%
<b>6. Displacement rates</b>	<b>Score</b>	<b>Rel. prob.</b>	<b>Norm. prob.</b>
No significant movement	0	50	50.0%
0.2 - 0.5 cm/year	1	50	50.0%
0.5 - 1 cm/year	2	0	0.0%
1 - 4 cm/year	3	0	0.0%
4 - 10 cm/year	4	0	0.0%
> 10 cm/year	5	0	0.0%
<b>7. Acceleration (if velocity is &gt;0.5 cm/yr and &lt;10 cm/yr)</b>	<b>Score</b>	<b>Rel. prob.</b>	<b>Norm. prob.</b>
No acceleration or change in slope deformation	0	0	50.0%
Increase in slope deformation	1	0	50.0%
<b>8. Increase of rock fall activity</b>	<b>Score</b>	<b>Rel. prob.</b>	<b>Norm. prob.</b>
No increase of rock fall activity	0	75	75.0%
Increase of rock fall activity	1	25	25.0%
<b>9. Past events</b>	<b>Score</b>	<b>Rel. prob.</b>	<b>Norm. prob.</b>
No post-glacial events of similar size	0	0	0.0%
One or several events older than 5000 years of similar size	0.5	100	100.0%
One or several events younger than 5000 years of similar size	1	0	0.0%





# Gamanjunni 3





# Hazard and risk classification of unstable rock slopes





# Hazard and risk classification of unstable rock slopes

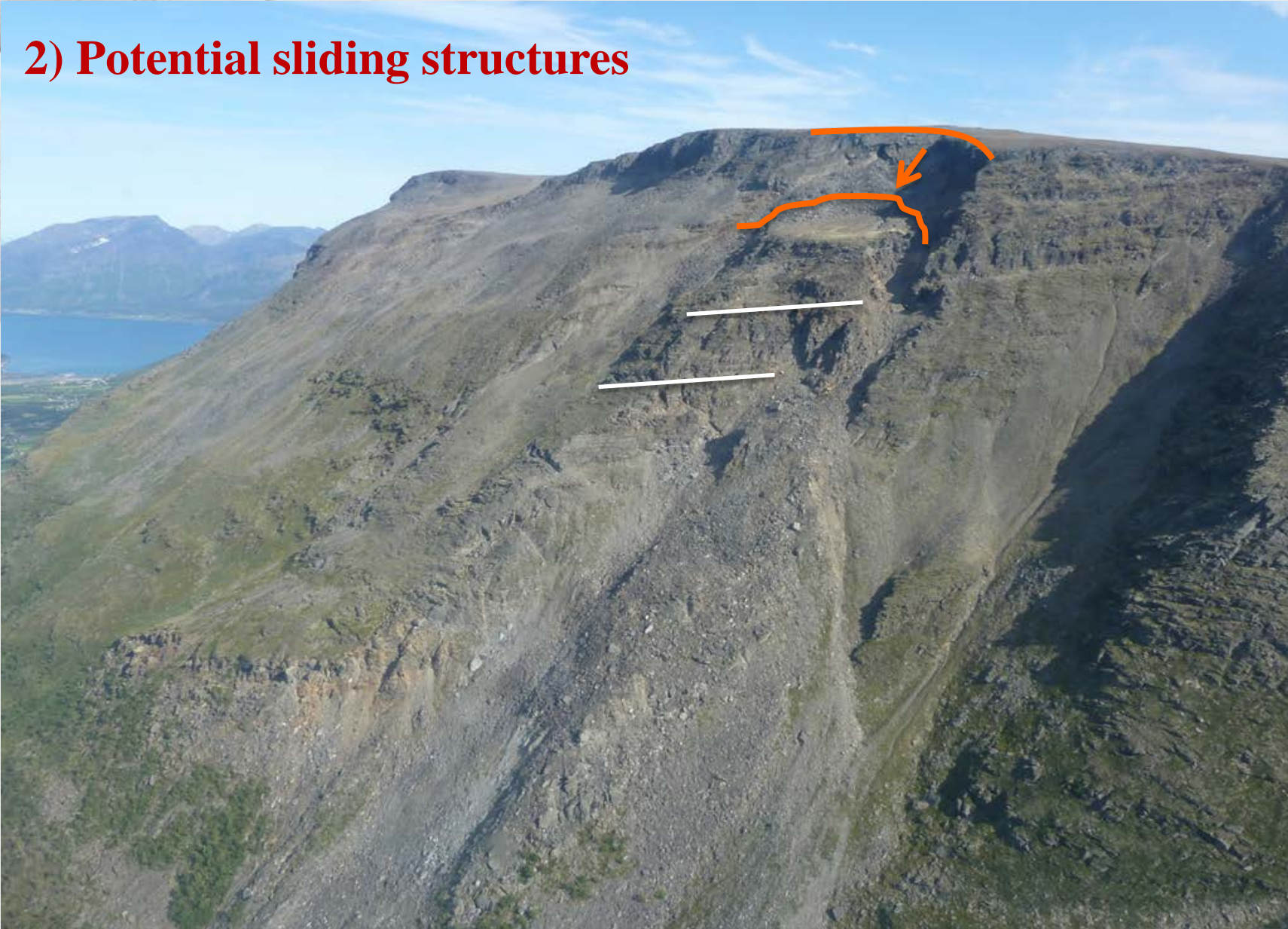
## 1) Back scarp





# Hazard and risk classification of unstable rock slopes

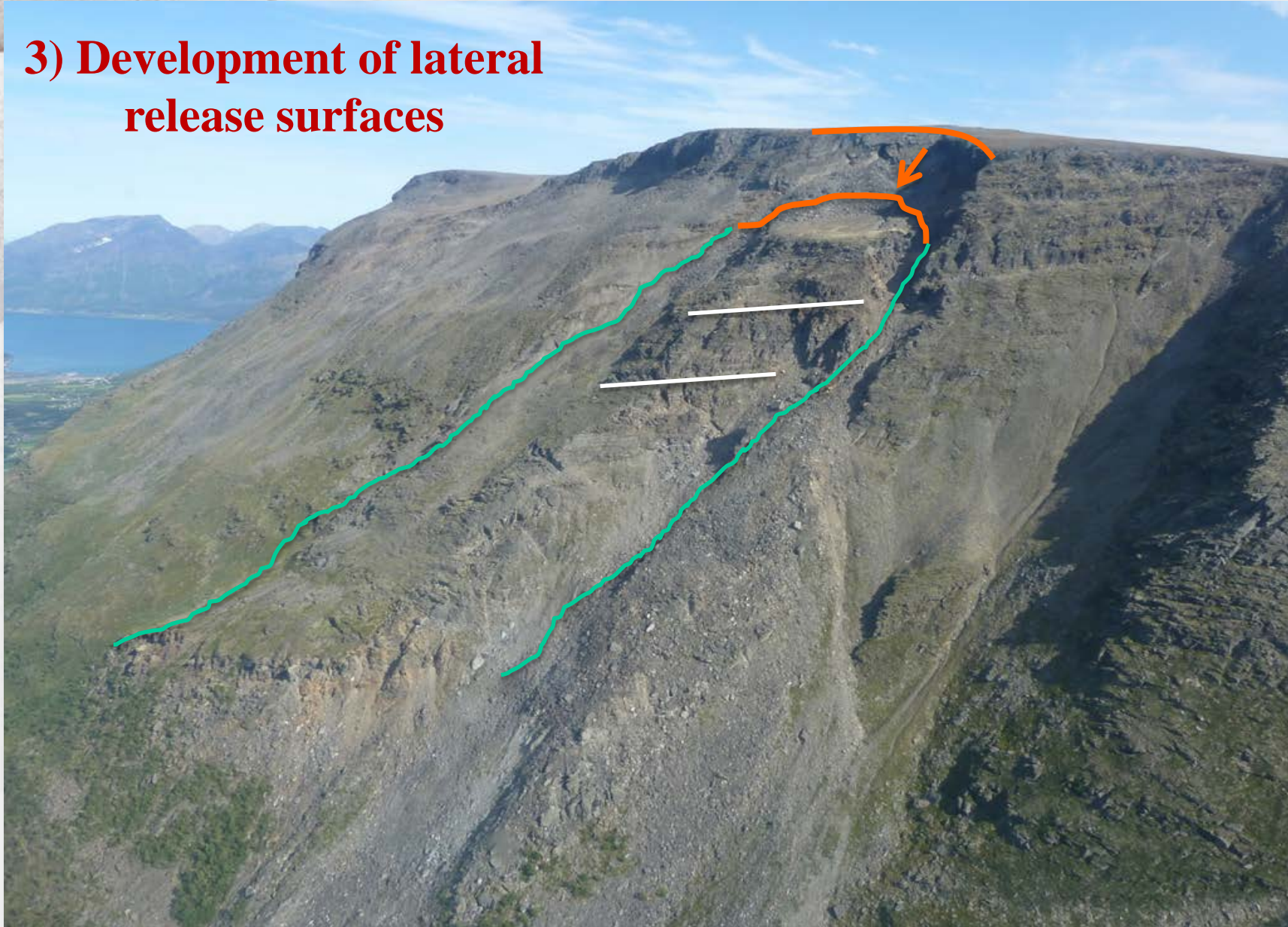
## 2) Potential sliding structures





# Hazard and risk classification of unstable rock slopes

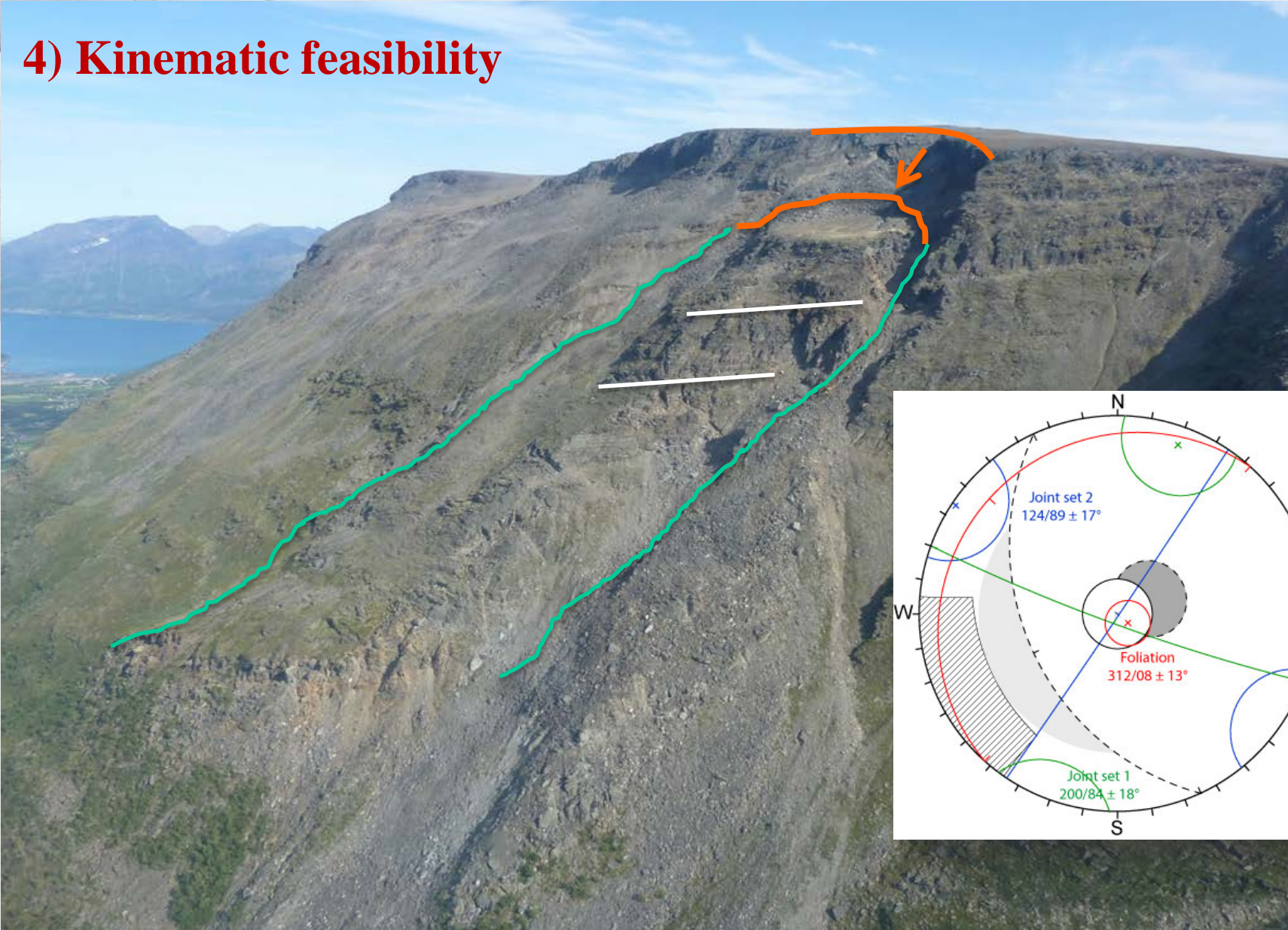
## 3) Development of lateral release surfaces





# Hazard and risk classification of unstable rock slopes

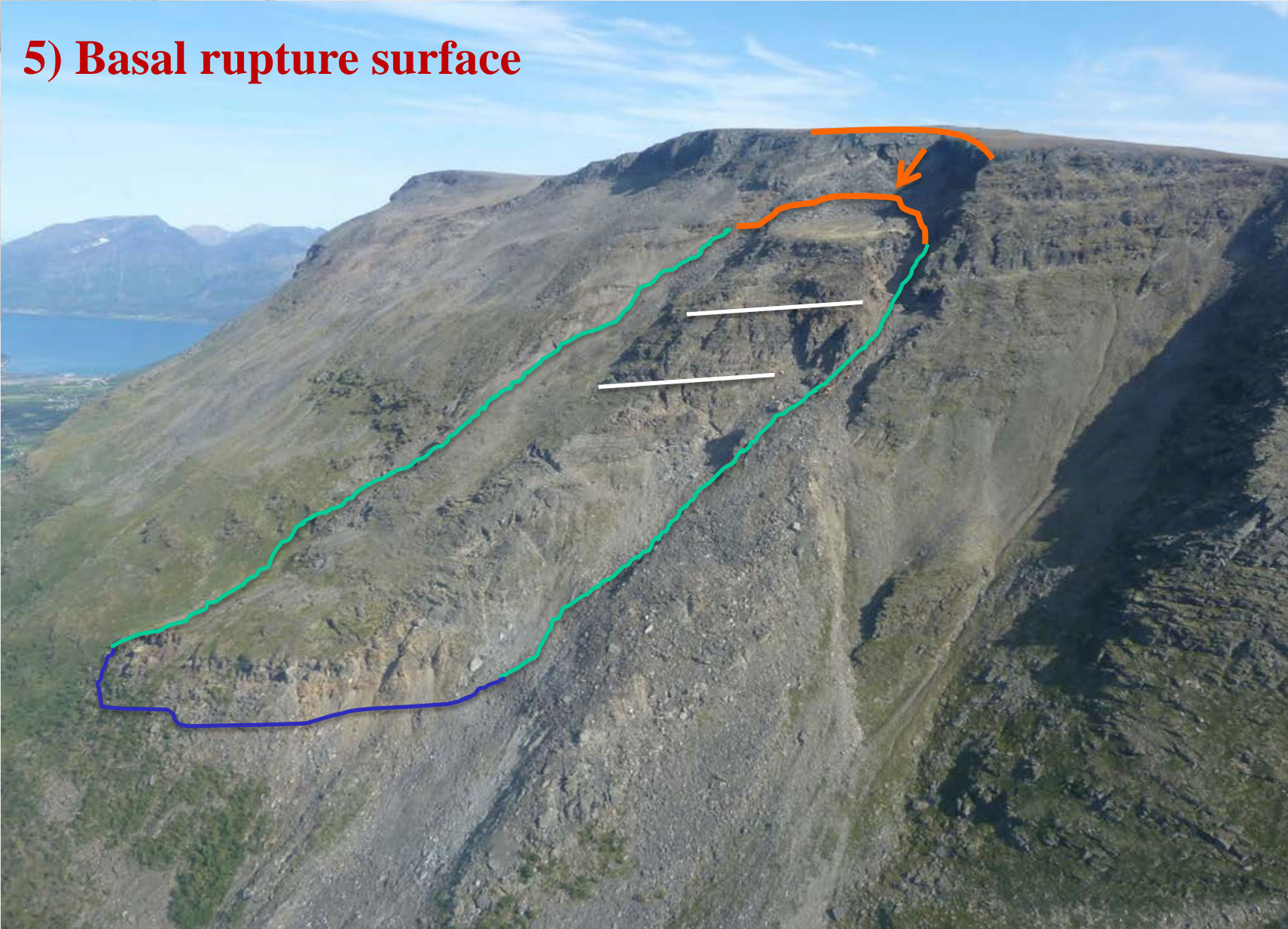
## 4) Kinematic feasibility





# Hazard and risk classification of unstable rock slopes

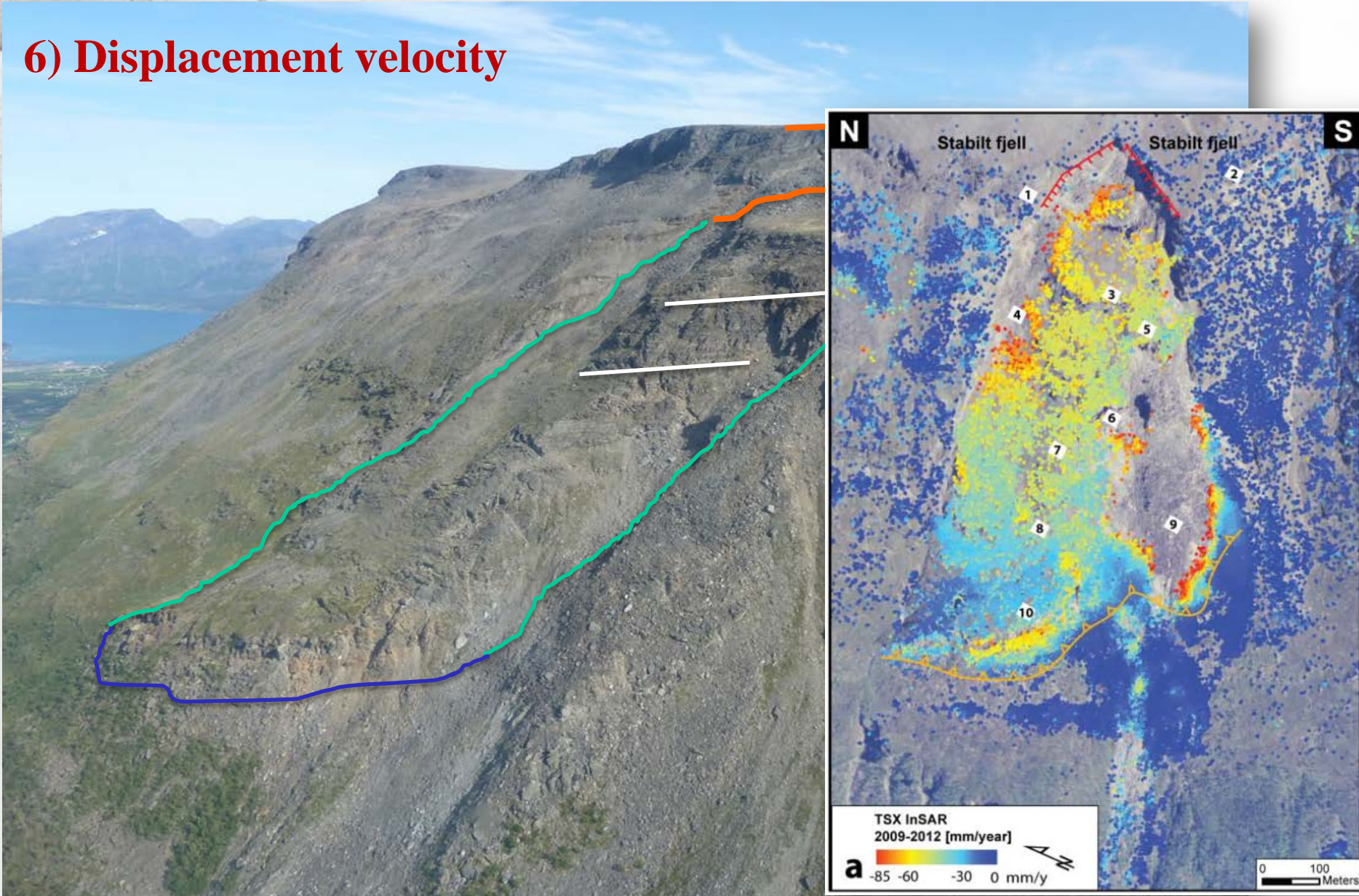
## 5) Basal rupture surface





# Hazard and risk classification of unstable rock slopes

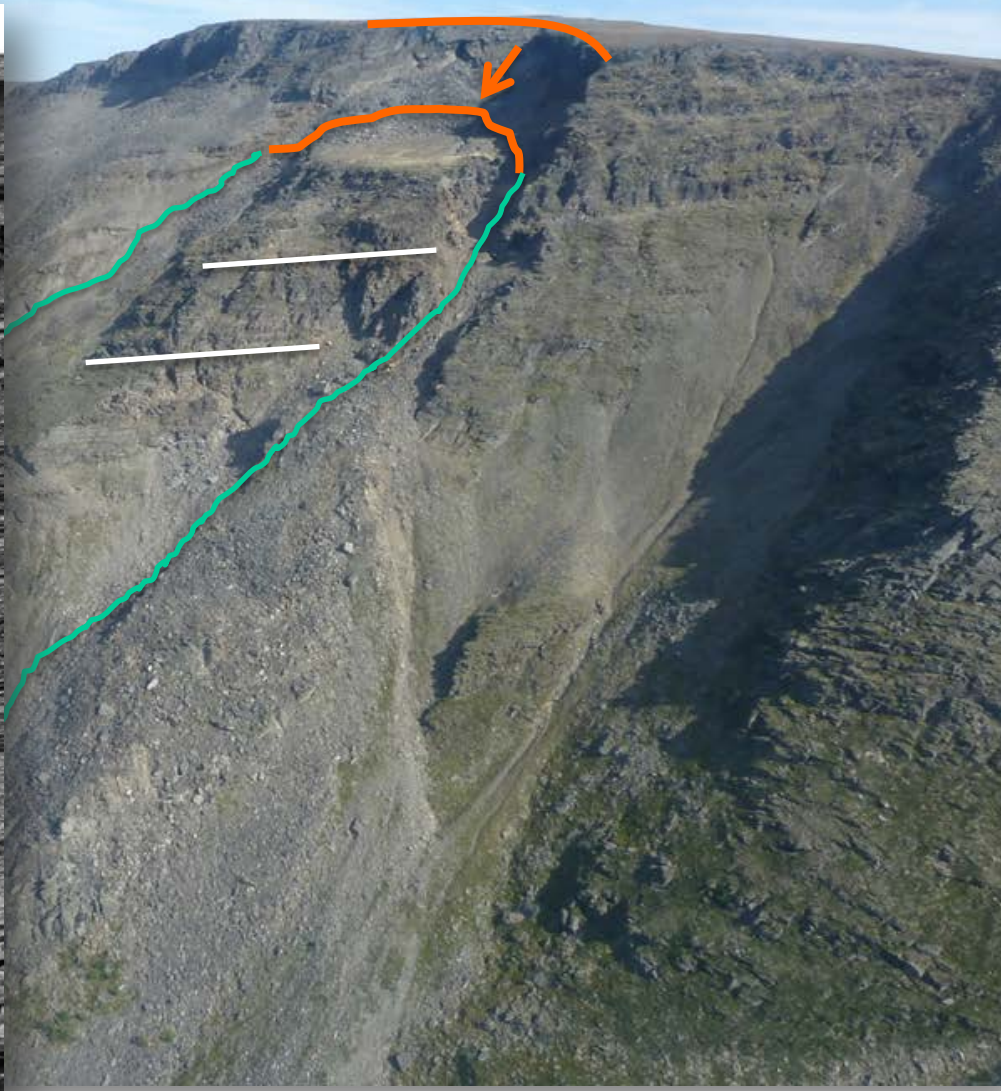
## 6) Displacement velocity





# Hazard and risk classification of unstable rock slopes

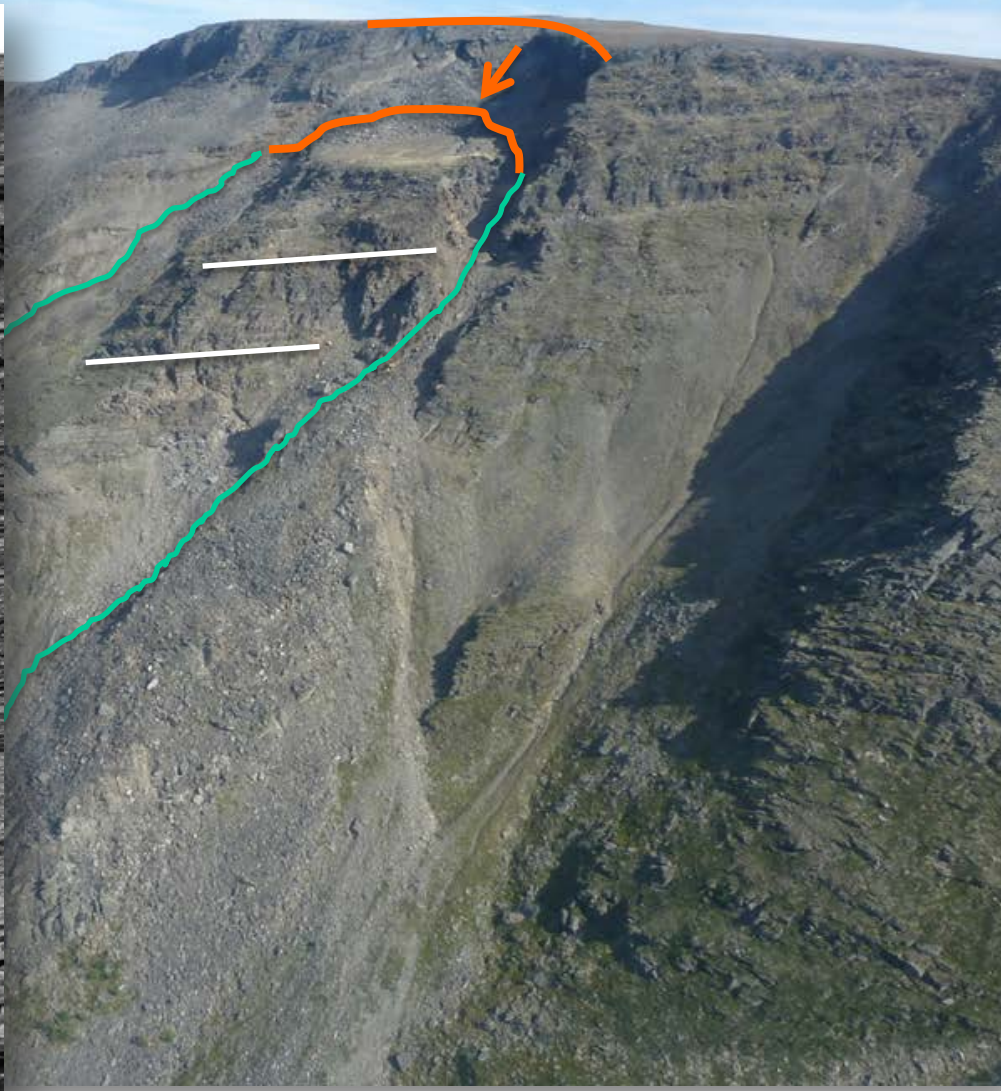
## 7) Acceleration of displacement velocity





# Hazard and risk classification of unstable rock slopes

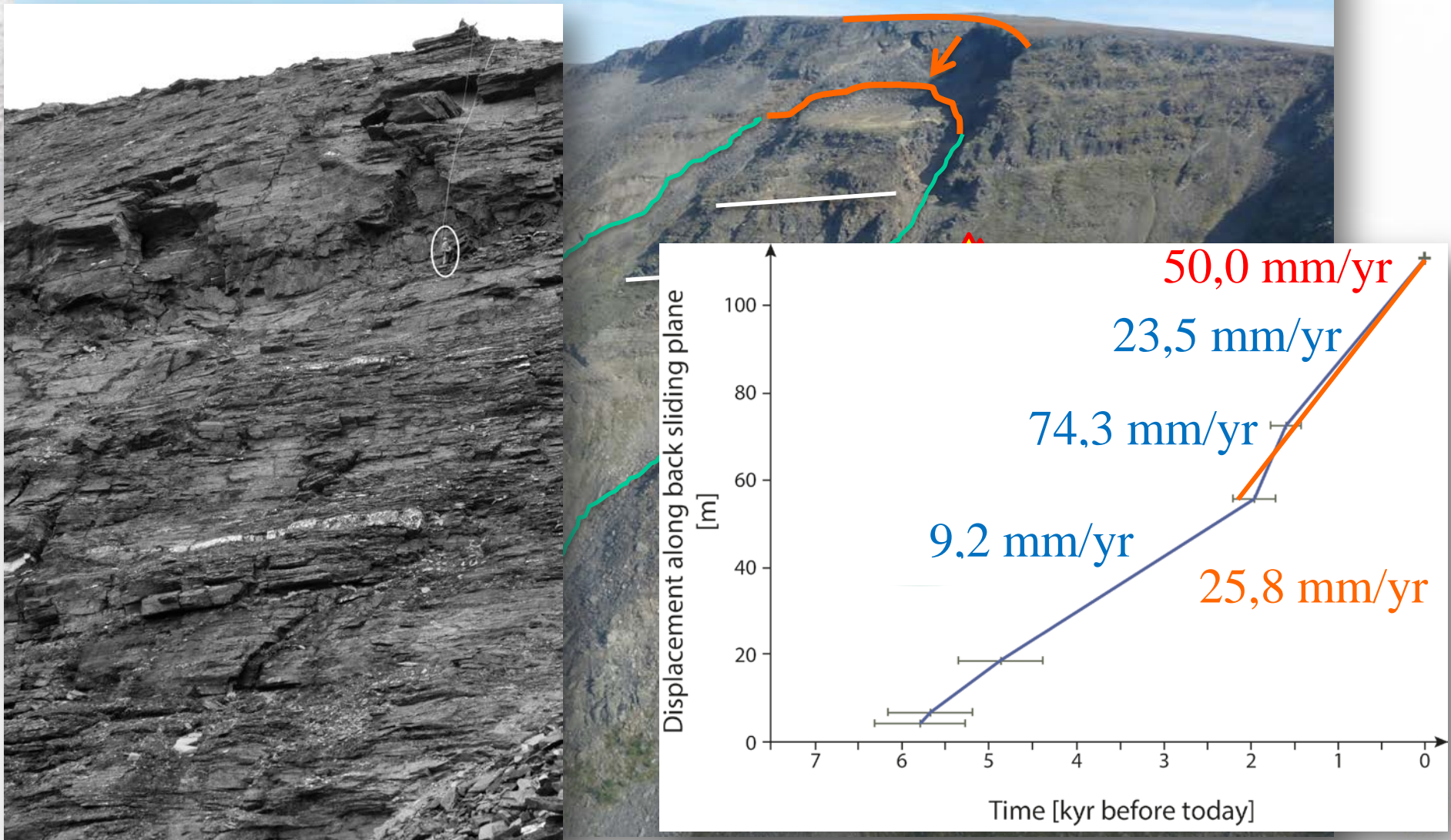
## 7) Acceleration of displacement velocity





# Hazard and risk classification of unstable rock slopes

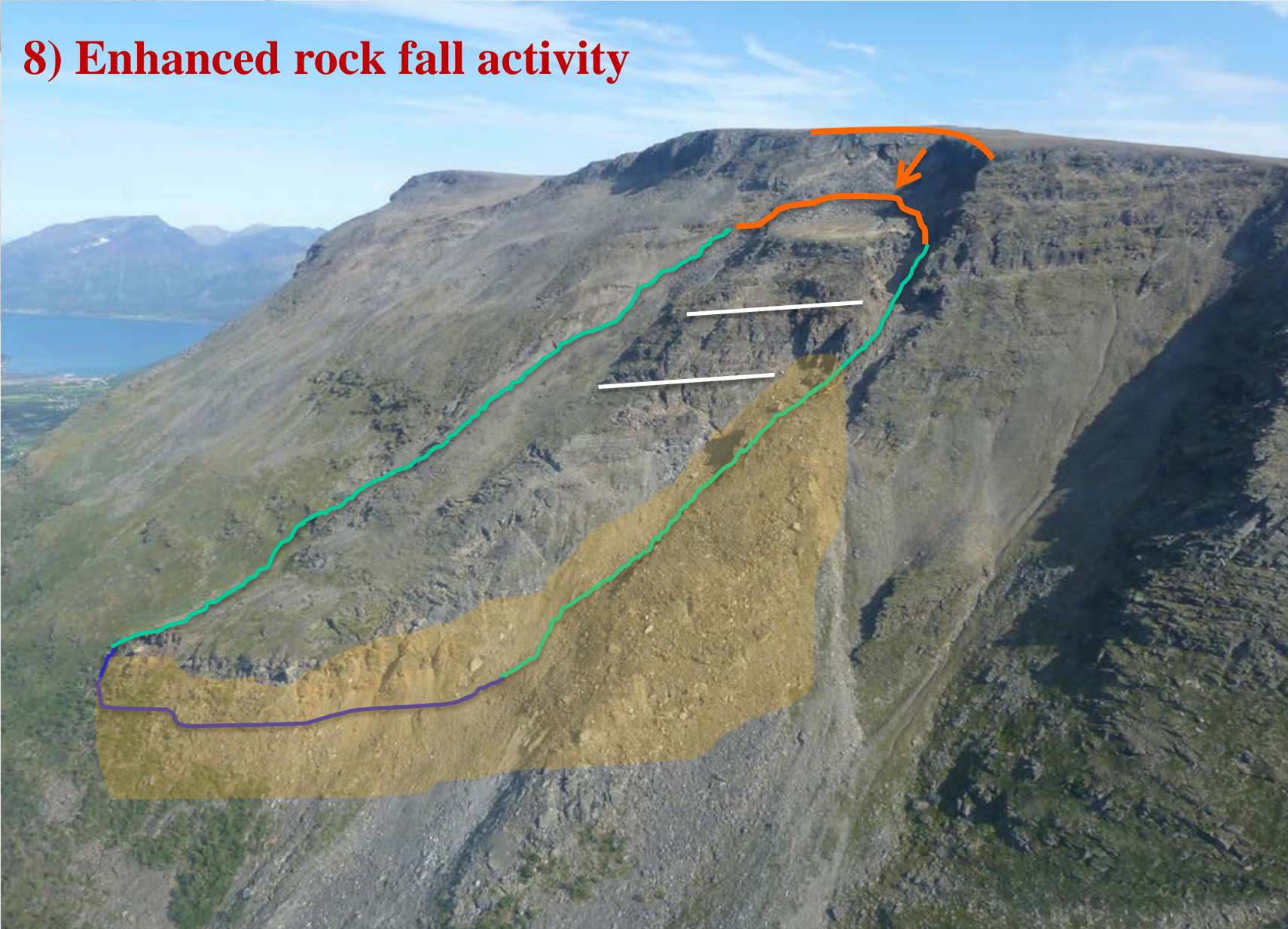
## 7) Acceleration of displacement velocity





# Hazard and risk classification of unstable rock slopes

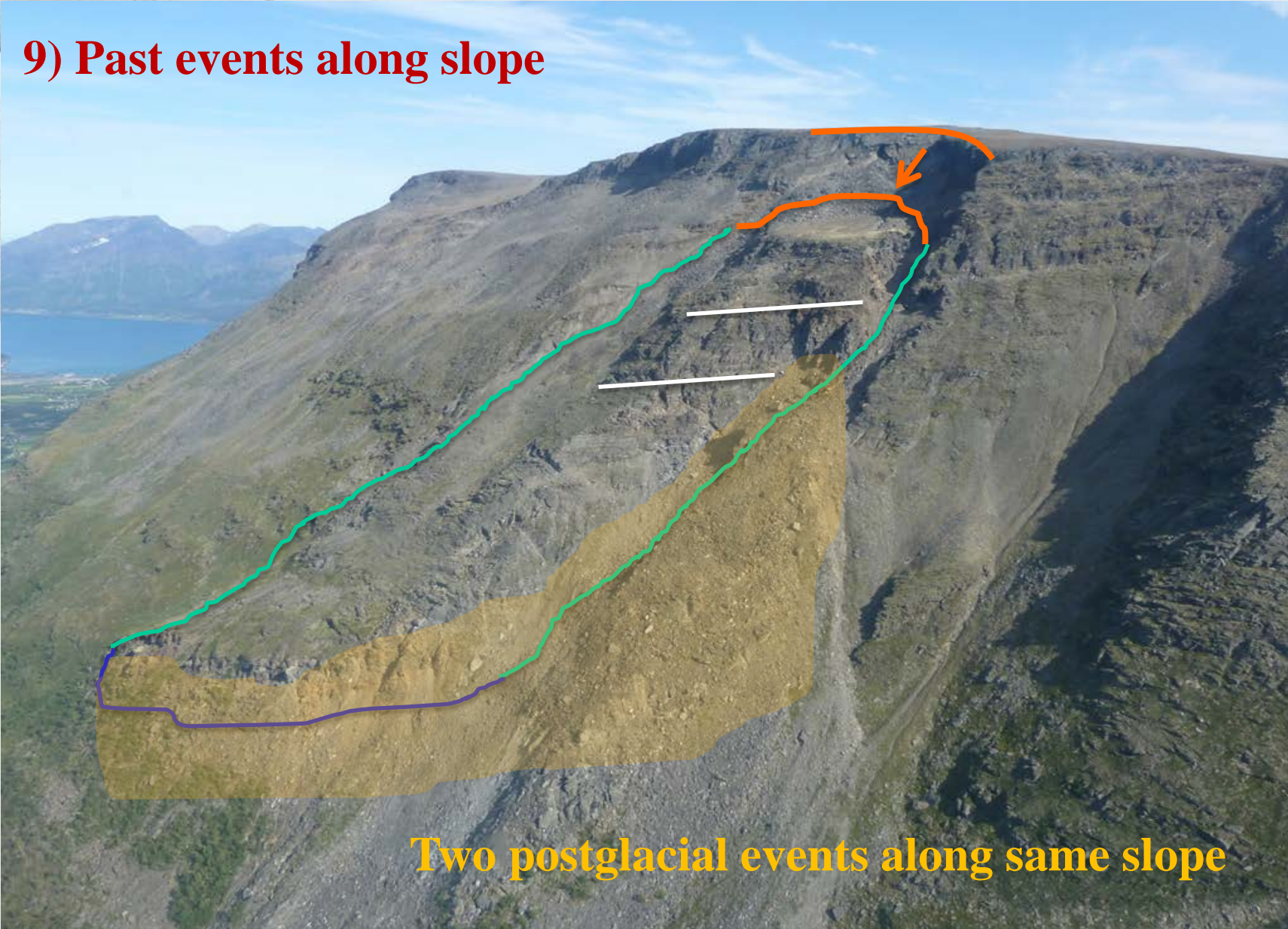
## 8) Enhanced rock fall activity





# Hazard and risk classification of unstable rock slopes

## 9) Past events along slope



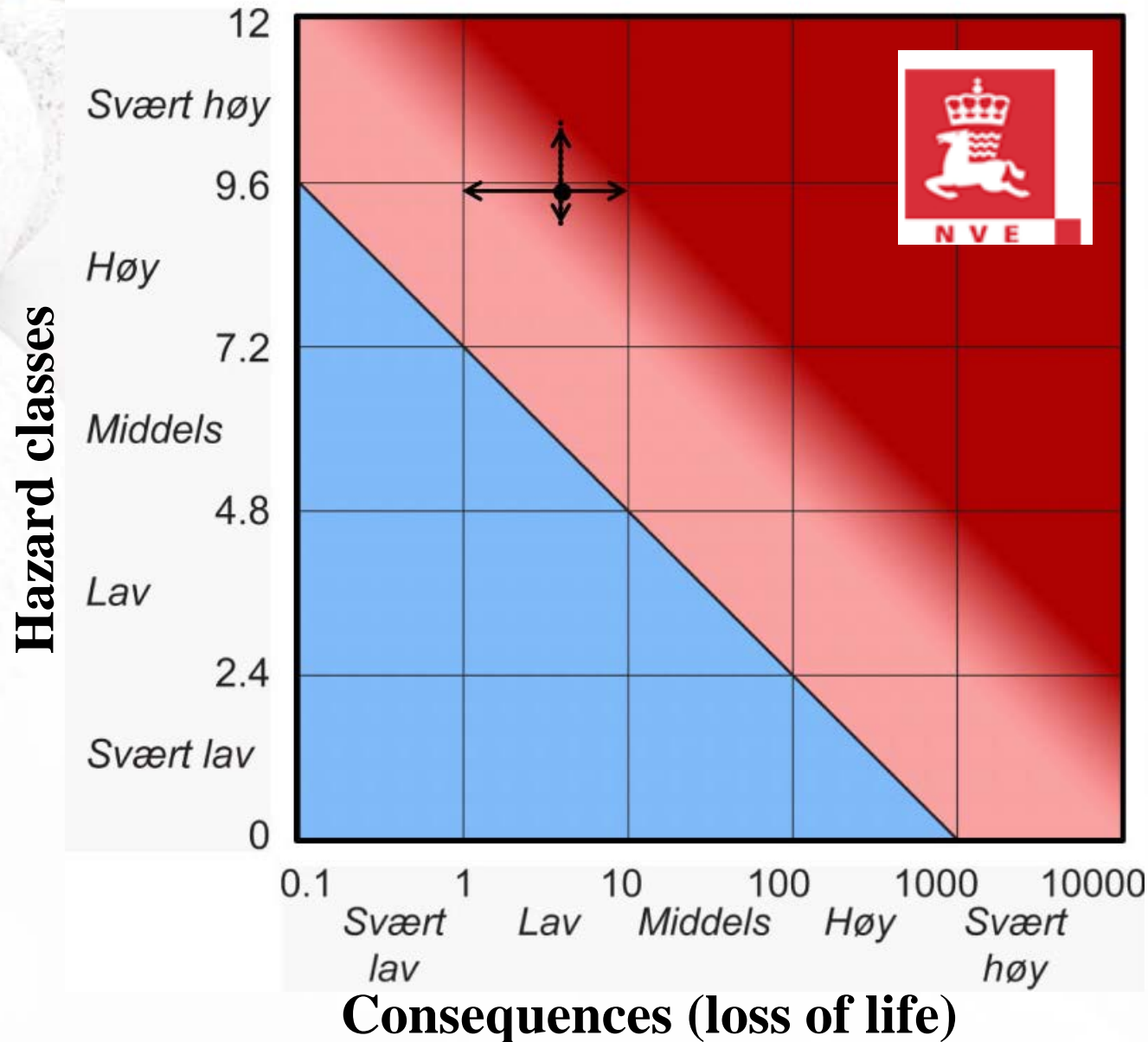
Two postglacial events along same slope





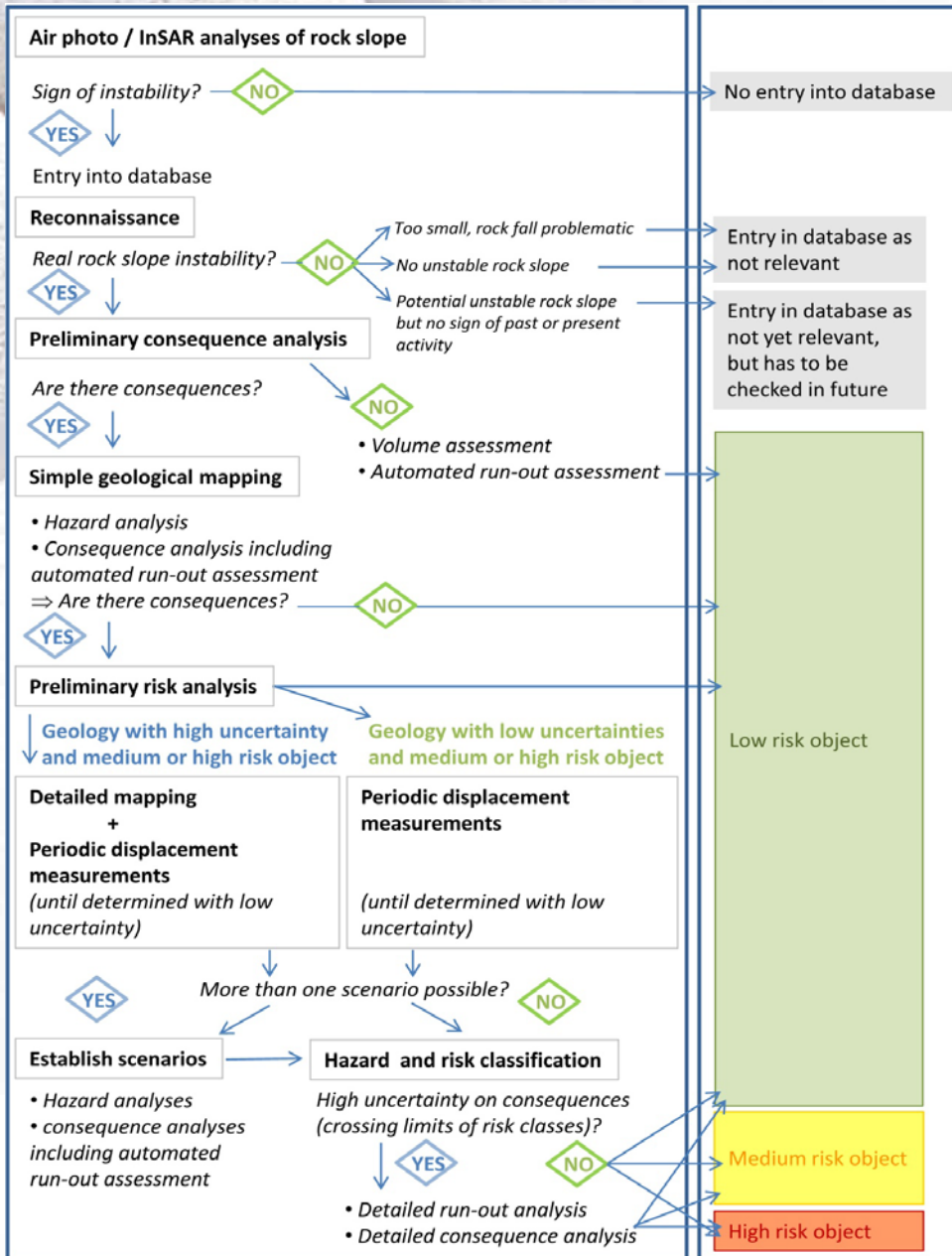
# Hazard and risk classification of unstable rock slopes

## Risk matrix Gamanjunni 3

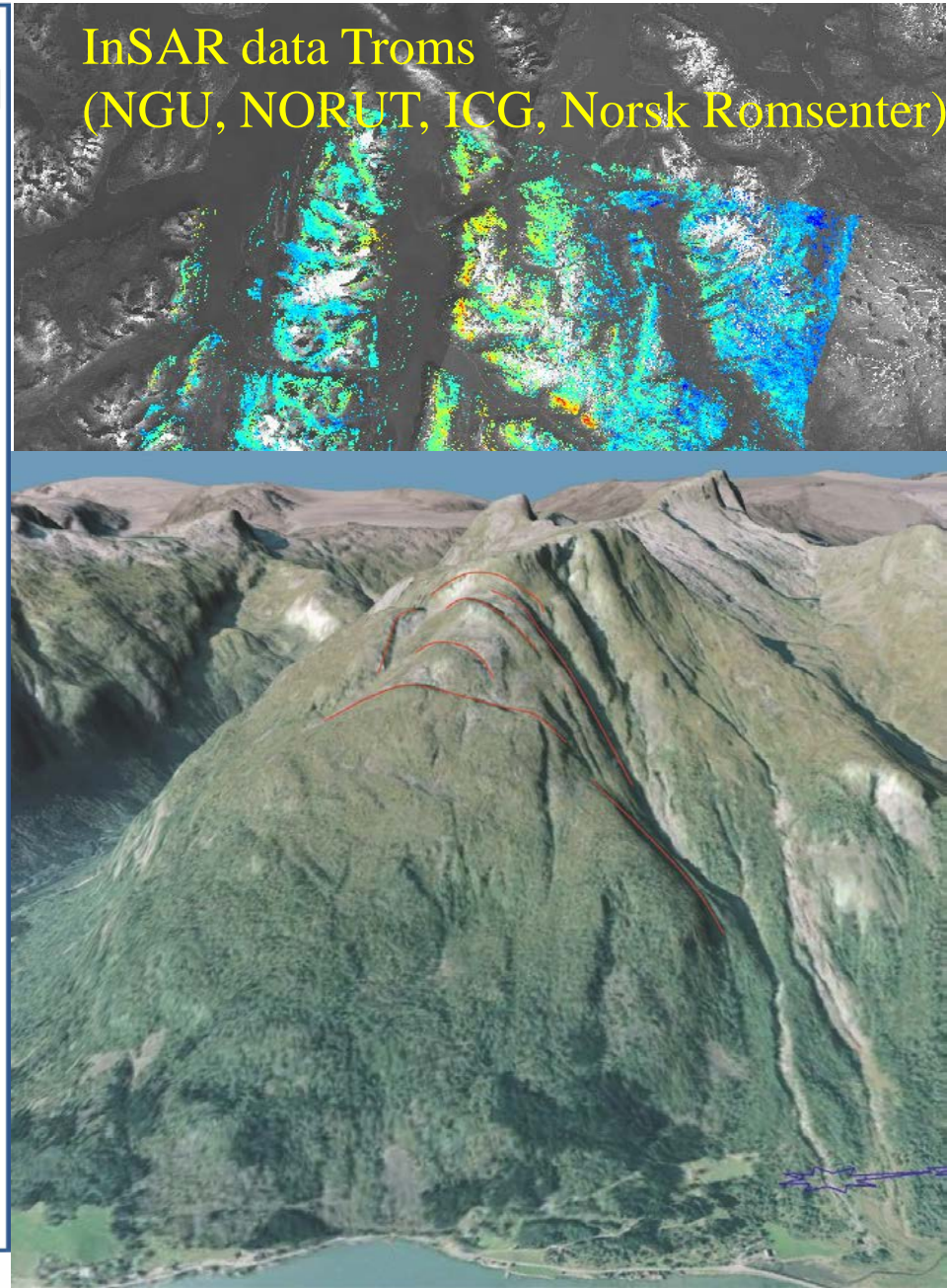




# Mapping methodology for unstable rock slopes

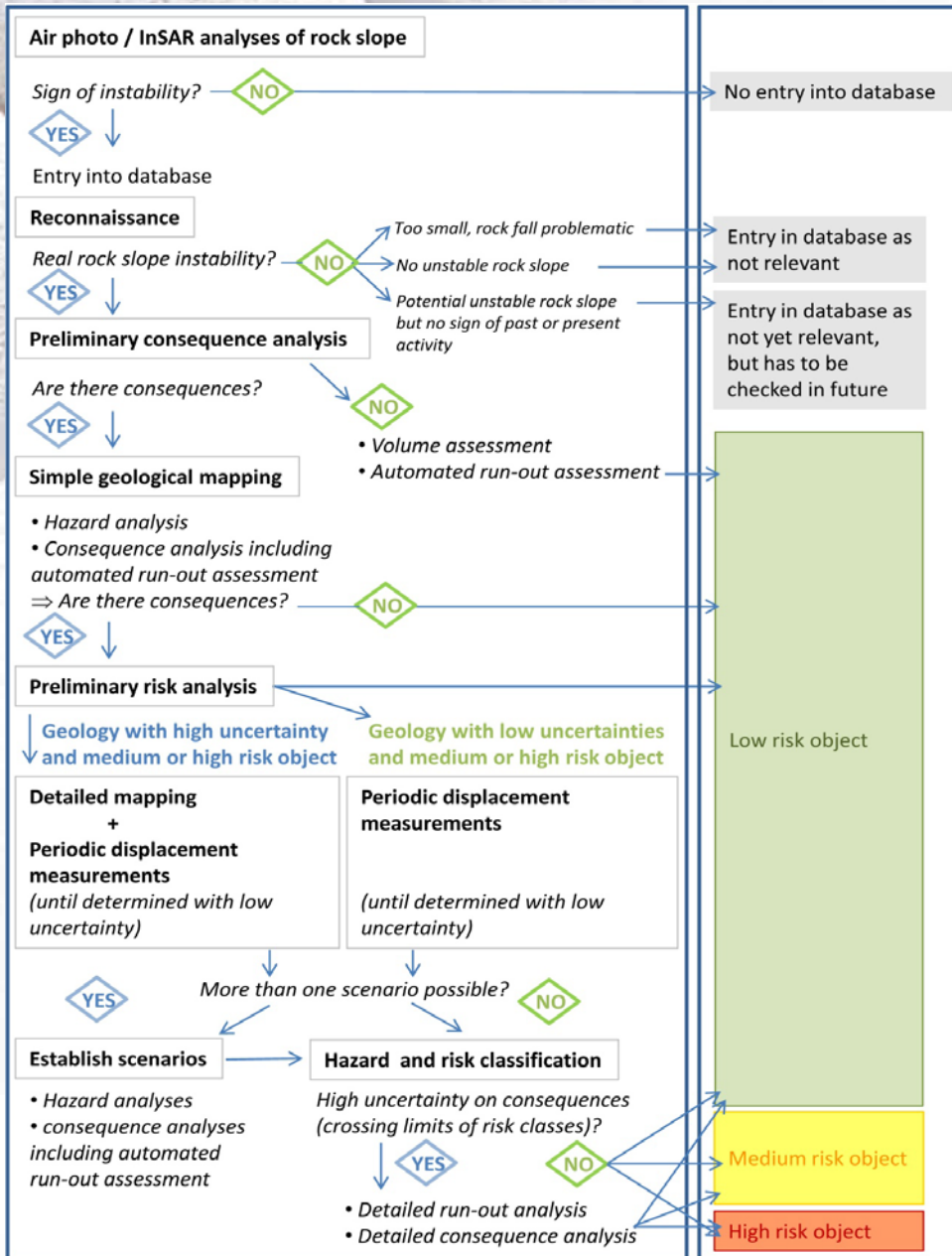


InSAR data Troms  
(NGU, NORUT, ICG, Norsk Romsenter)



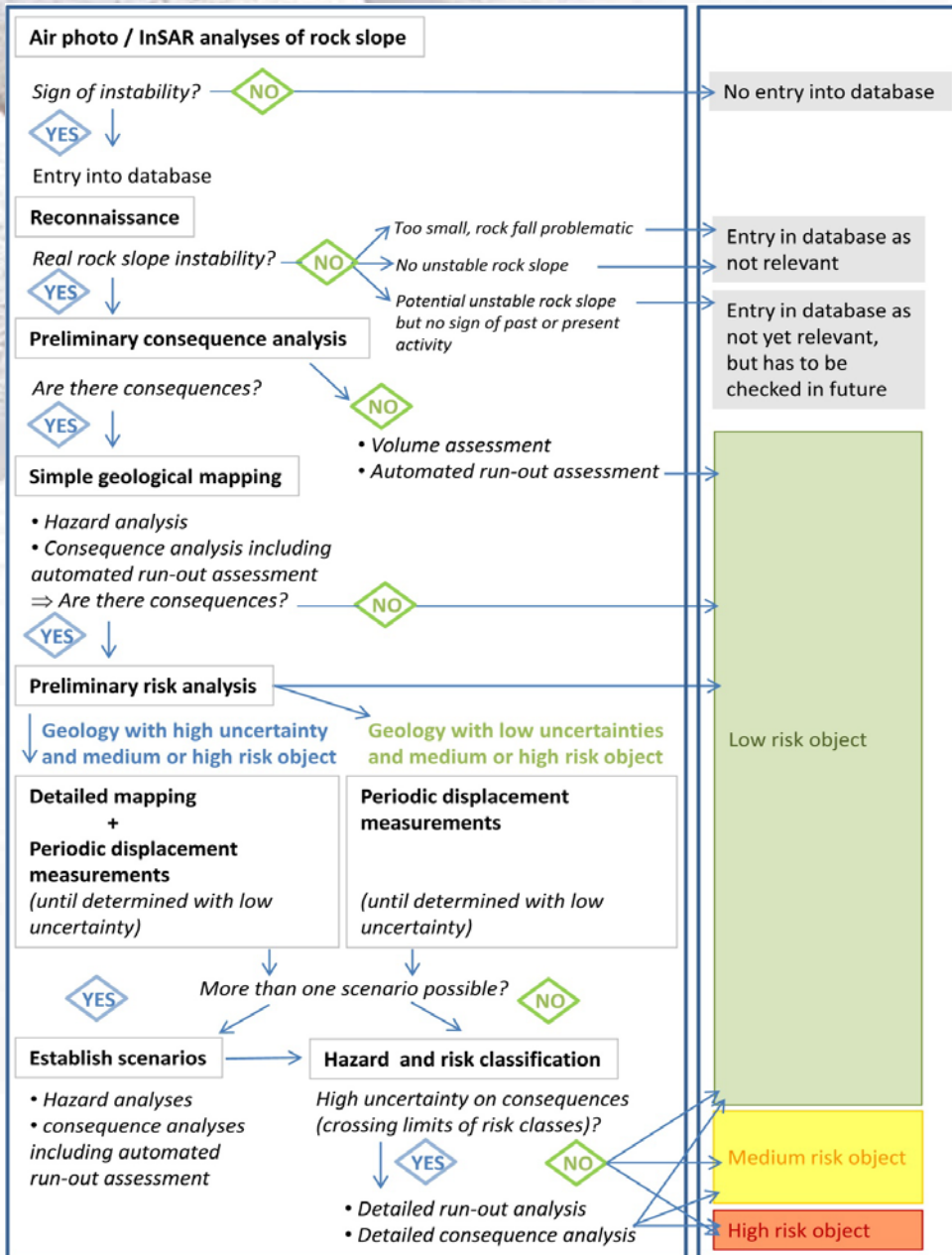


# Mapping methodology for unstable rock slopes



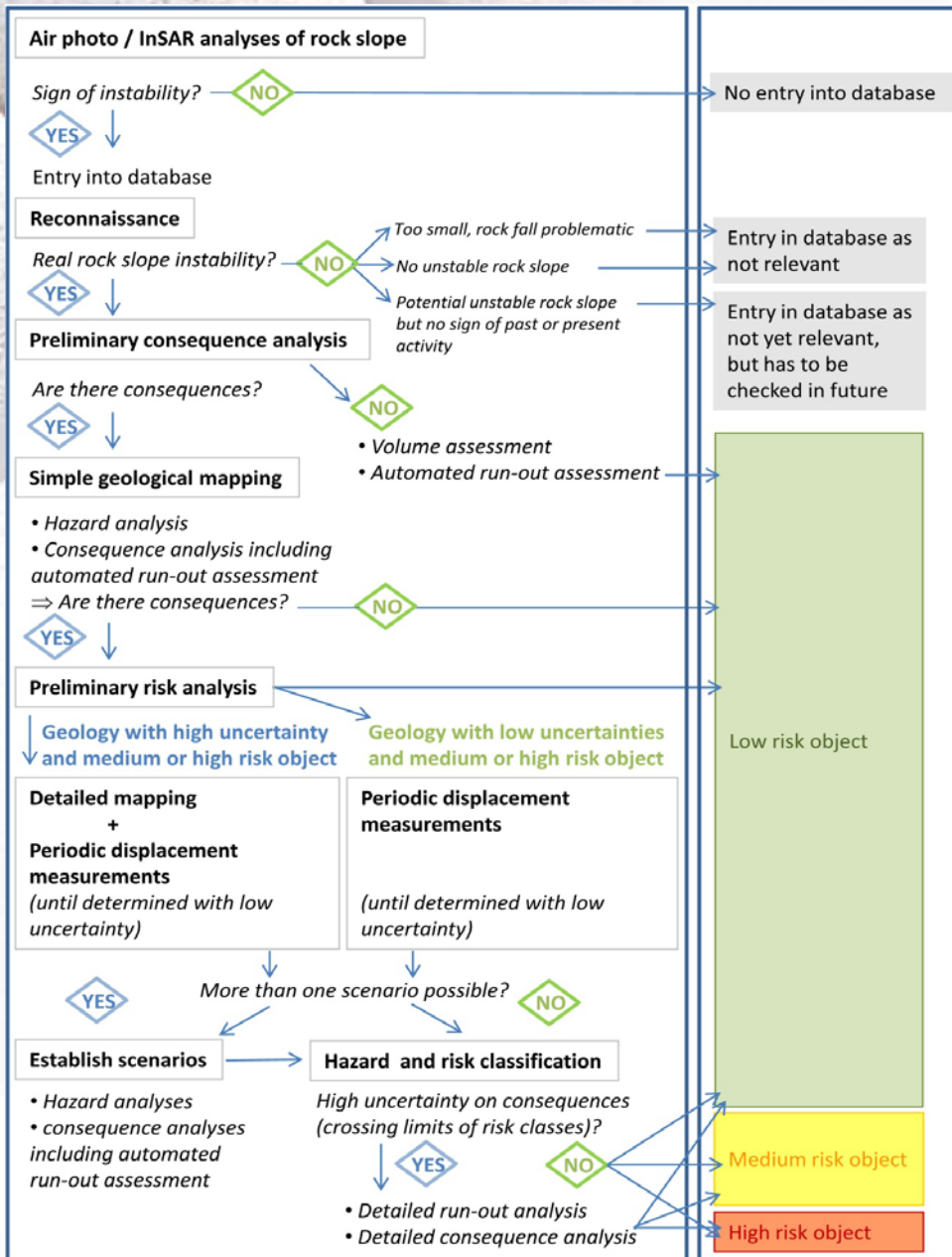


# Mapping methodology for unstable rock slopes



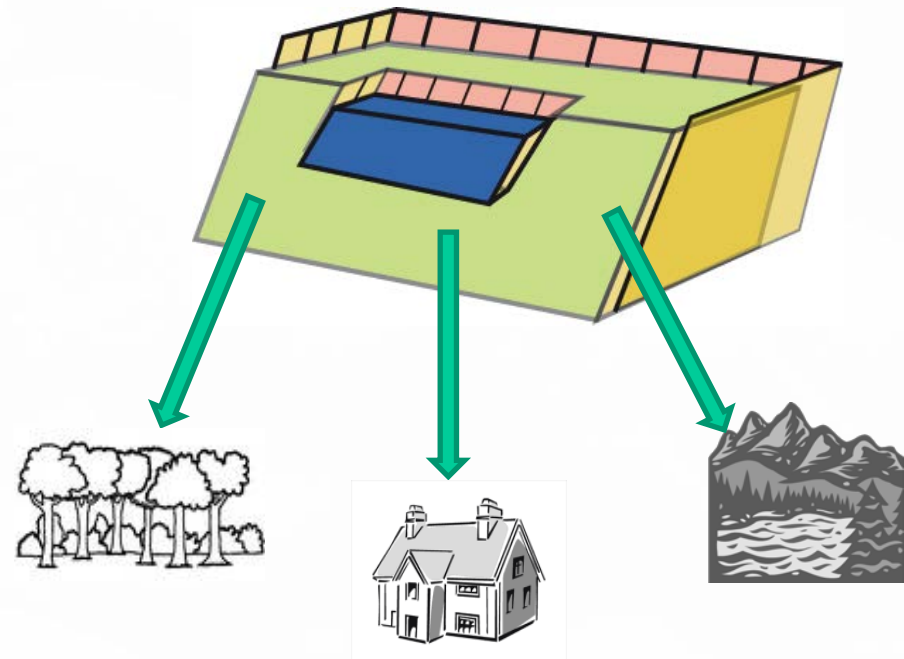
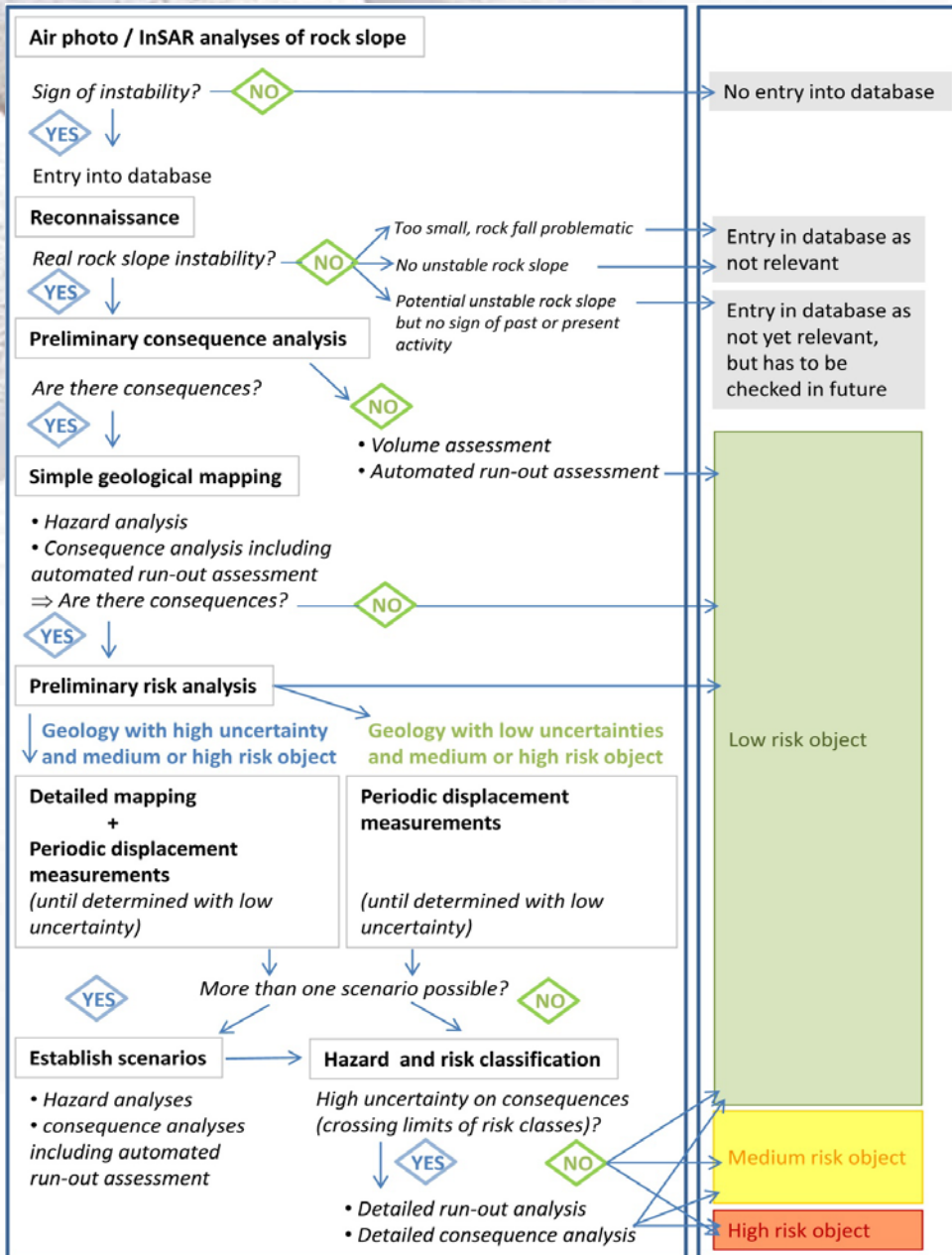


# Mapping methodology for unstable rock slopes



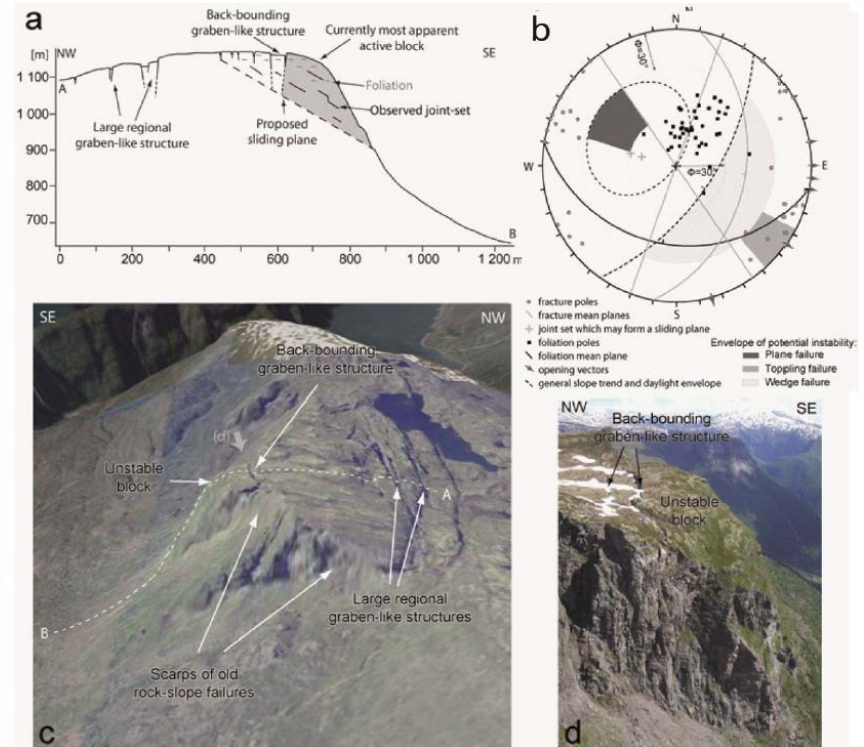
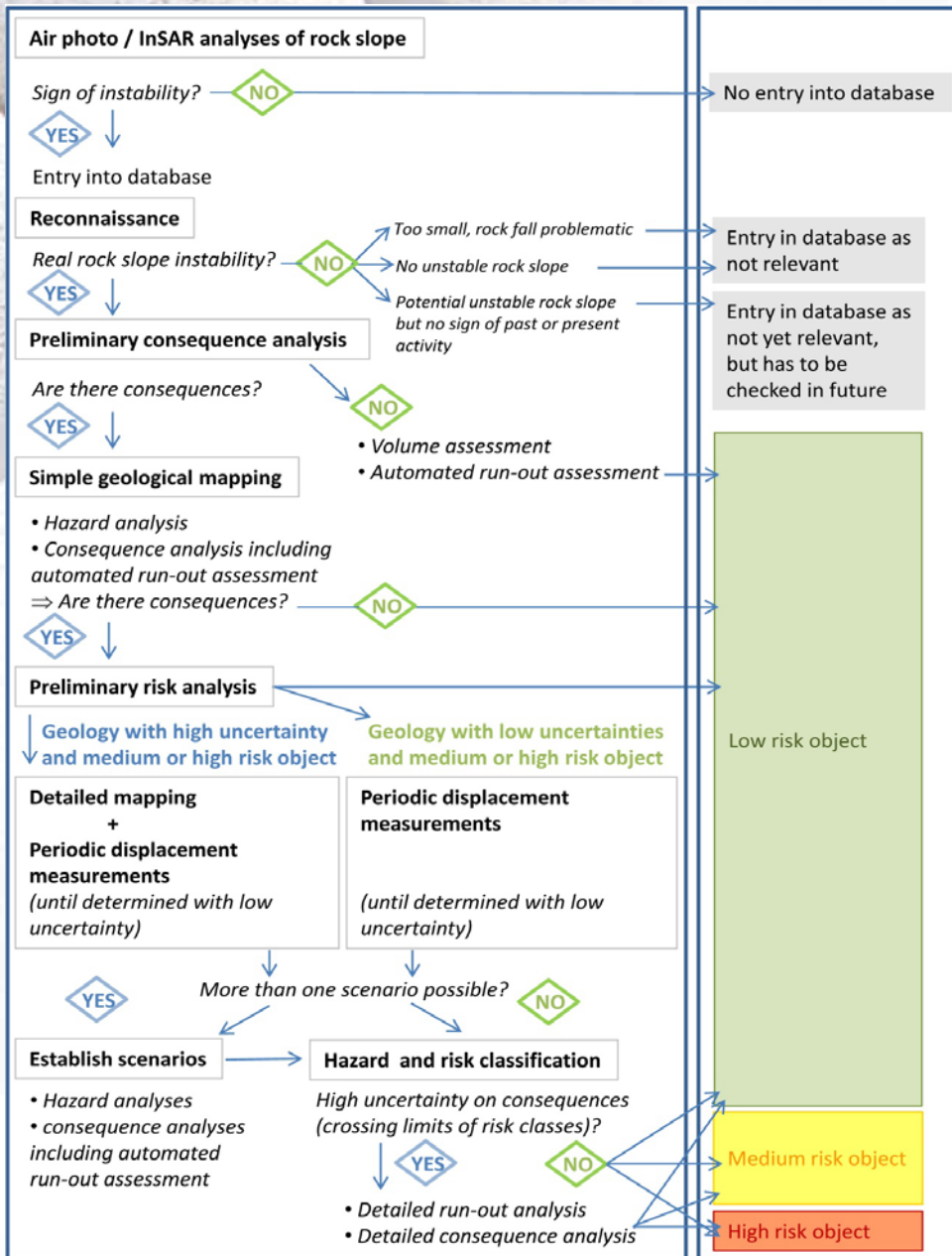


# Mapping methodology for unstable rock slopes



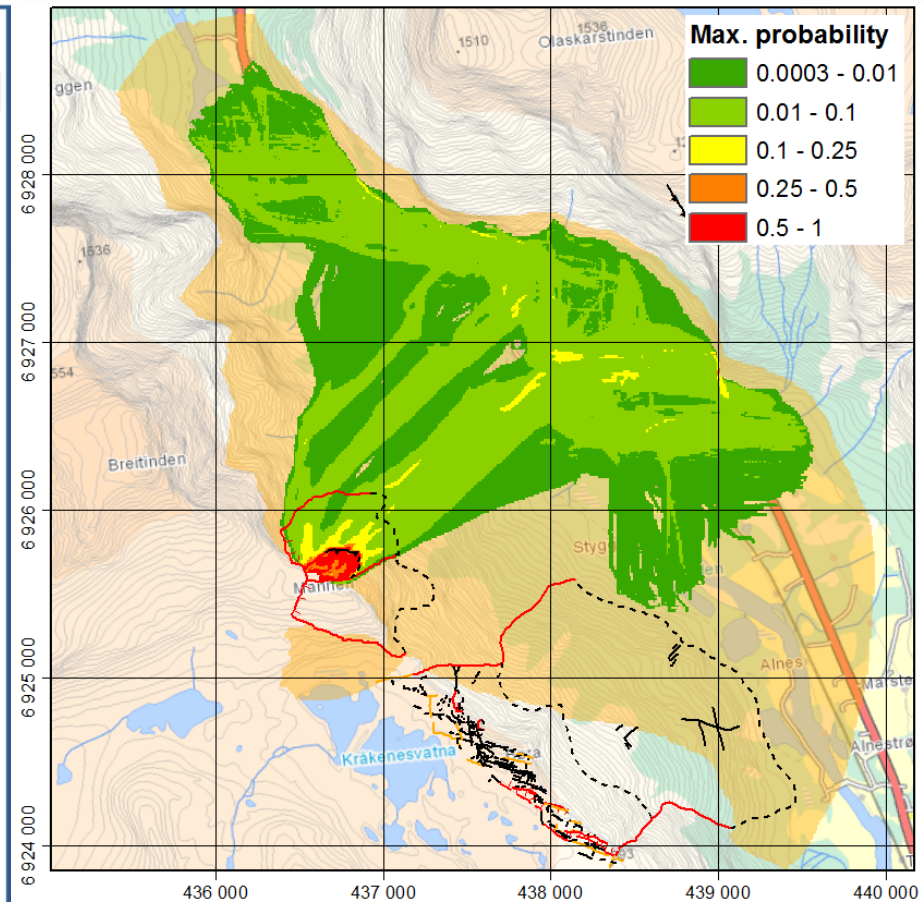
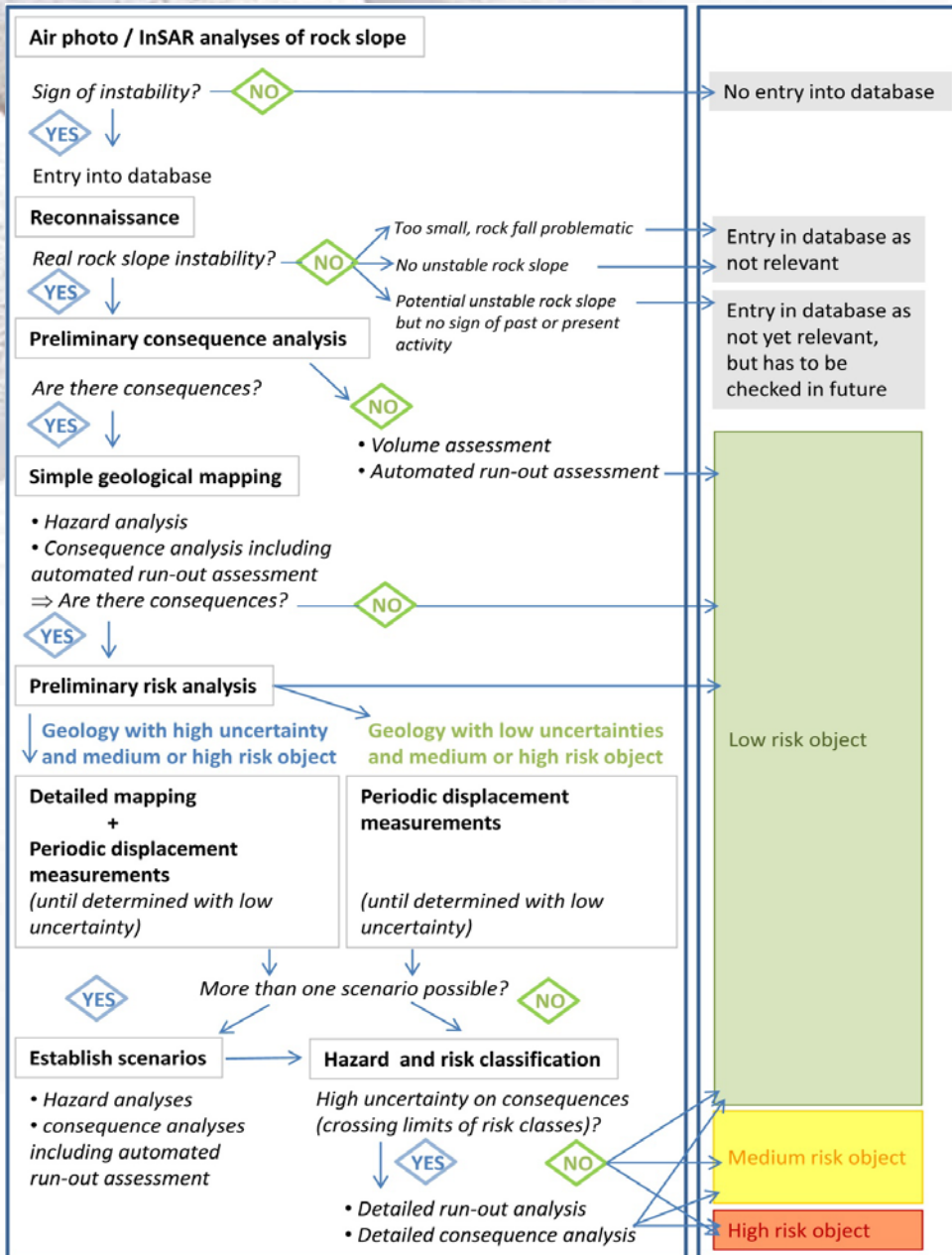


# Mapping methodology for unstable rock slopes





# Mapping methodology for unstable rock slopes

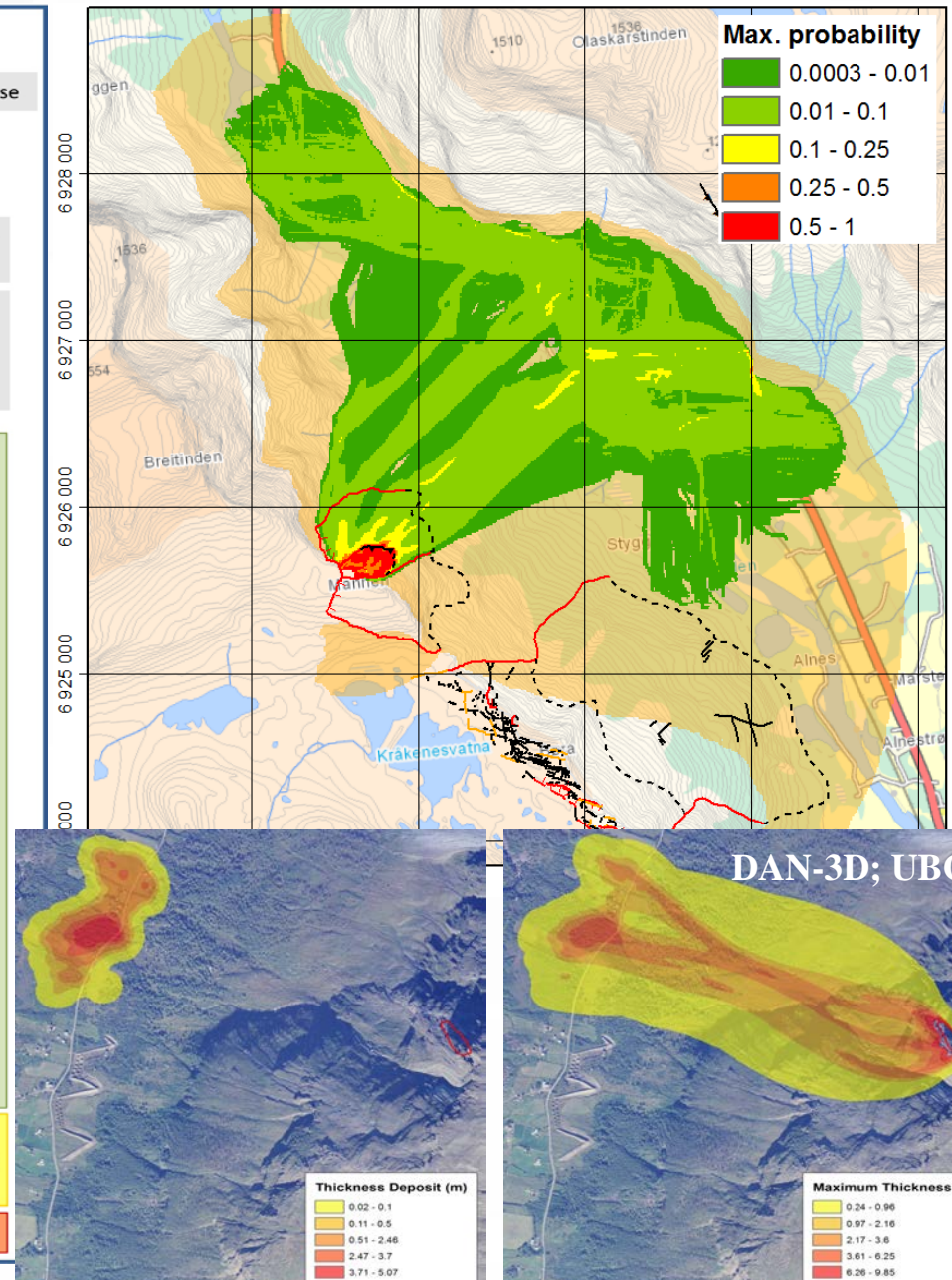
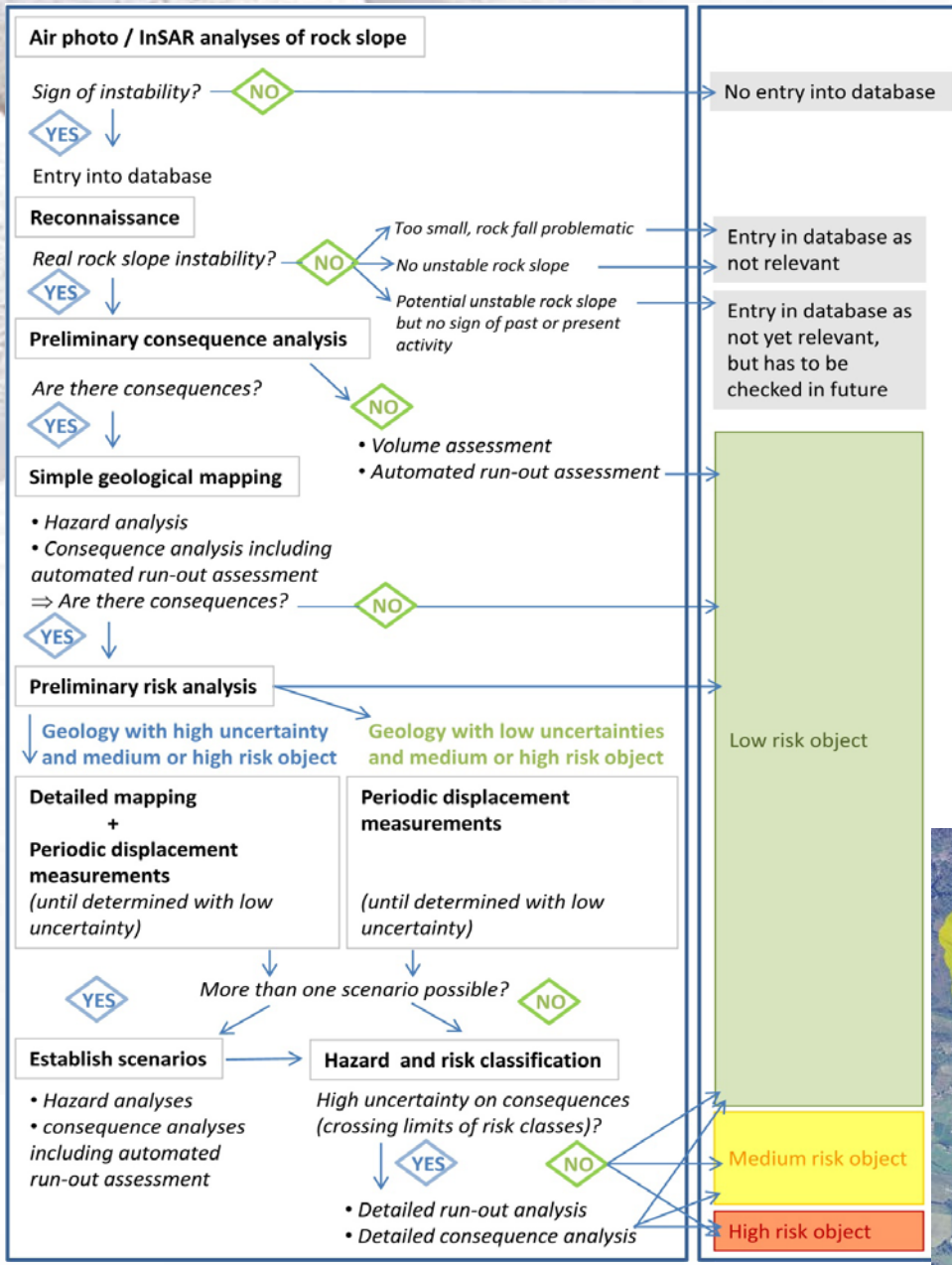


Flow-R, University of Lausanne



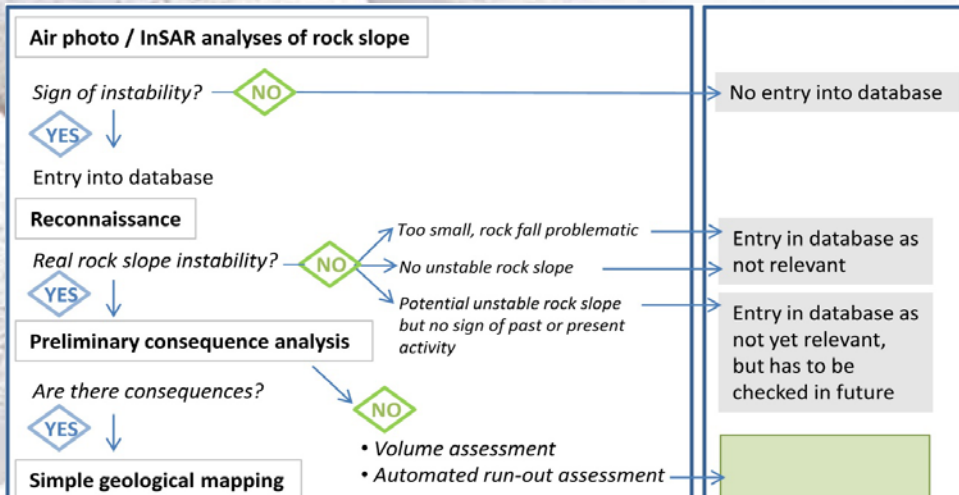


# Mapping methodology for unstable rock slopes





# Mapping methodology for unstable rock slopes



## Extensiometers



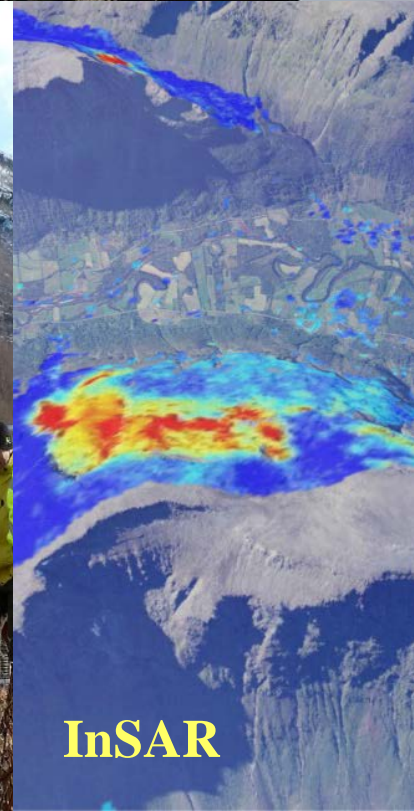
## dGNSS



## LIDAR



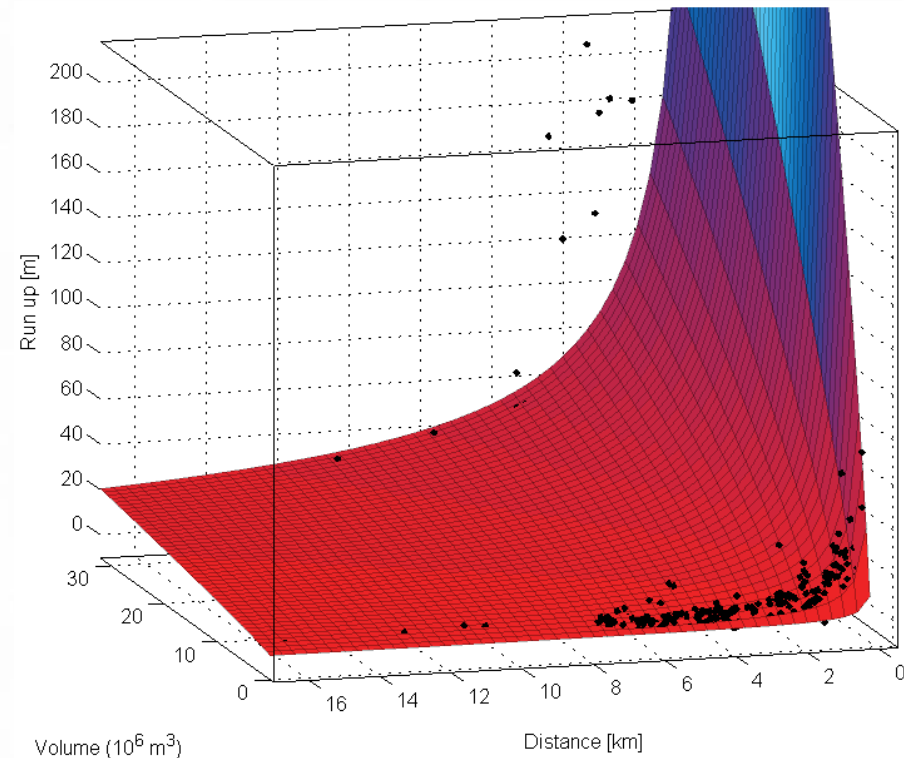
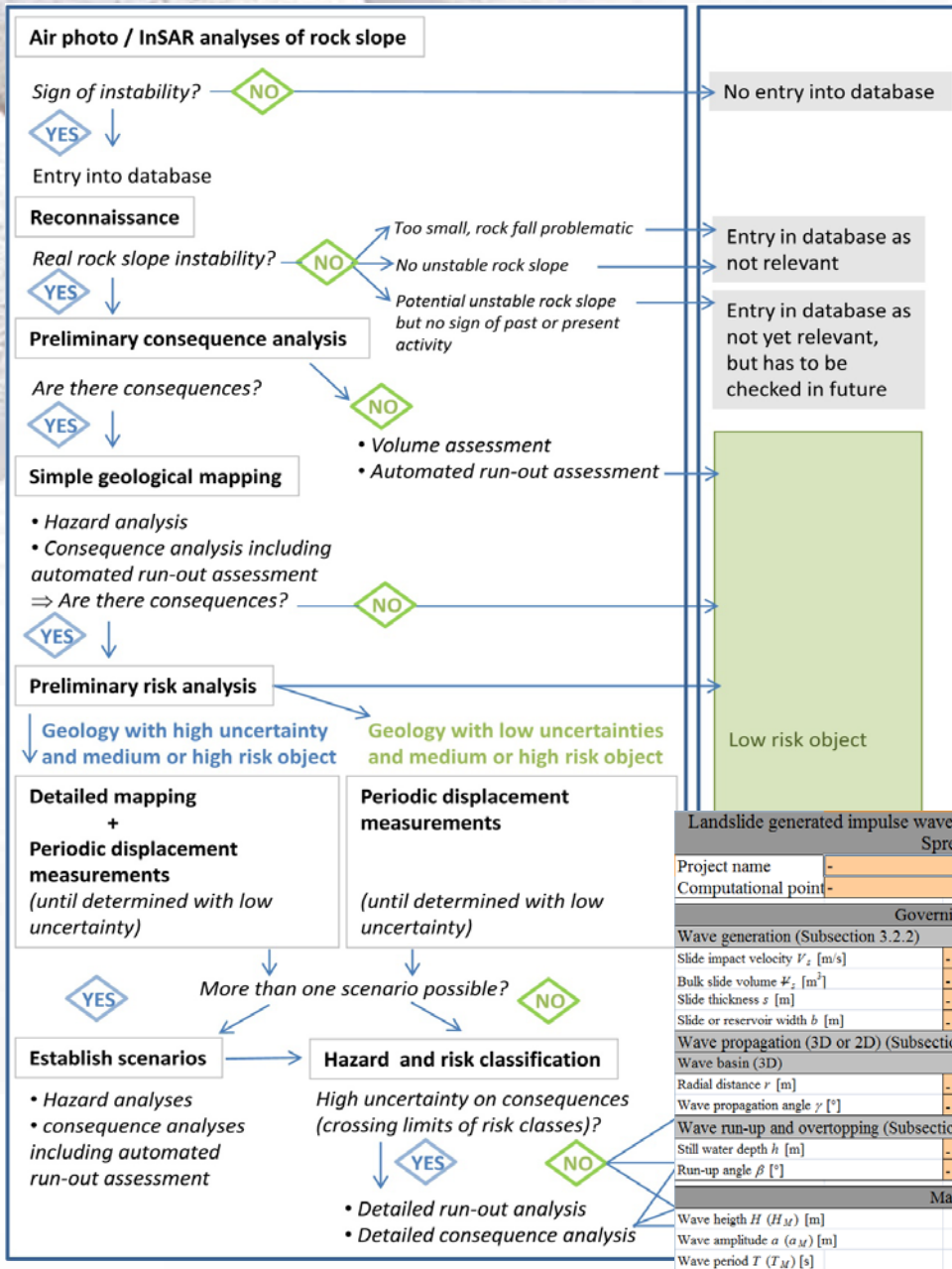
## Gb InSAR



## InSAR



# Mapping methodology for unstable rock slopes



Roberts et al. 2014

Landslide generated impulse waves in reservoirs - Basics and computation			
Spread sheets			
Project name	-	Operator	-
Computational point	-	Date	-
Governing parameters			
Wave generation (Subsection 3.2.2)			
Slide impact velocity $V_I$ [m/s]	-	Bulk slide density $\rho_s$ [kg/m <sup>3</sup> ]	-
Bulk slide volume $V_s$ [m <sup>3</sup> ]	-	Bulk slide porosity $n$ [%]	-
Slide thickness $s$ [m]	-	Slide impact angle $\alpha$ [°]	-
Slide or reservoir width $b$ [m]	-	Still water depth $h$ [m]	-
Wave propagation (3D or 2D) (Subsection 3.2.2)			
Wave basin (3D)		Wave channel (2D)	
Radial distance $r$ [m]	-	Streamwise distance $x$ [m]	-
Wave propagation angle $\gamma$ [°]	-		
Wave run-up and overtopping (Subsection 3.3.2)			
Still water depth $h$ [m]	-	Freeboard $f$ [m]	-
Run-up angle $\beta$ [°]	-	Crest width $b_K$ [m]	-
Main results			
Wave height $H$ ( $H_M$ ) [m]	-		
Wave amplitude $a$ ( $a_M$ ) [m]	-		
Wave period $T$ ( $T_M$ ) [s]	-		

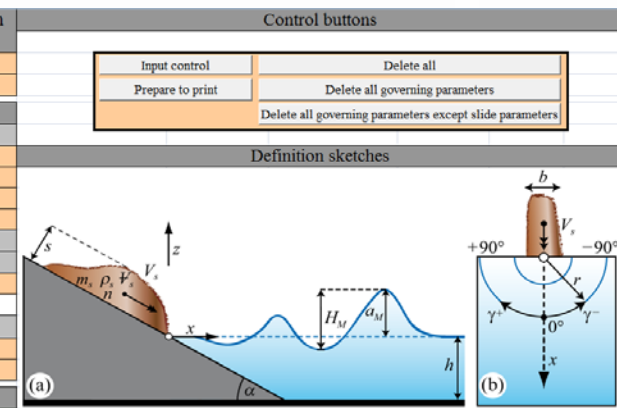


Figure 3-3 Sketches defining the governing parameters on impulse wave generation and the most important wave parameters in (a) 2D and (b) 3D.

VAW, ETH Zurich



# Mapping methodology for unstable rock slopes

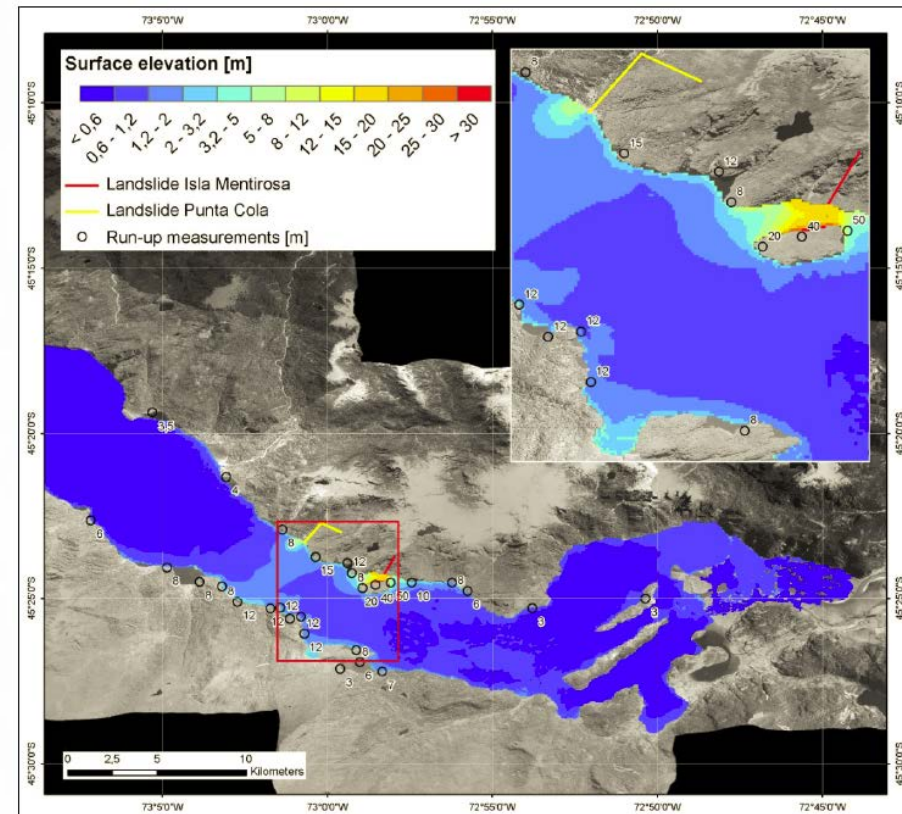
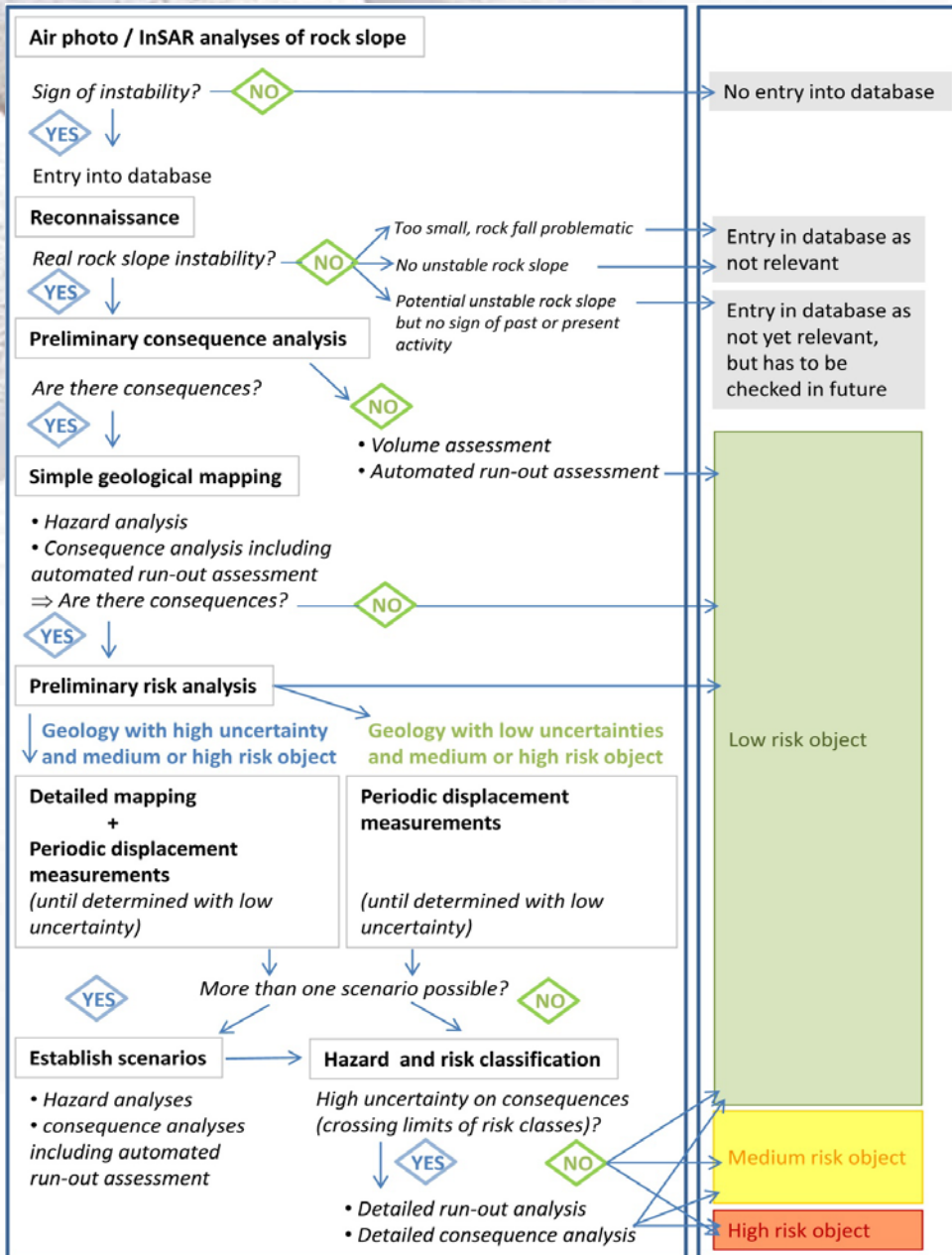
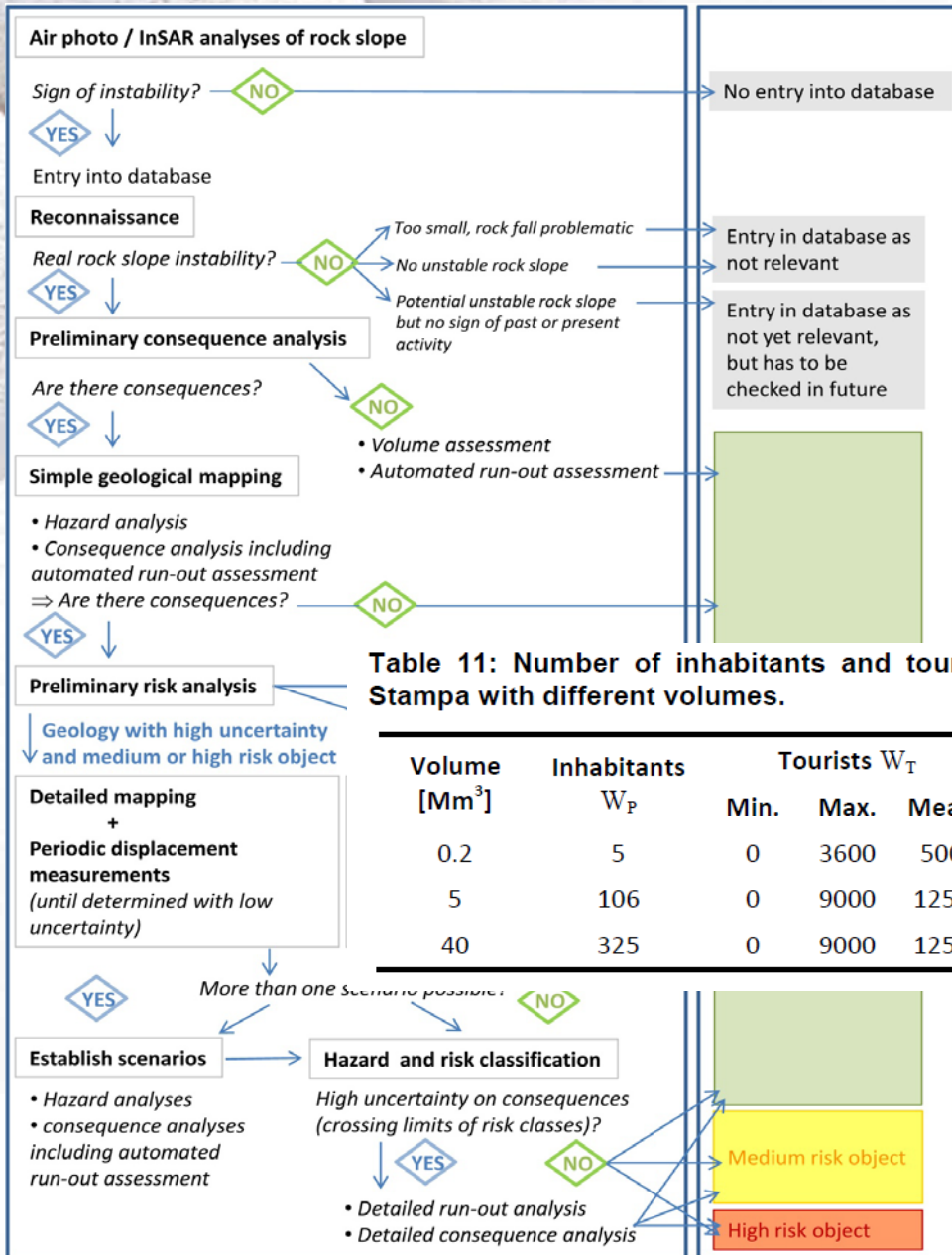


Figure 11: Modelled maximum surface elevation and comparison to measured run-up values.





# Mapping methodology for unstable rock slopes



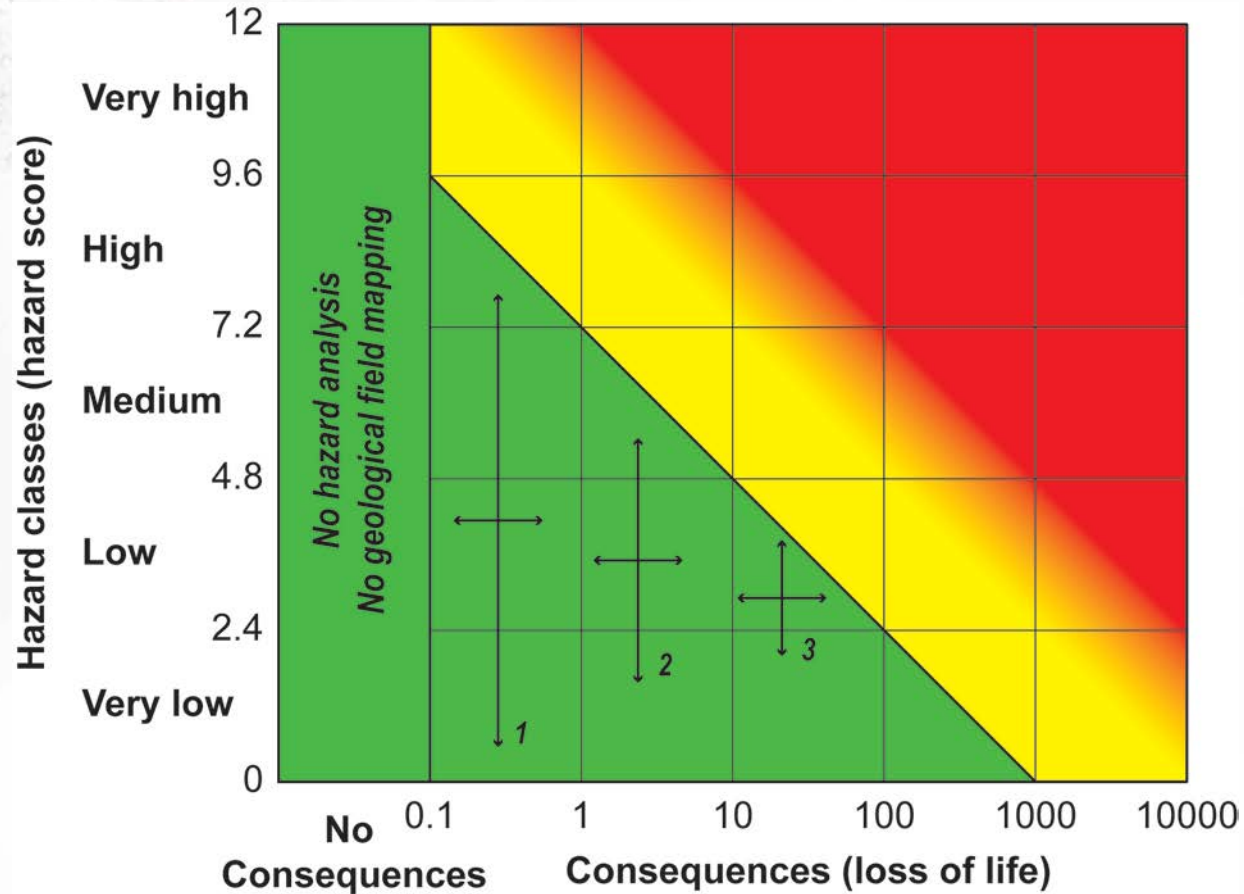
**Table 11: Number of inhabitants and tourists exposed to displacement waves created by rockslides from Stampa with different volumes.**

Volume [Mm <sup>3</sup> ]	Inhabitants W <sub>P</sub>	Tourists W <sub>T</sub>			Total exposed persons, W <sub>TOT</sub>			Potential life loss		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
0.2	5	0	3600	500	5	1805	130	4	1264	91
5	106	0	9000	1250	106	4606	419	74	3224	293
40	325	0	9000	1250	325	4825	638	228	3378	446





# Mapping methodology for unstable rock slopes





# Mapping methodology for unstable rock slopes

## Skrednett

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Fjellskred

Stein- og snøskred

Jord- og flomskred

Kvikkleire

Skredfasesoner

Skredhendelser

### Landsdekkende aktsomhetskart for jord- og flomskred

15.05.2014 08:36:00


NVE publiserer aktsomhetskart for jord- og flomskred. Aktsomhetskartet viser områder med potensiell fare for jord- og flomskred. Kartet gir kommunene et godt grunnlag for en første vurdering av skredfare.

### Faresonekart skred for Loppa kommune


05.05.2014 08:30:00

Mandag 5. mai overleverte Norges vassdrags- og energidirektorat (NVE) faresonekart for skred til Loppa kommune.

[Faginformatjon](#) | [Nyttige lenker](#) | [Om dataene](#) | [Nedlastning / WMS](#)



Norges vassdrags- og energidirektorat




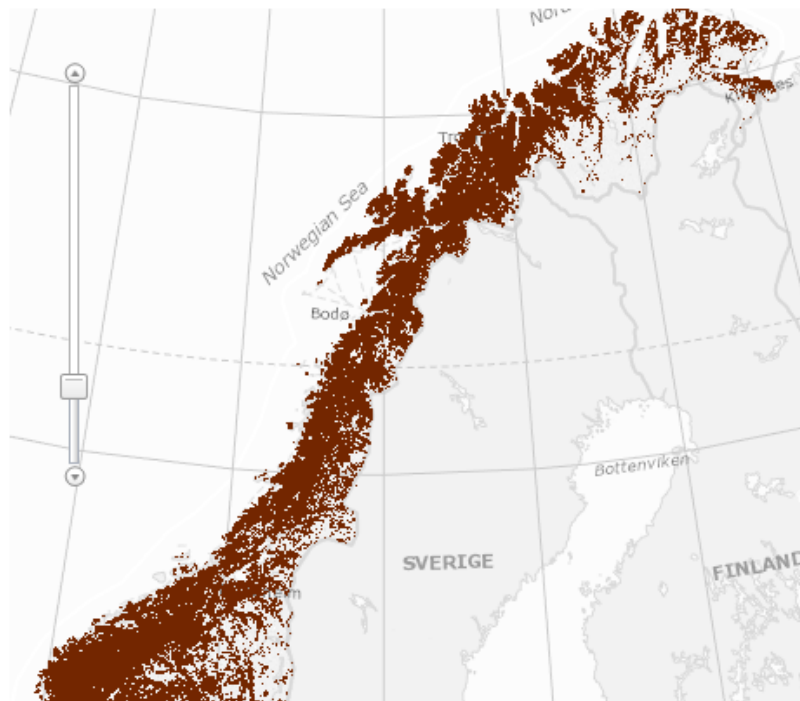
NGU  
Norges geologiske undersøkelse

[Statens vegvesen](#)

[Jernbaneverket](#)

[Forsvarets militærgeografiske tjeneste](#)





<http://www.skrednett.no/>

# Mapping methodology for unstable rock slopes

**Skreddata på nett**

1: 6539067  Øst: -403985.43 Nord: 7310399.13

Søk Kart Verktøy Informasjon

Standardkart Lag kart

- ☐ Ustabile fjellparti - oversikt
- ☐ Ustabile fjellparti - morfologi
- ☐ Ustabile fjellparti - volum
- ☐ Ustabile fjellparti - bevegelse
- ☐ Ustabile fjellparti - faregrad
- ☐ Ustabile fjellparti - risikograd
- ☒ Ustabile fjellparti - undersøkt område
- ☐ Ustabile fjellparti - målestasjon, type\_OLD
- ☐ Ustabile fjellparti - målestasjon, bevegelse\_OLD
- ☐ Grunnundersøkelser - Troms

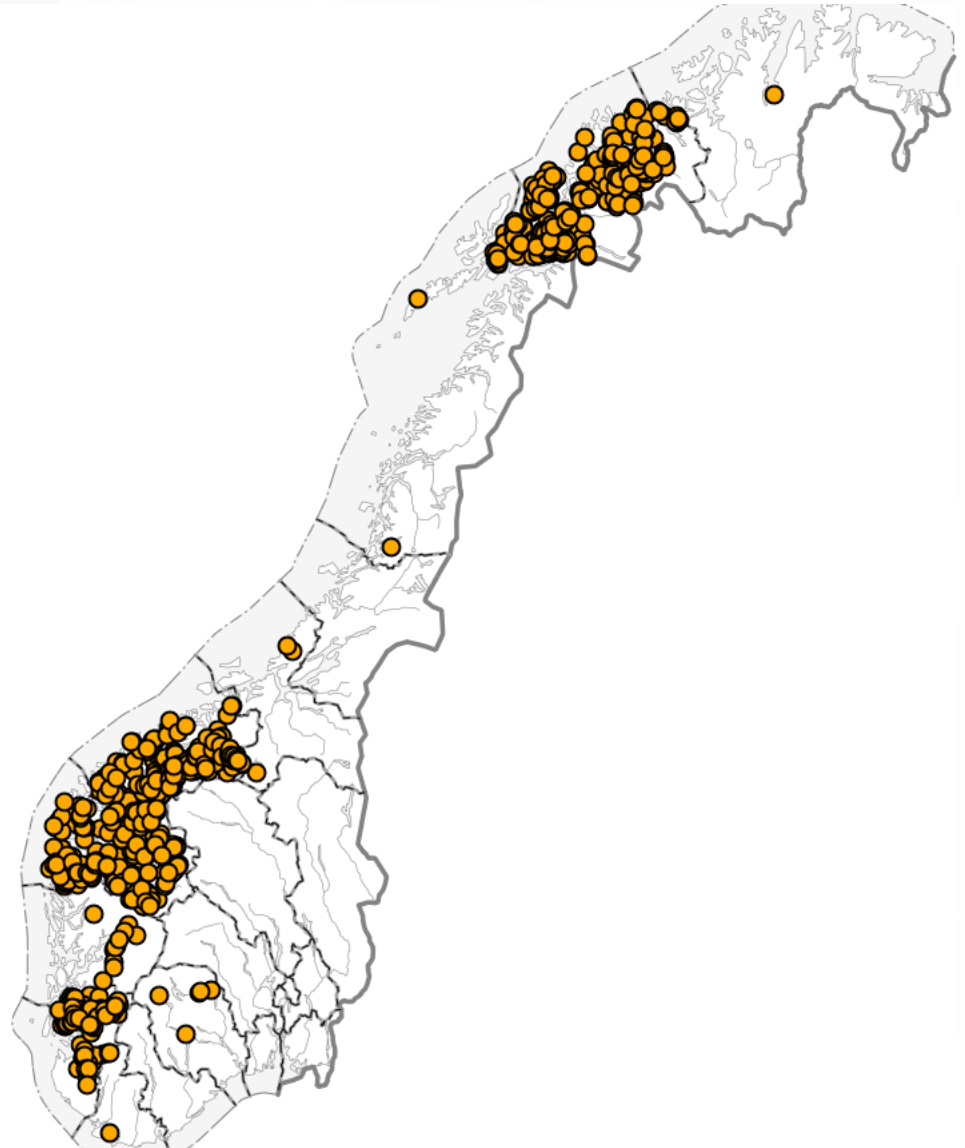
Velkommen til skreddata på nett.

Du kan veksle mellom ulike "Standardkart" i "Kart"-fanen.

Få informasjon om skredobjekt ved å trykke på "i"-knappen i "Verktøy"-fanen.

(Anbefalt nettleser: IE7)







# Thank you for your attention

Financed by:



**VG** GRAFIKK: Kenneth Lauveng

[Reginald.Hermanns@NGU.NO](mailto:Reginald.Hermanns@NGU.NO)

