Pipeline routing in landslide prone terrain

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The presentation is based, in part, on a paper due in the July/August issue of *Innovation,* the journal of the Association of Engineers and Geoscientists of BC.

Geertsema M, Clague JJ submitted. Pipeline routing in landslide prone terrain. Innovation.

Outline

- introduction
- recognizing the hazard
- characterizing the hazard
- mitigating the hazard
- conclusions

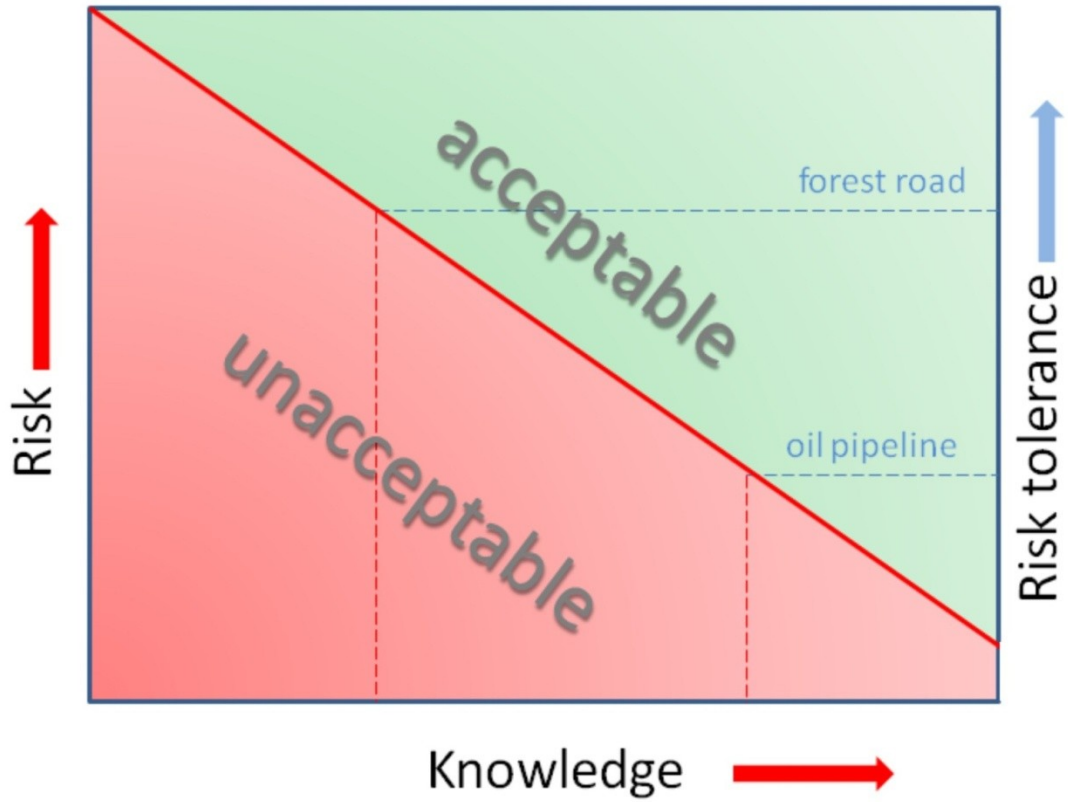
BC and its neighbours are blessed with an abundance of oil and gas

BC is located between sources and markets

BC has a lot of landslide prone terrain

landslides

- impact objects down slope in the runout zone
- impact objects on a slope and carry them along



Risk can be reduced with increased knowledge.
Society's risk tolerance differs for different land-use activities.
More knowledge is needed for safely routing an oil pipeline than a forest road.

recognizing landslide hazard

- type of landslide
- detectability
- area of consideration
- subsurface conditions

Type of landslide (a few examples)

rock fall

Source: Chua Chin Hon

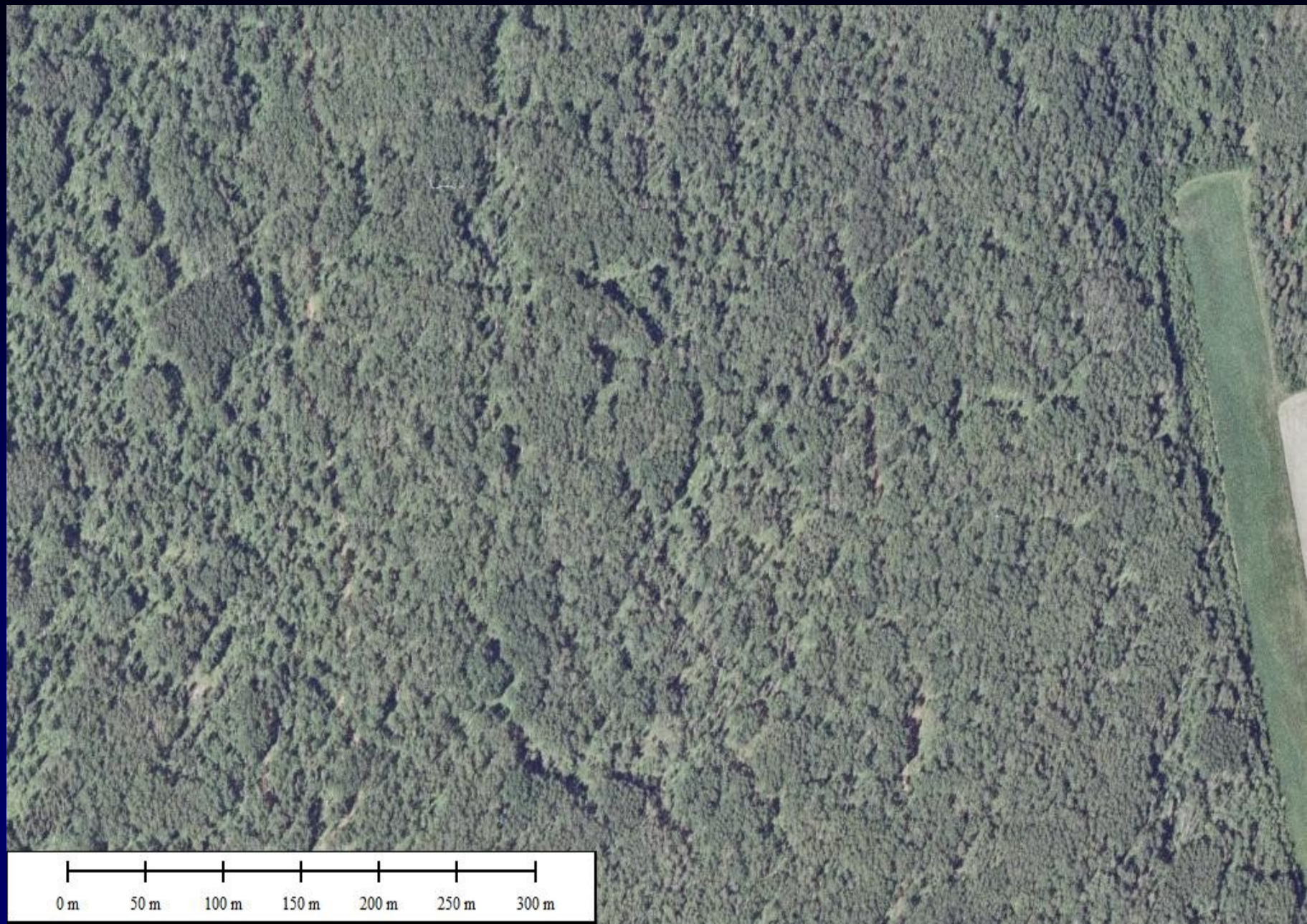
earth slide

mud flow
A
2004 10 6

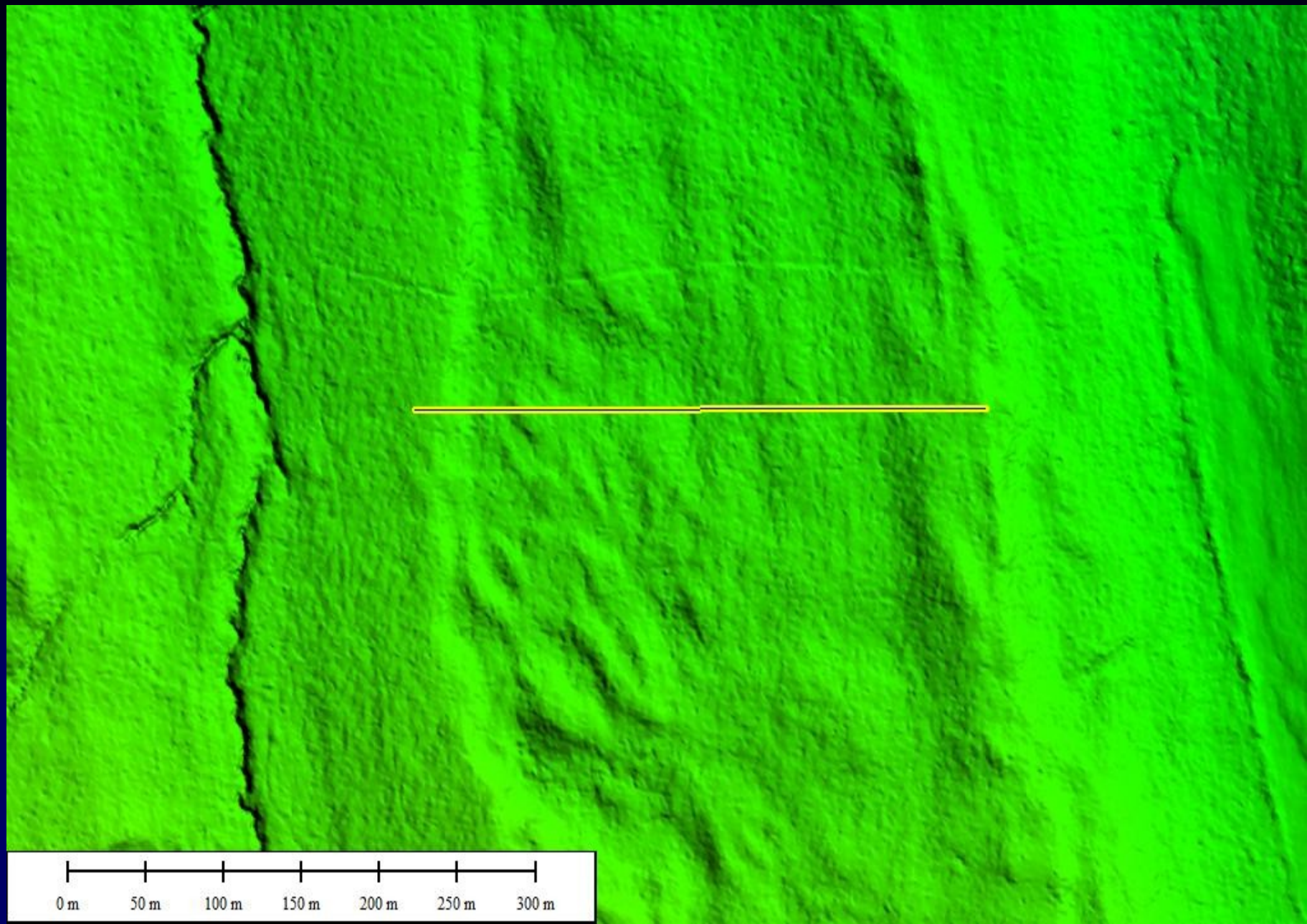
detectability

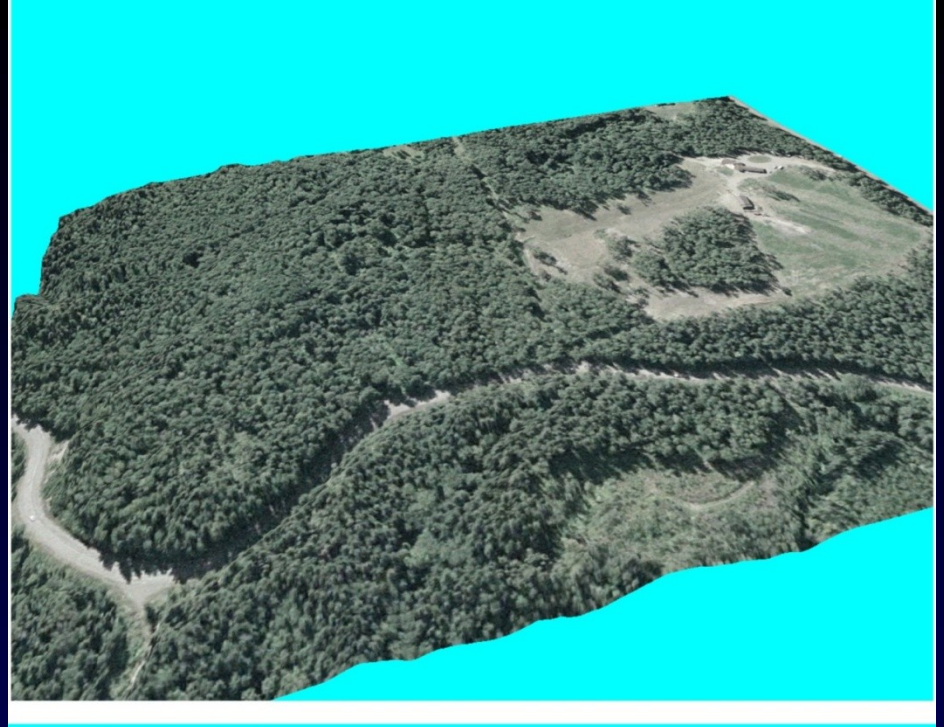
- forest cover
- snow cover
- scale

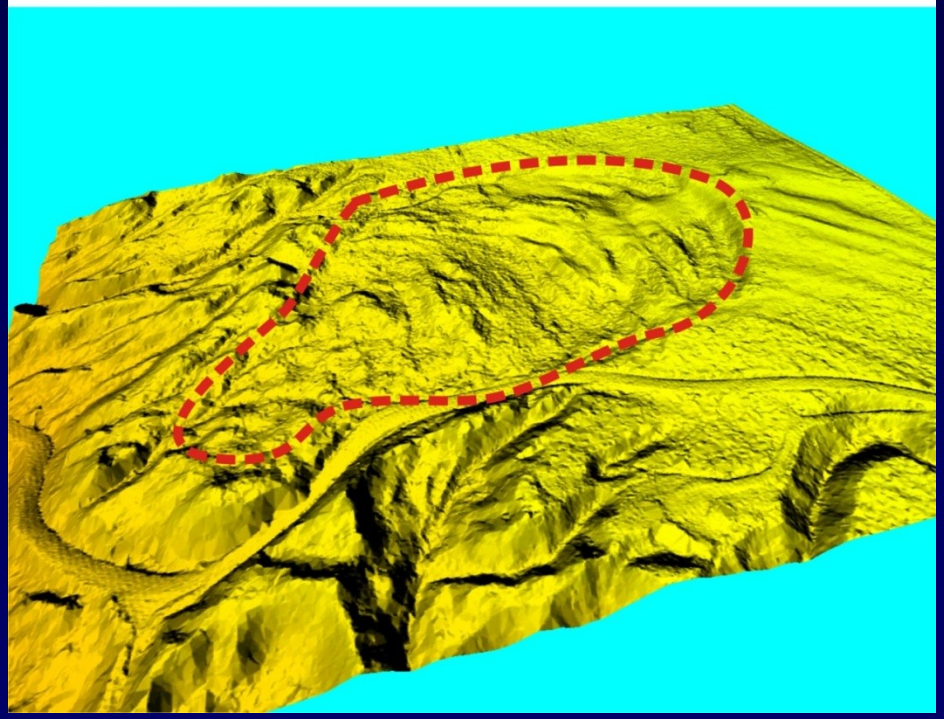
Forest cover often results in undercounting of landslides (Brardinoni et al. 2003).



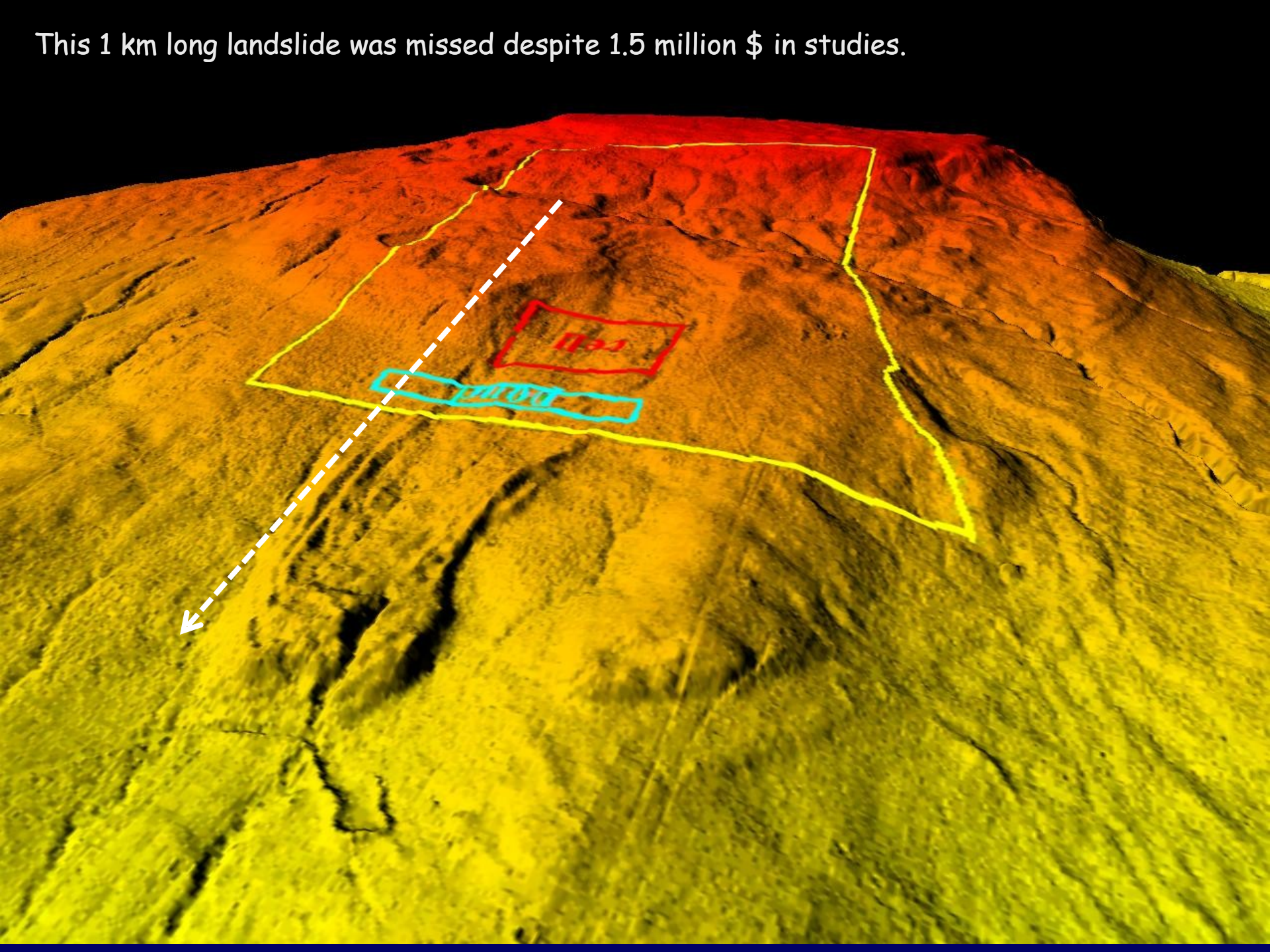
Bare earth LiDAR reveals much.





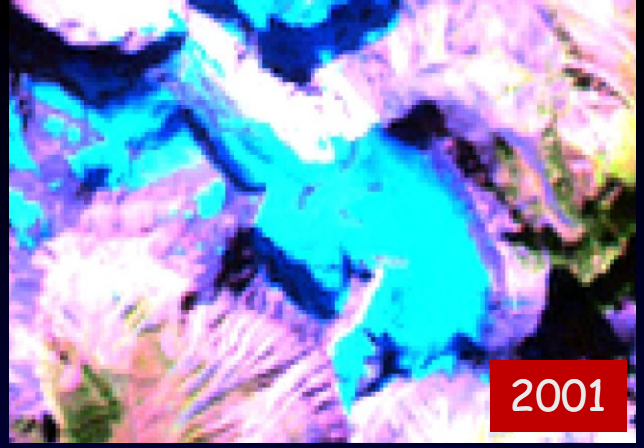


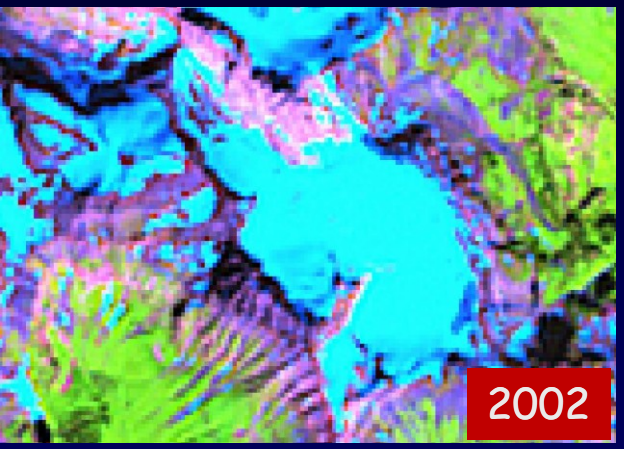
This 1 km long landslide was missed despite 1.5 million $ in studies.

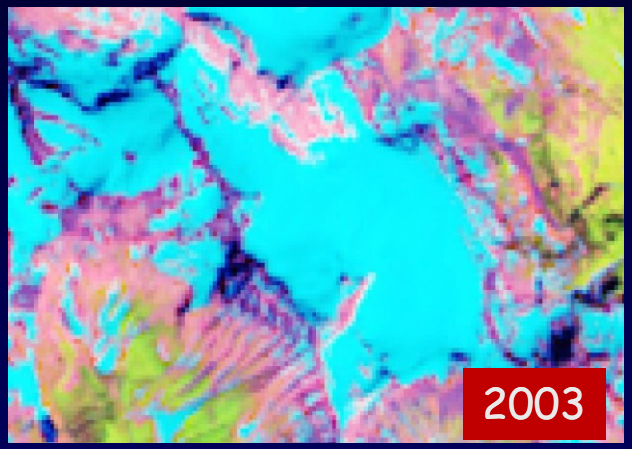


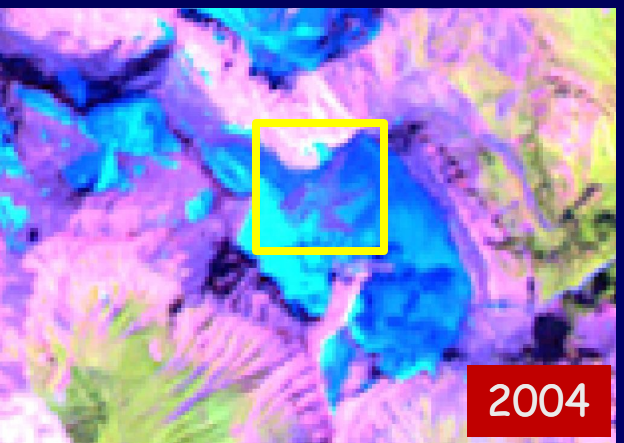
snow

Landsat









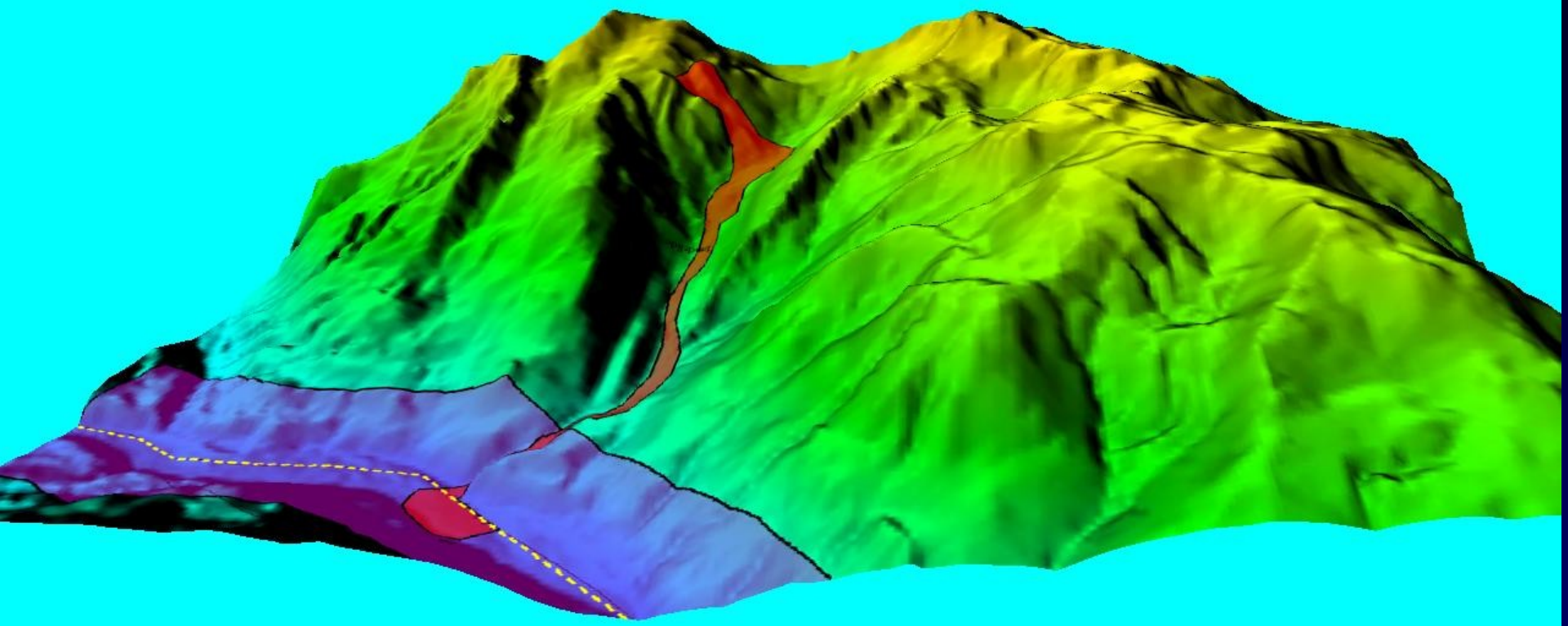
snow

2004

scale

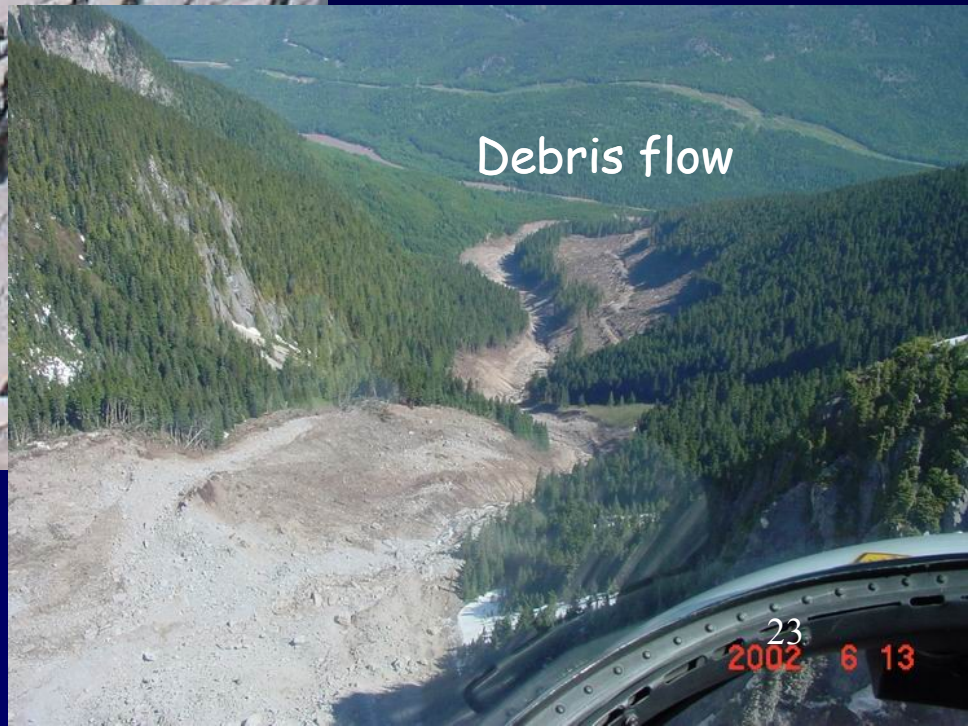
- Magnitude frequency relationships (power law)
- Big landslide advantage:
  - 1. fewer
  - 2. easier to detect in field and on coarse imagery
  - 3. likelihood of detection may increase with time – opposite for smaller landslides

Area of consideration



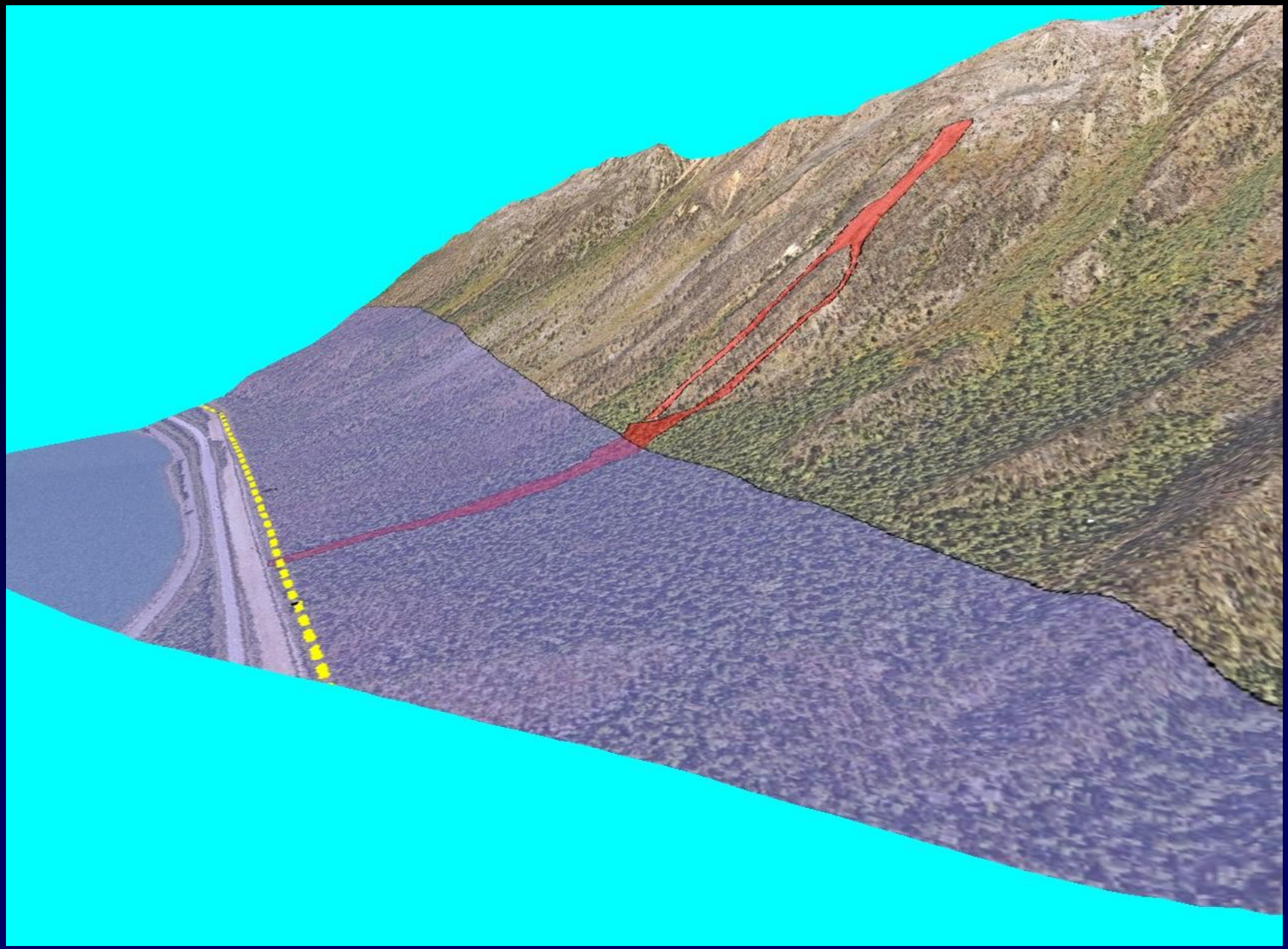
The 2002 Zymoetz rock slide – debris flow, near Terrace, initiated near the height of land in a tributary valley far from a typical, 1-km-wide landslide study corridor (blue). The landslide (red) travelled 4.3 km and ruptured a buried natural gas pipeline (dashed yellow line) near Zymoetz River.

Study corridors should go to the height of land



Zymoetz rock slide - debris flow 2002

pipeline rupture
Zymoetz River
2002 6 13



Subsurface conditions

- permafrost
- quick clays
- buried lake sediments

The pipeline (yellow dashed line) was severed when the ground moved beneath it.
The landslide occurred within a typical 1-km-wide study corridor (purple),
but the real hazard, the sensitive clay, was hidden from view.
In valleys where glaciomarine clays are expected based on mapping or
apriori knowledge of geologic history, subsurface testing is recommended.

characterizing landslide hazard

- causes and triggers
- frequency
- travel angle (runout, retrogression distance)
- lurking issues

Landslide causes and triggers

- Glacial conditioning (paraglacial response – e.g. debuttressing)
- Climate change
- Earthquakes (amplification in mountain ridges – liquefaction)
- Landuse (land modification)

just a few of the considerations . . .

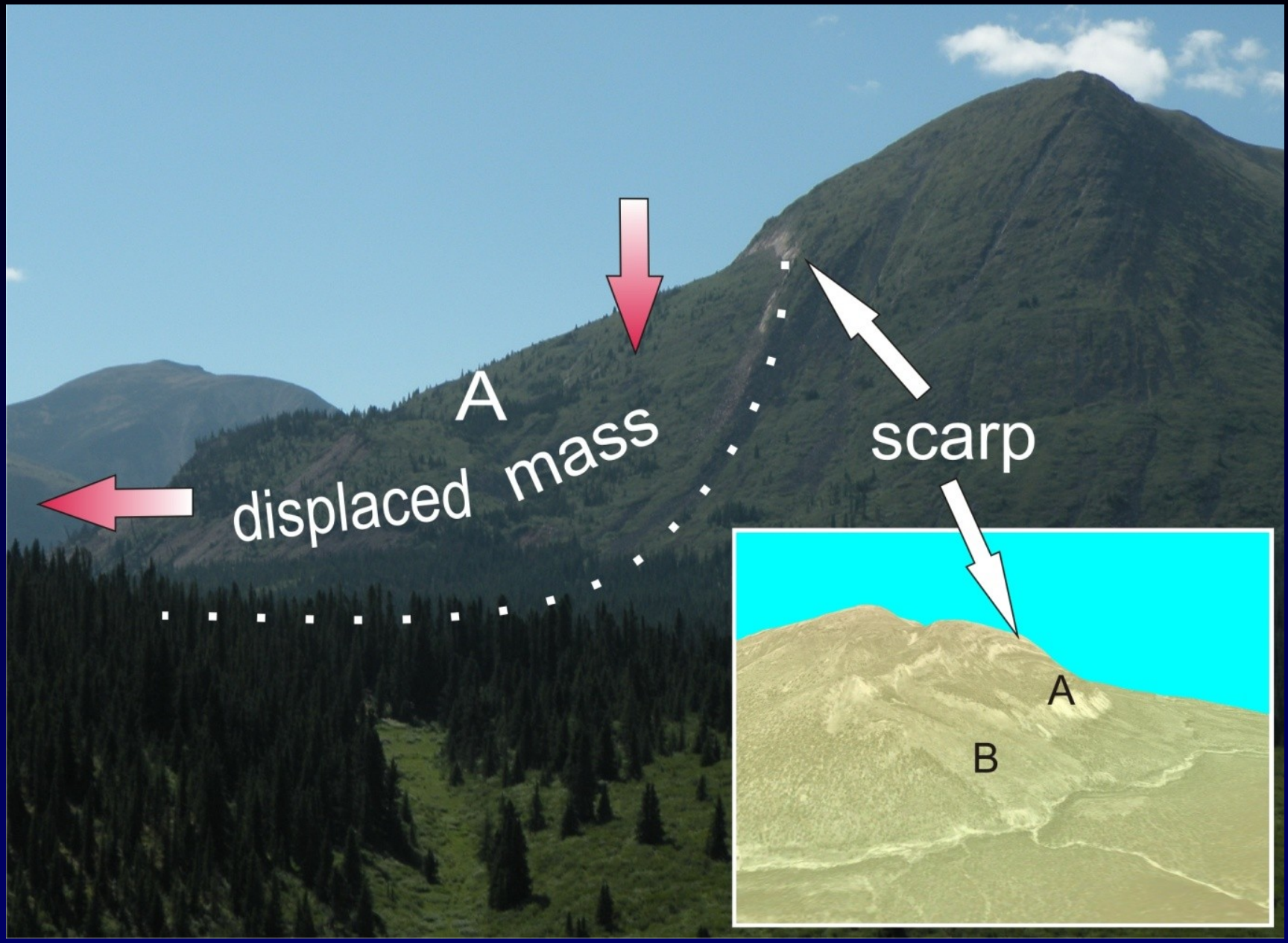
Both glaciation and deglaciation weaken rock masses.

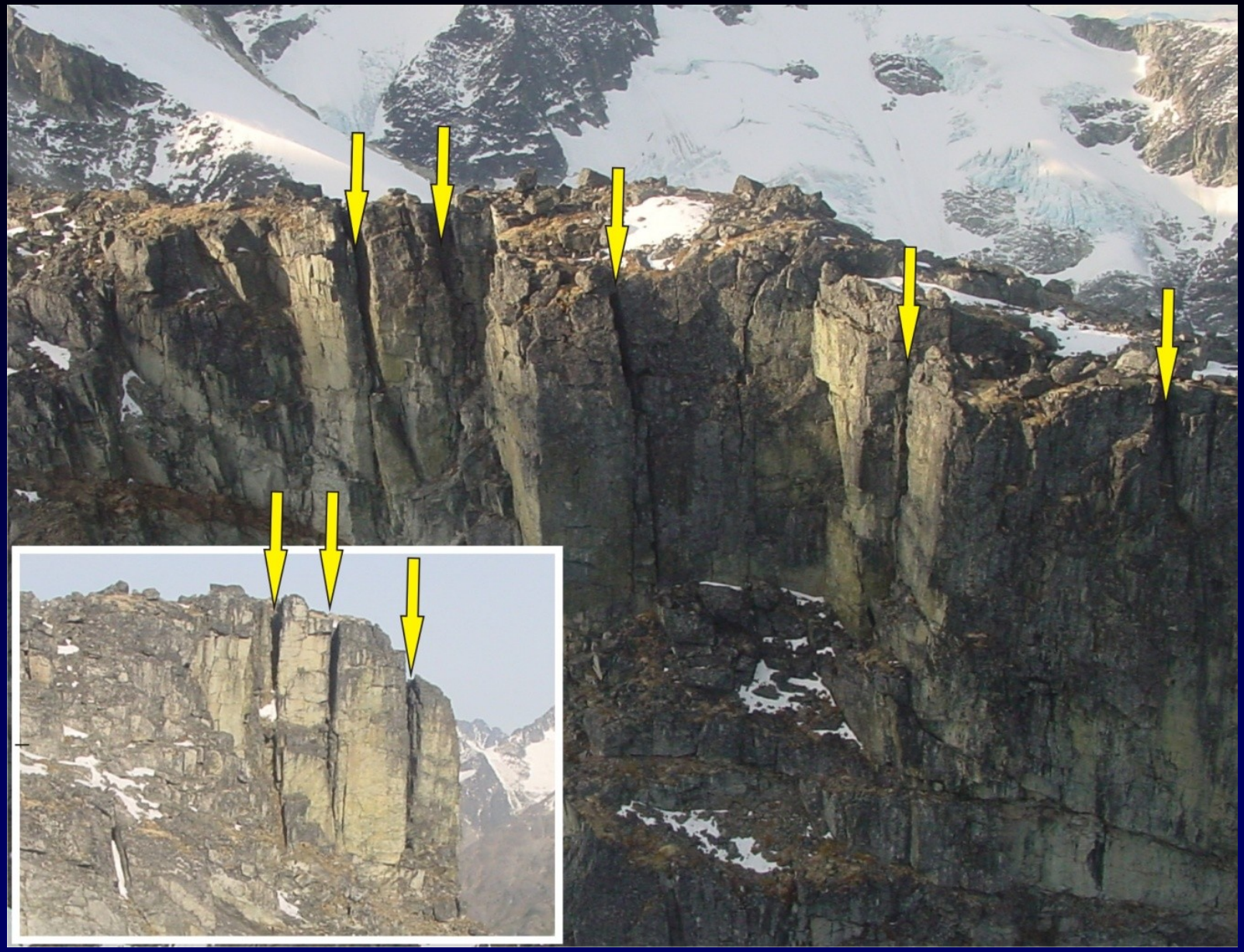
1. through deepening and widening of valleys (glacial erosion)
2. ice loading resulting in the development of stress fractures
3. debuttressing (during deglaciation)
4. stress release as manifested by joint expansion

Resulting landslides.

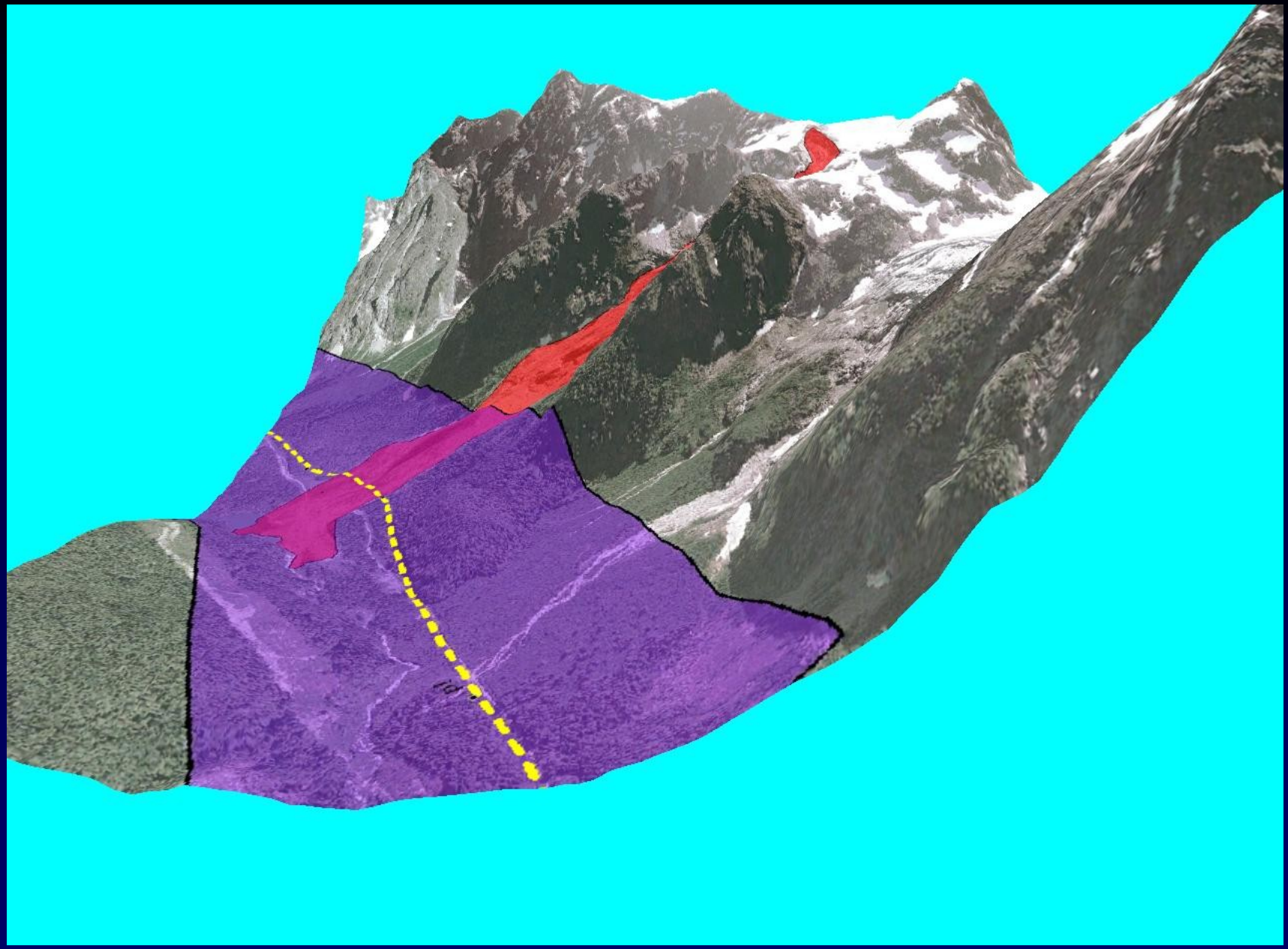
1. rock topple
2. rock fall
3. deep seated slope deformation (very slow)
4. catastrophic rock avalanches

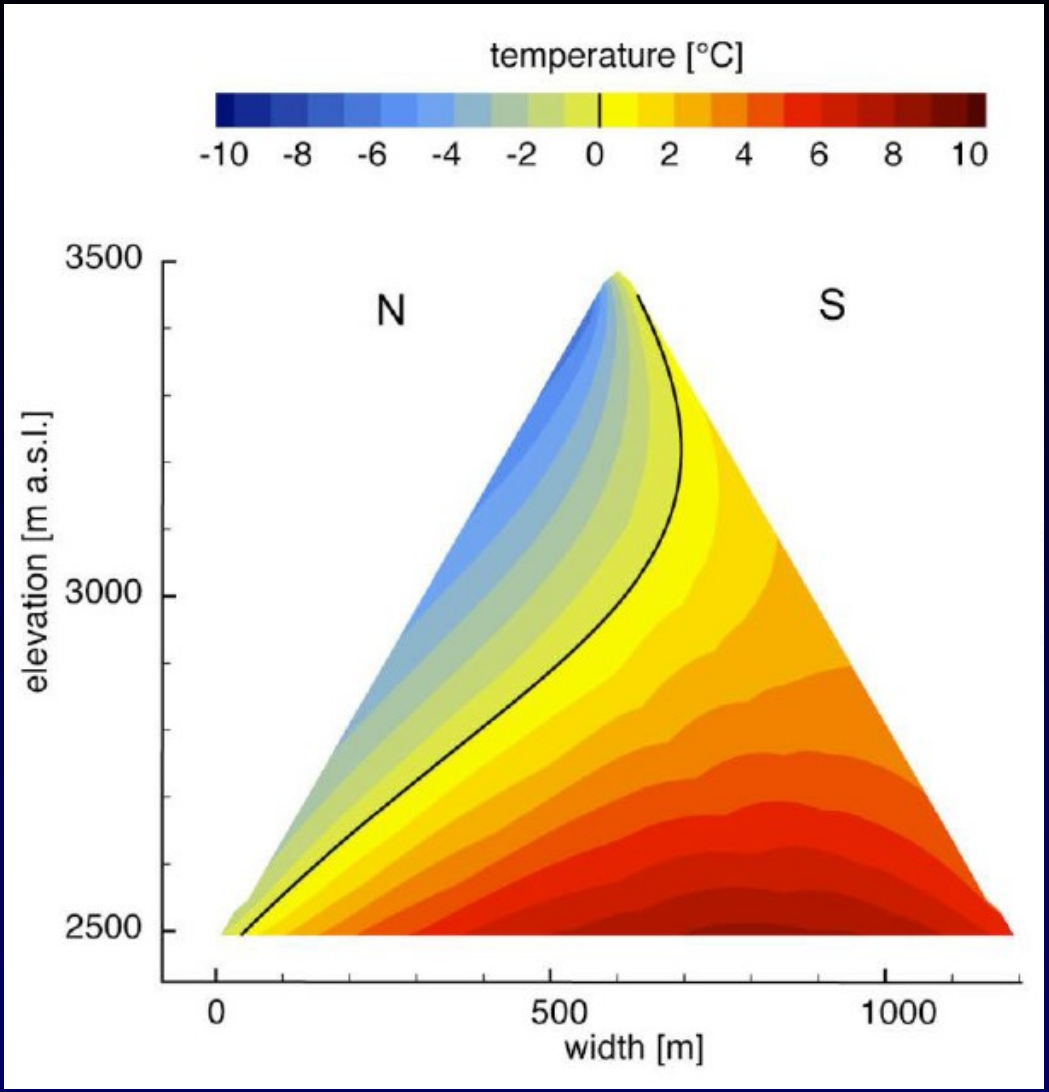
The spatial and temporal association of rock landslides with previously glaciated areas suggests that glacial conditioning of rock slopes plays an important role in their occurrence.


A
displaced mass
scarp
A
B



2002 10 22





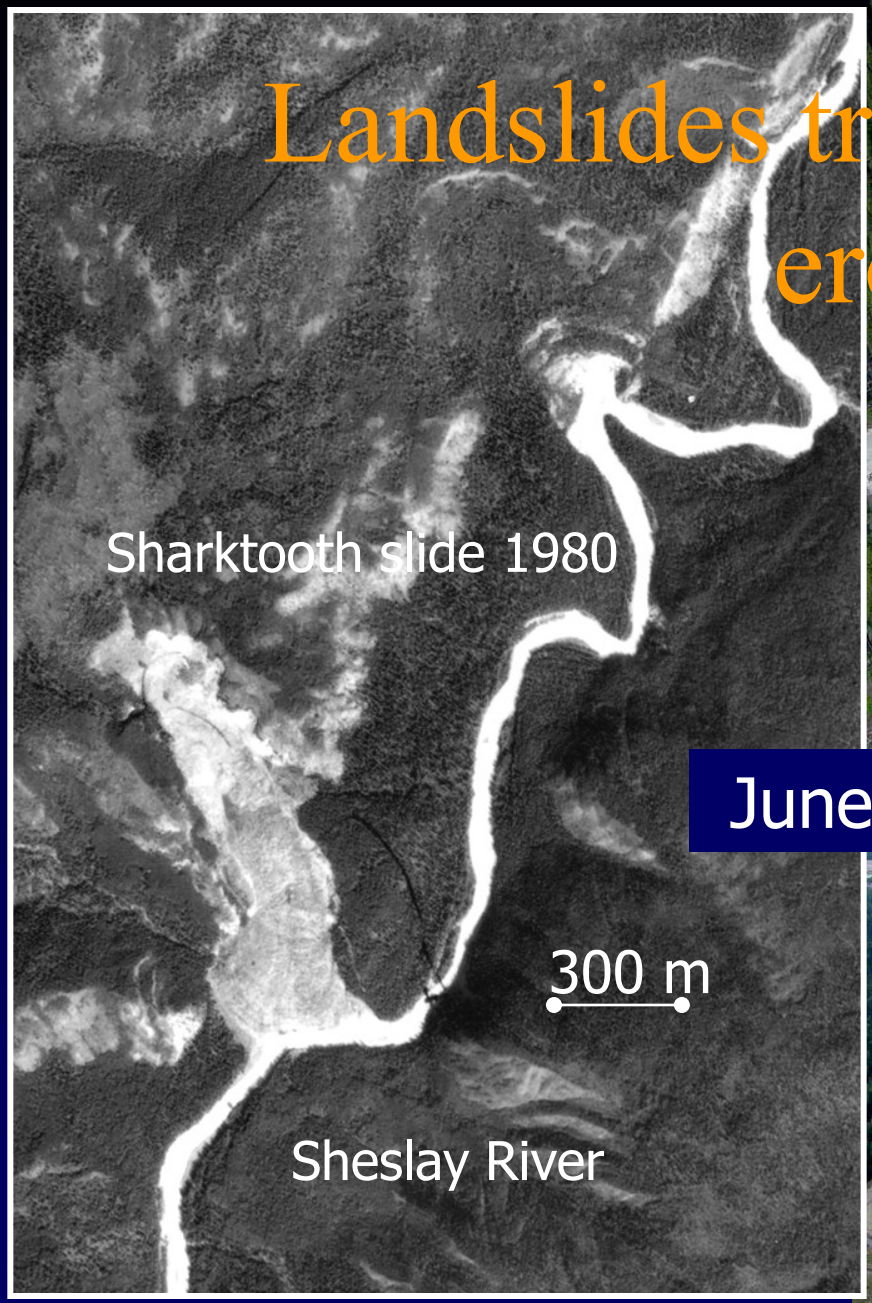
Noetzli J, Gruber S. 2009. Transient thermal effects in alpine permafrost. The Cryosphere 3:85-99.

Mountain permafrost and long runout landslides?

wildfire, forest floor reduction, permafrost thaw, landslide (flow)

Forest harvesting response?

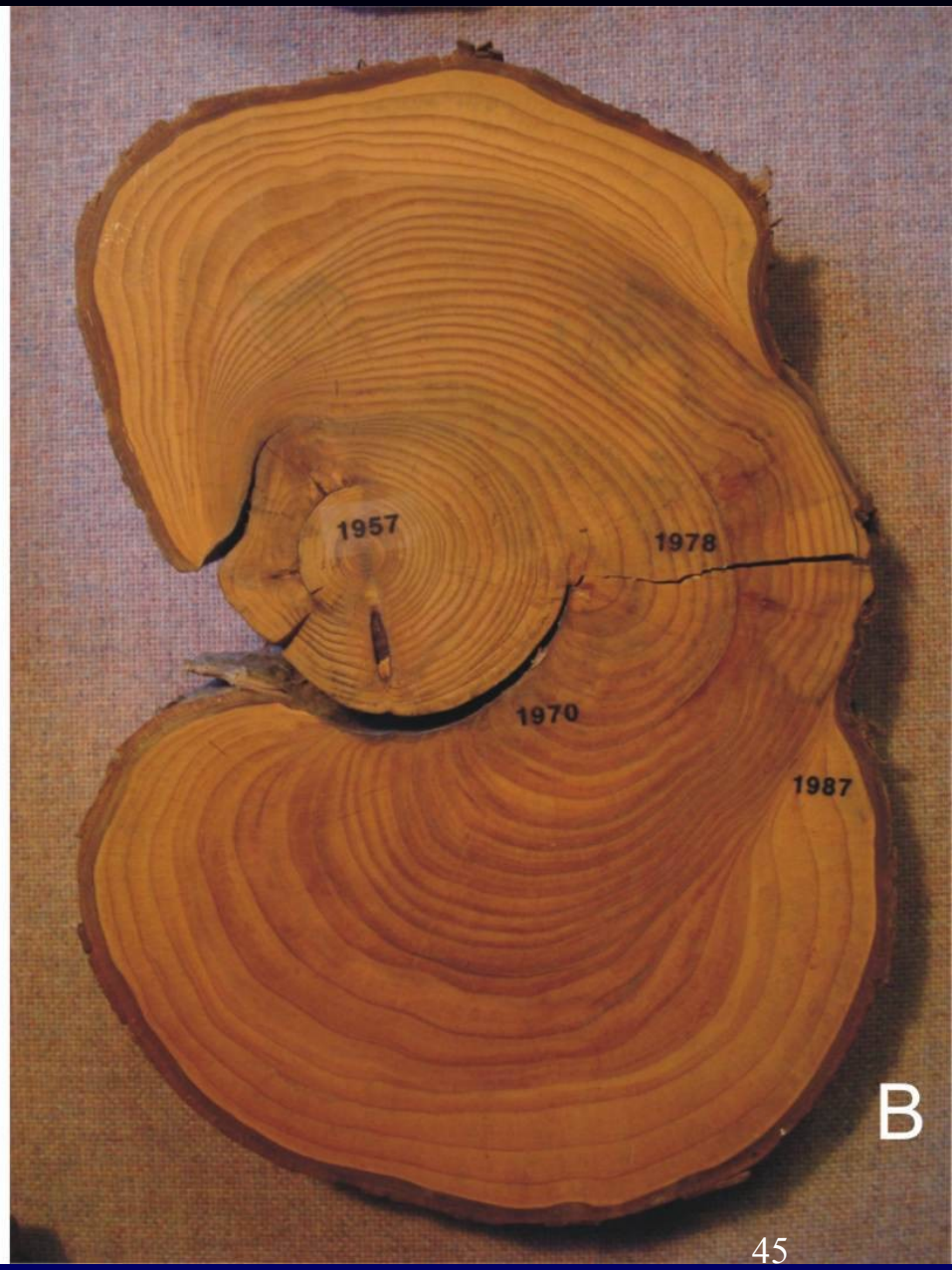
Landslides triggered by bank erosion



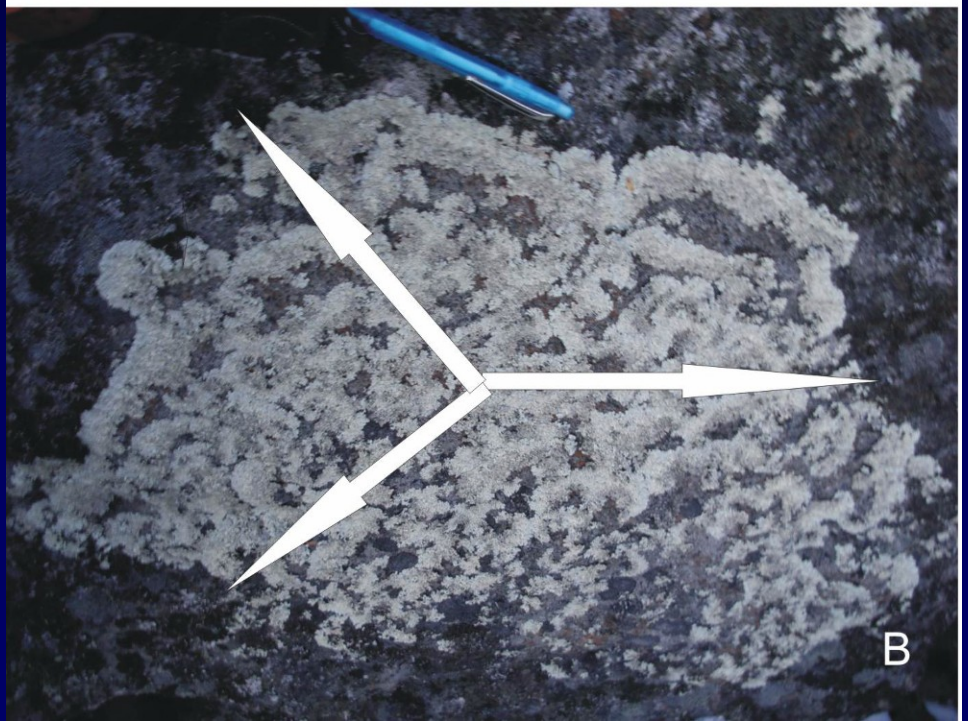
June 2002 rain on snow flood event

Landslide frequency

2002 10 21
A


1957
1978
1970
1987
B

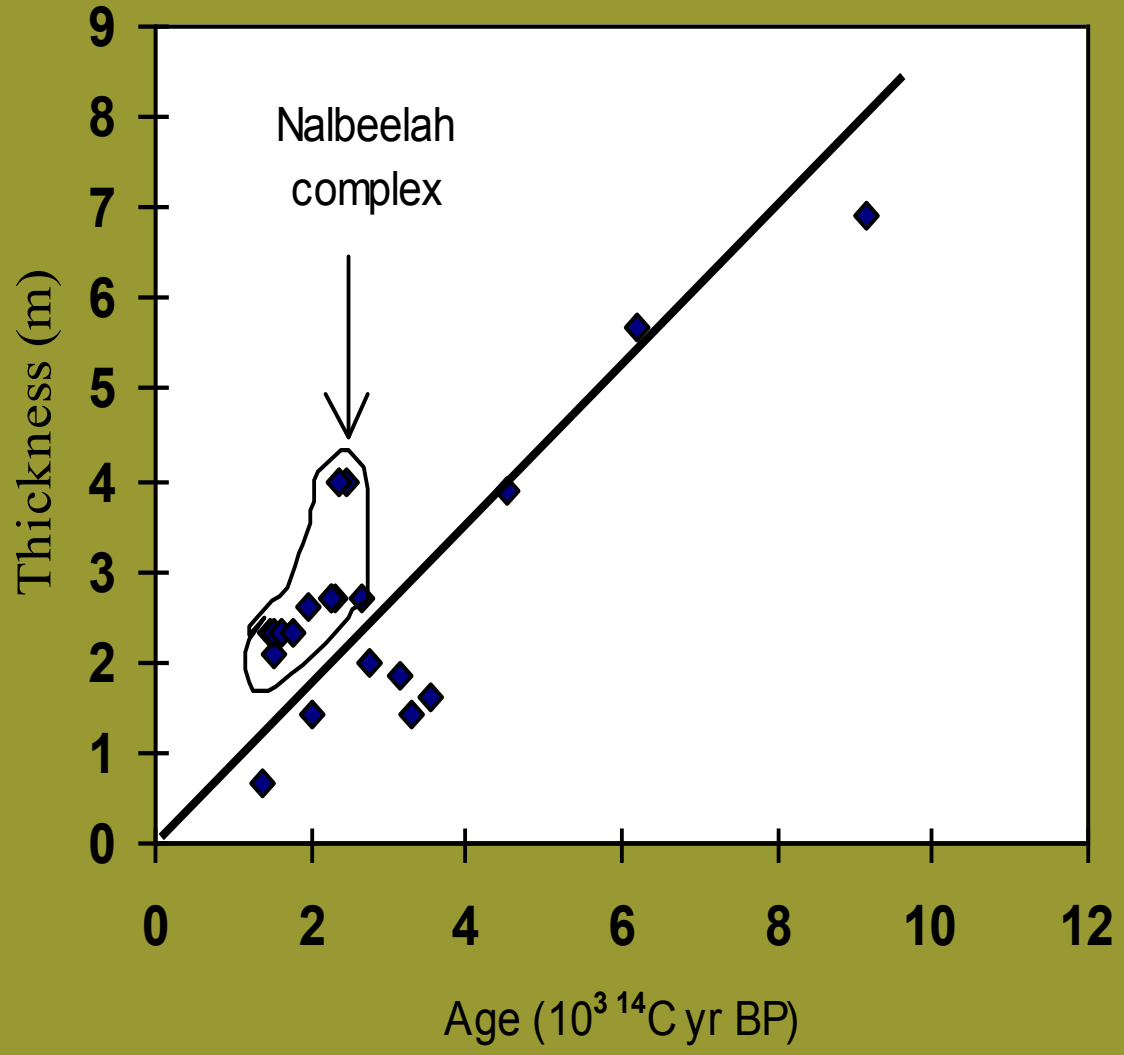
A


B

2008/ 7/ 4
47

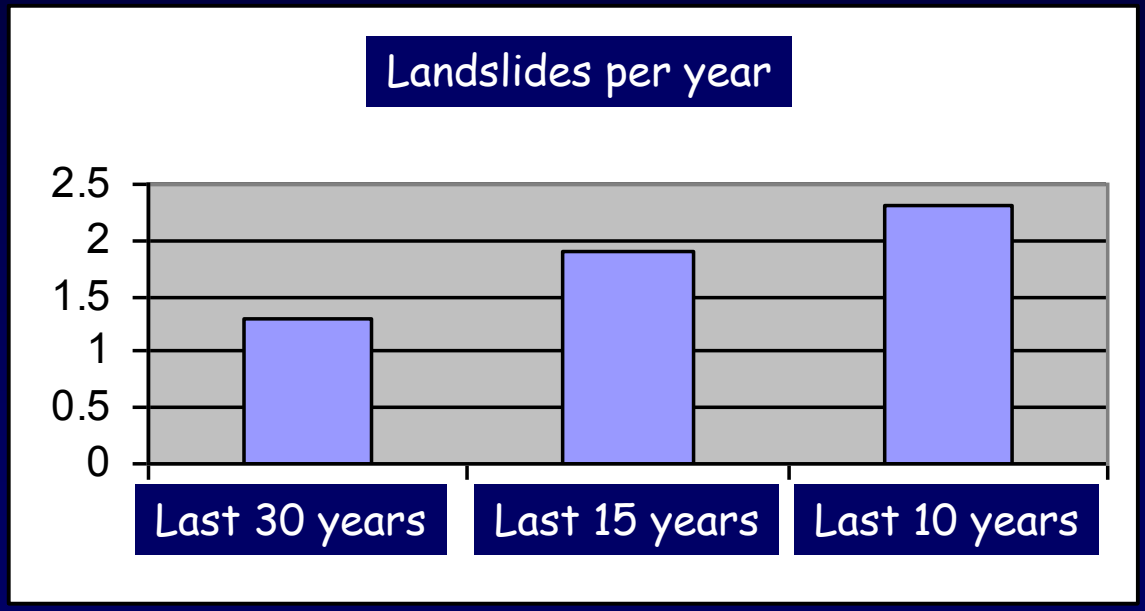
1

Peat deposits (Age vs. Thickness)



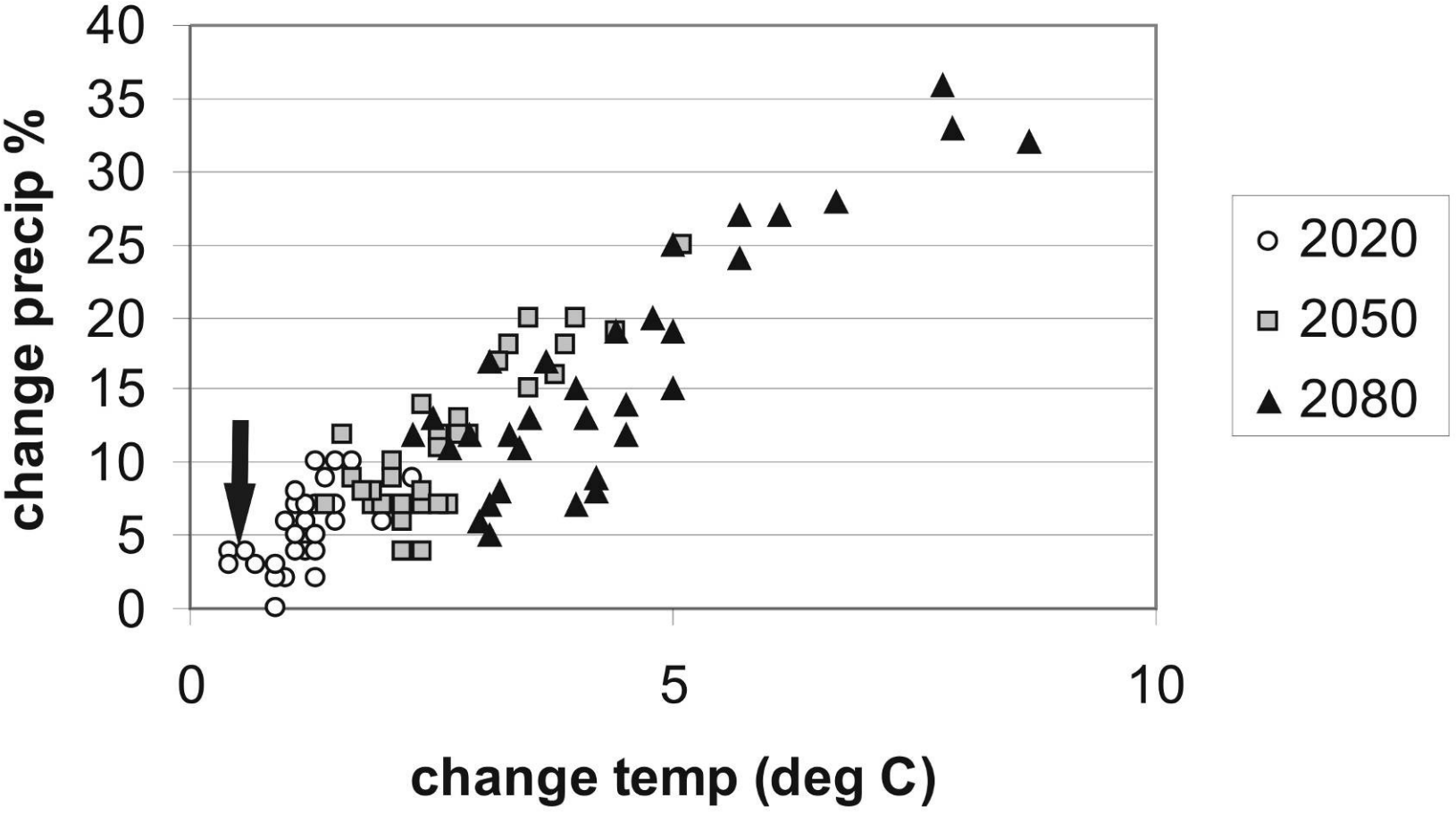
Frequency of large landslides in northern British Columbia (1973-2003)

Year range	Total landslides	Landslides per year
Last 30 years	38	1.3
Last 15 years	28	1.9
Last 10 years	23	2.3



Geertsema, M., Clague, J.J. Schwab, J.W.; Evans, S.G. 2006. An overview of recent large landslides in northern British Columbia, Canada. *Engineering Geology* 83: 120-143.

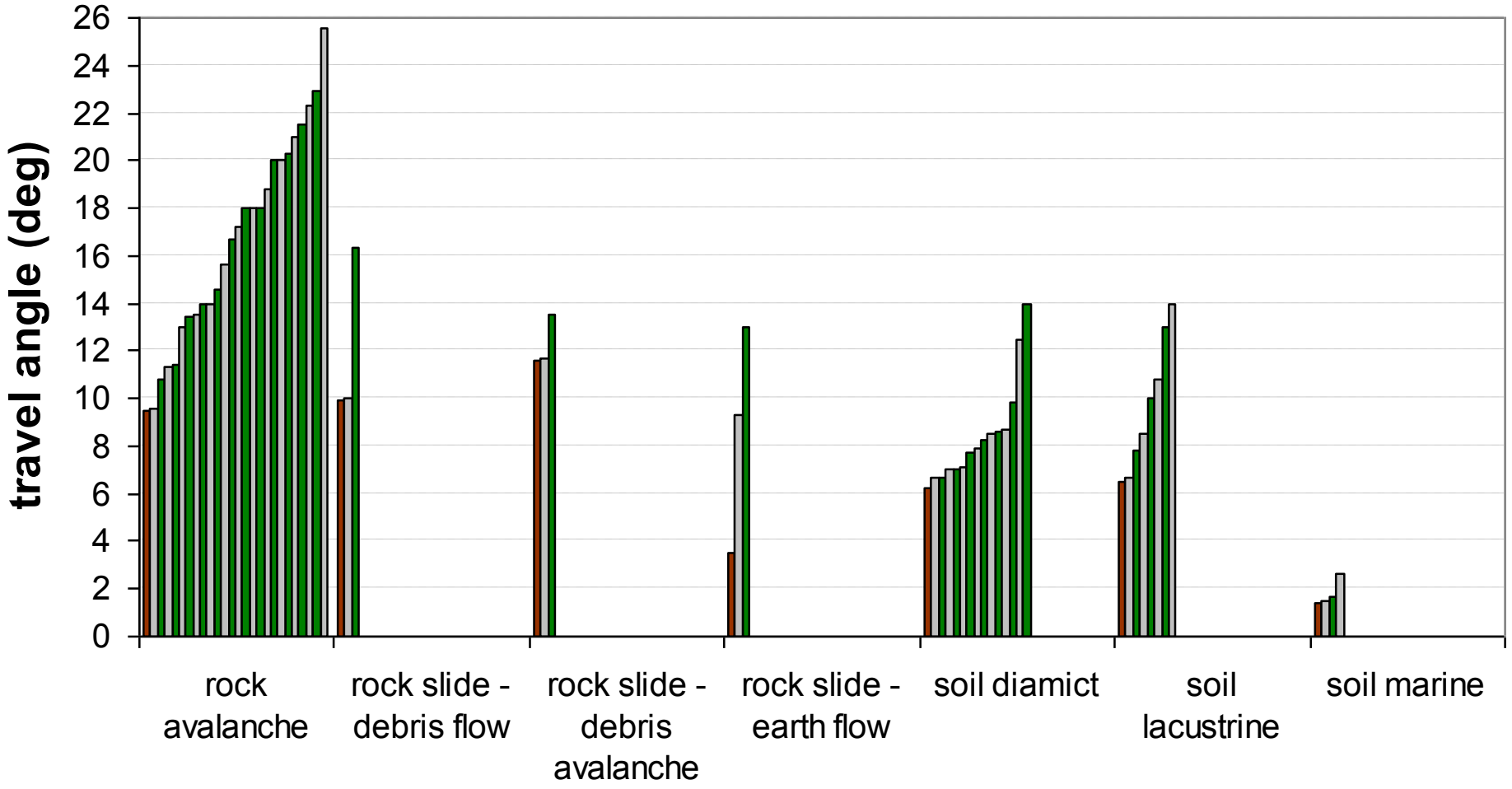
Annual climate change scenarios



Landslide travel angle

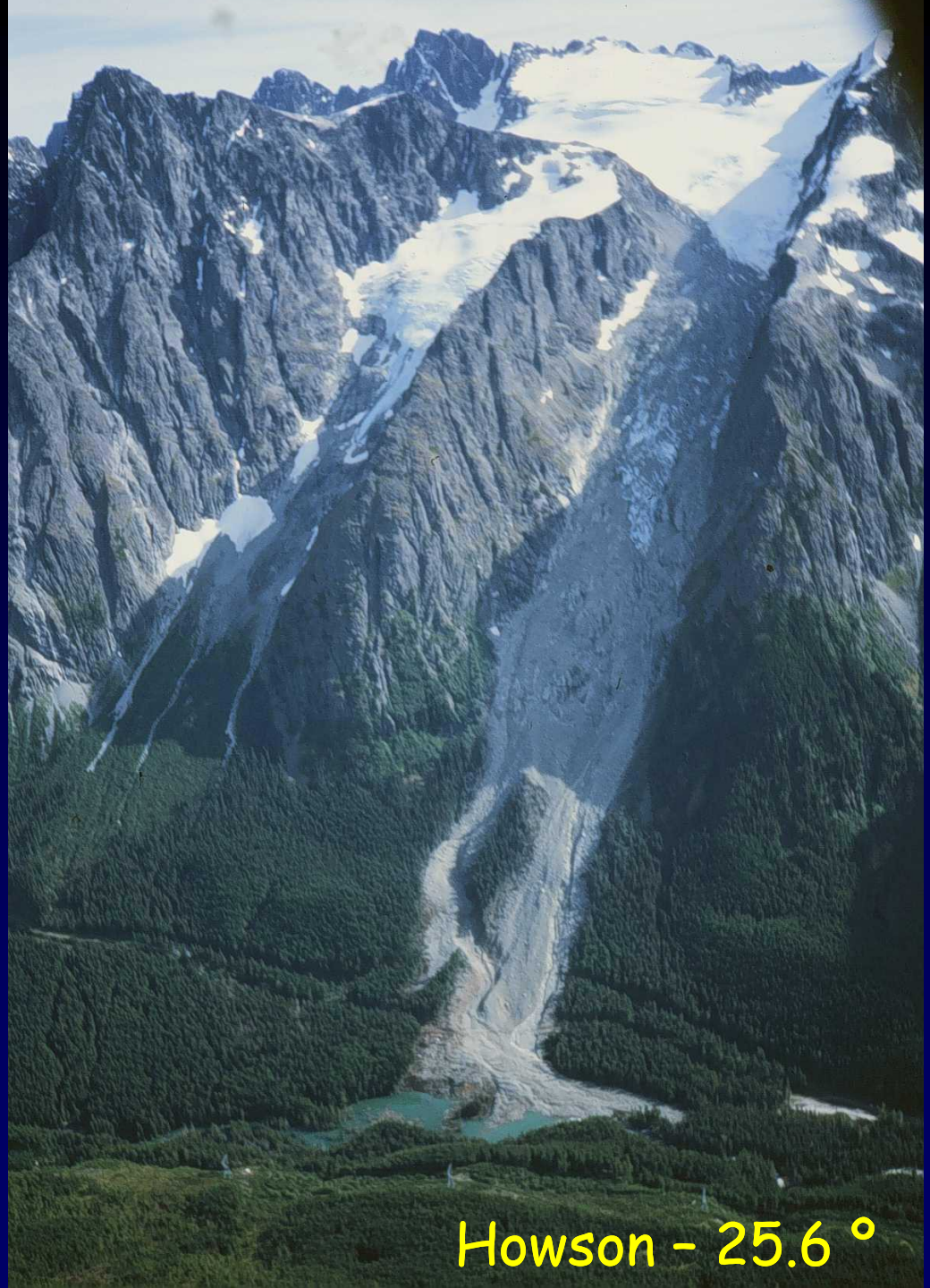
Considerations

- Set forwards
- Set backs
- Retrogression vs total distance both are important
- Being carried along by debris or being hit by debris
- Groupings along material type and mode of failure



Source: Geertsema M, Cruden DM, 2008. Travels in the Canadian Cordillera. 4th Canadian Conference on Geohazards. Quebec PQ

Landslides in rock


Howson – 25.6 °

Landslides in rock and soil

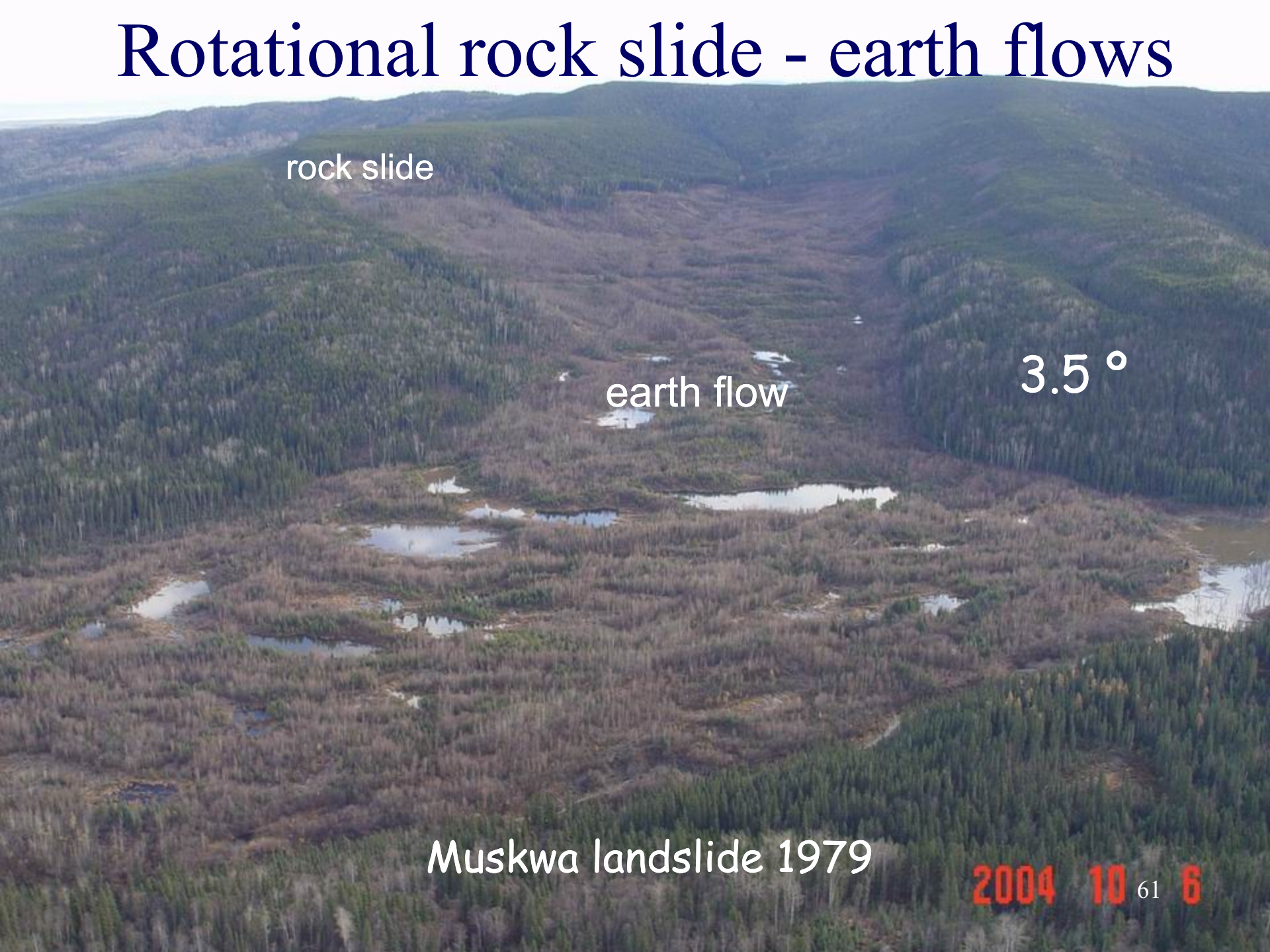
Sutherland - 11.7 °
2005 8 26

Harold Price – 9.9 º

2002 Harold Price rock slide – debris avalanche - debris flow

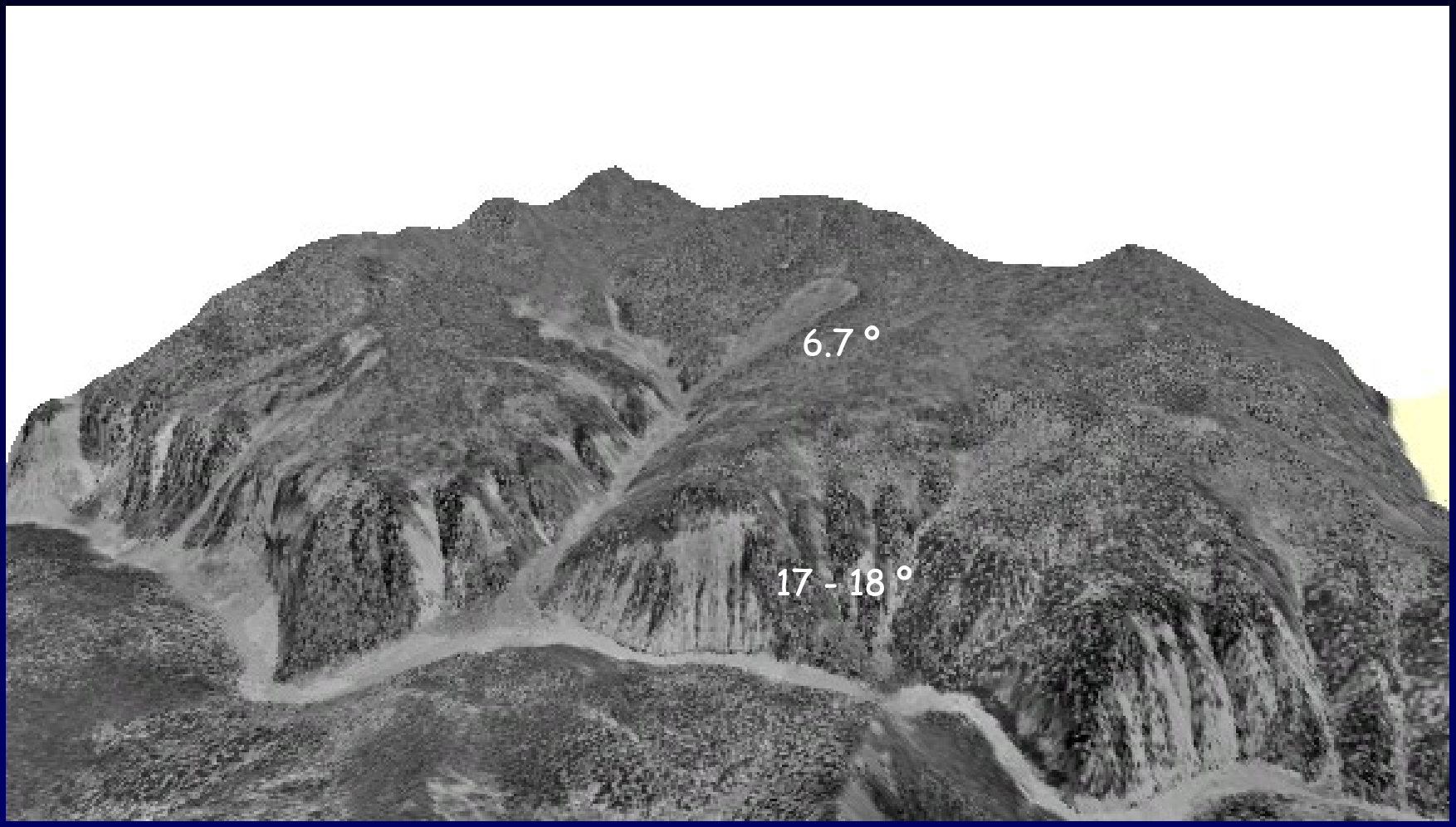
Grizzly slide NWT – 9.3°

Rotational rock slide - earth flows

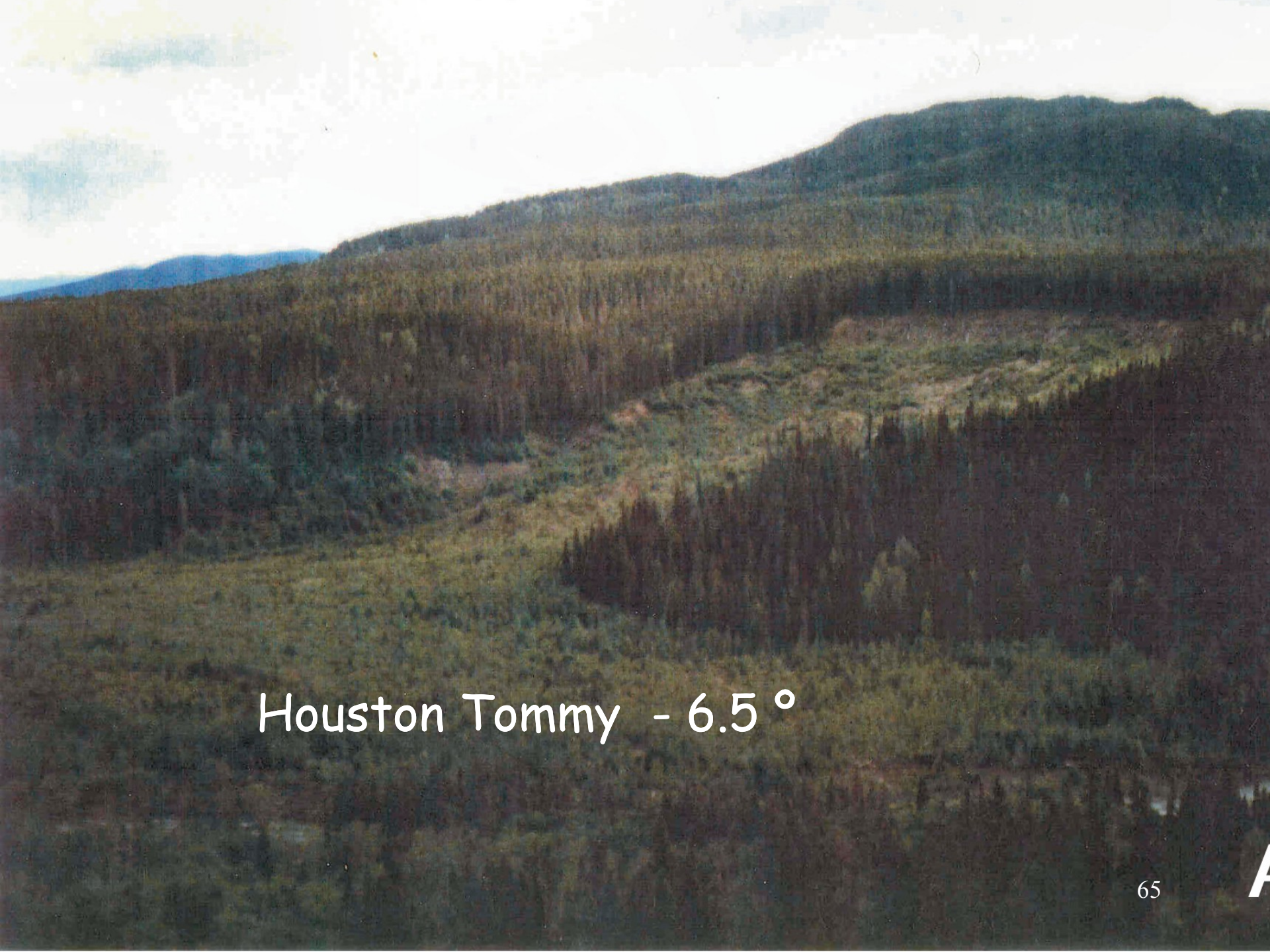


Landslides in soil

Buckinghorse - 6.7 º



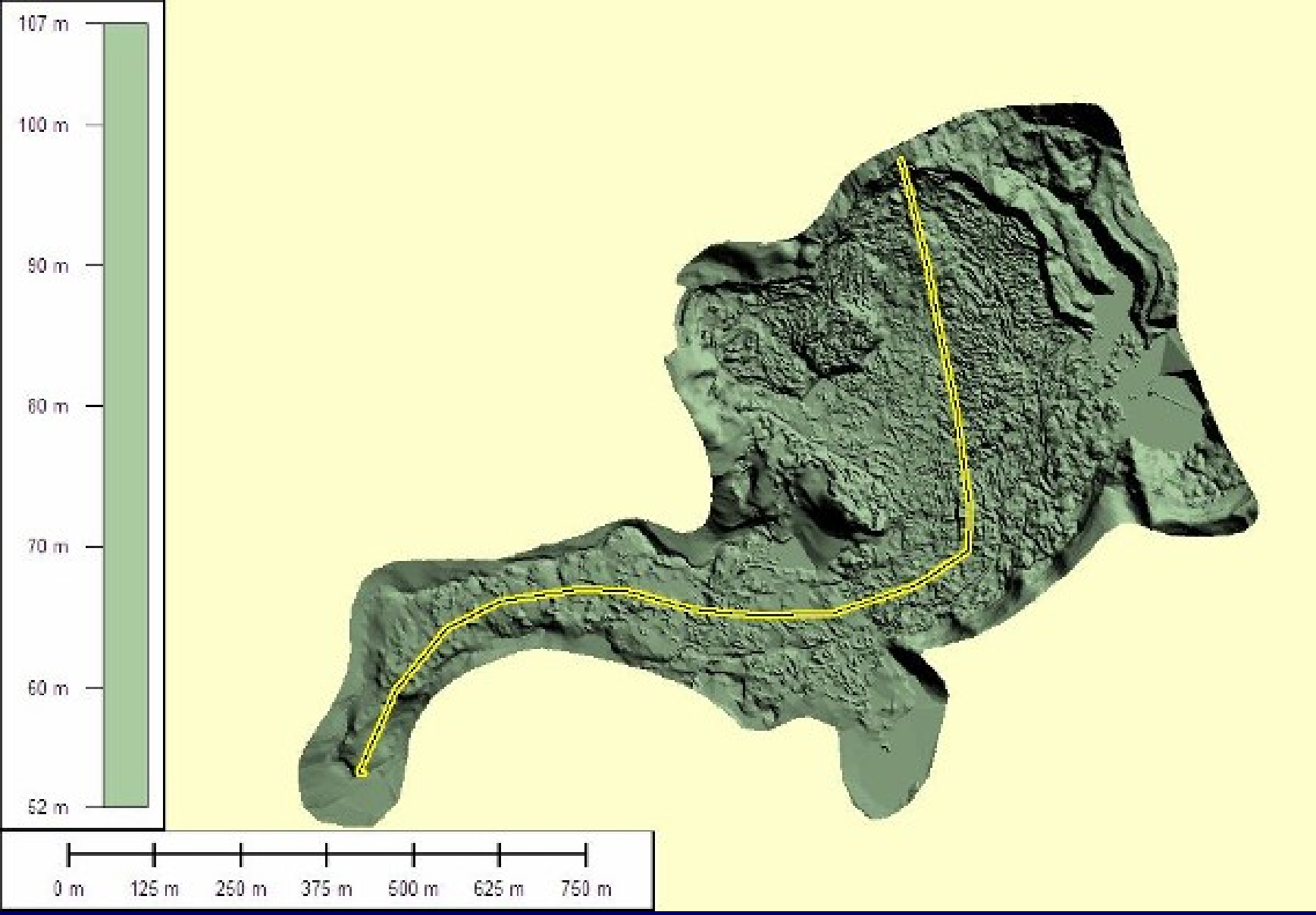
Attachie 1973


Houston Tommy - 6.5 °

Landslides in soil

- glaciomarine sediments

Khyex landslide – 2.6 °



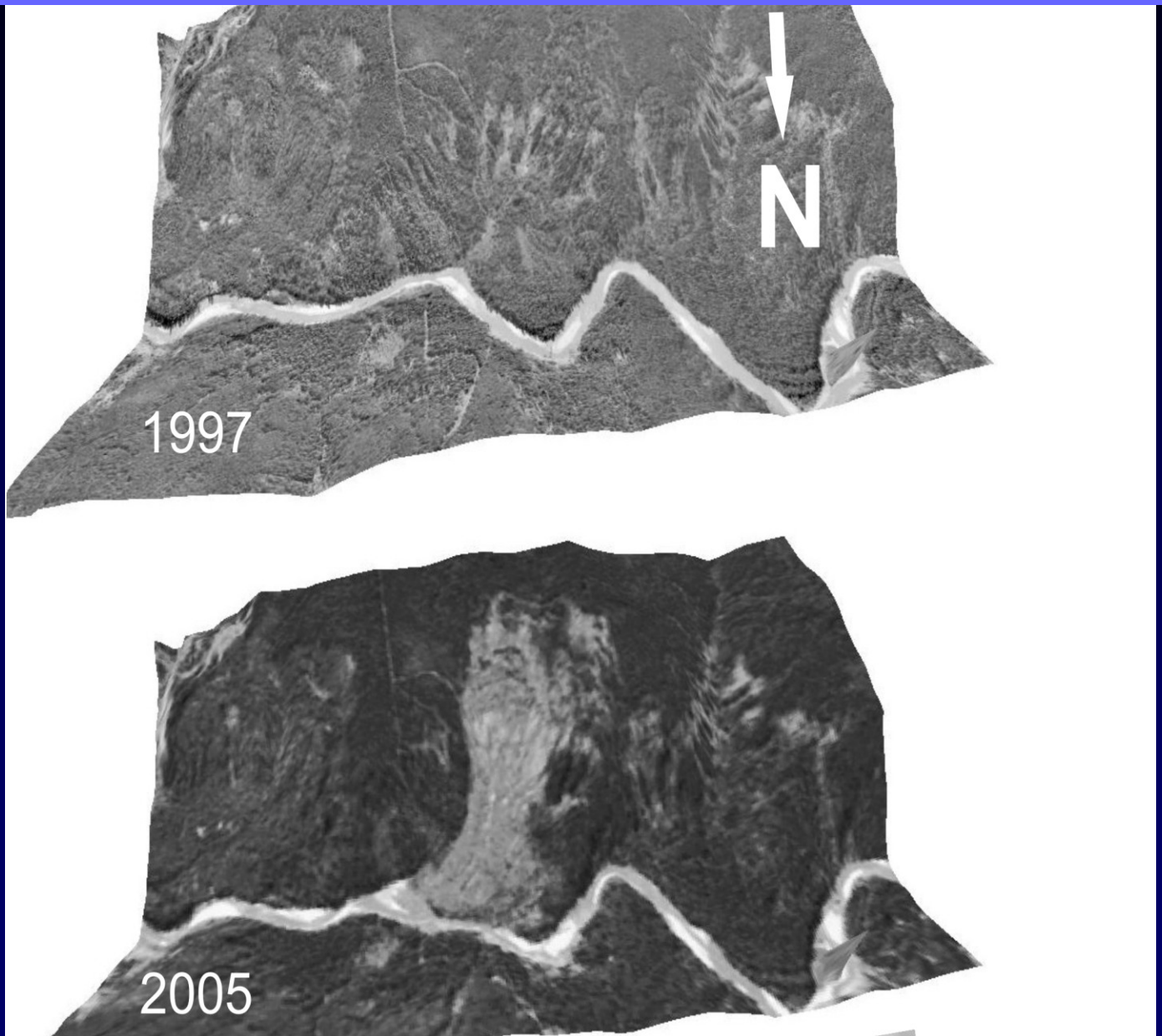
Mink Creek – 1.7 º

Lurkers

- Factor of safety

  needs to consider worst case scenario
  often hidden from view

Small debris slides along in 1997 belie a more serious problem, evident in 2005



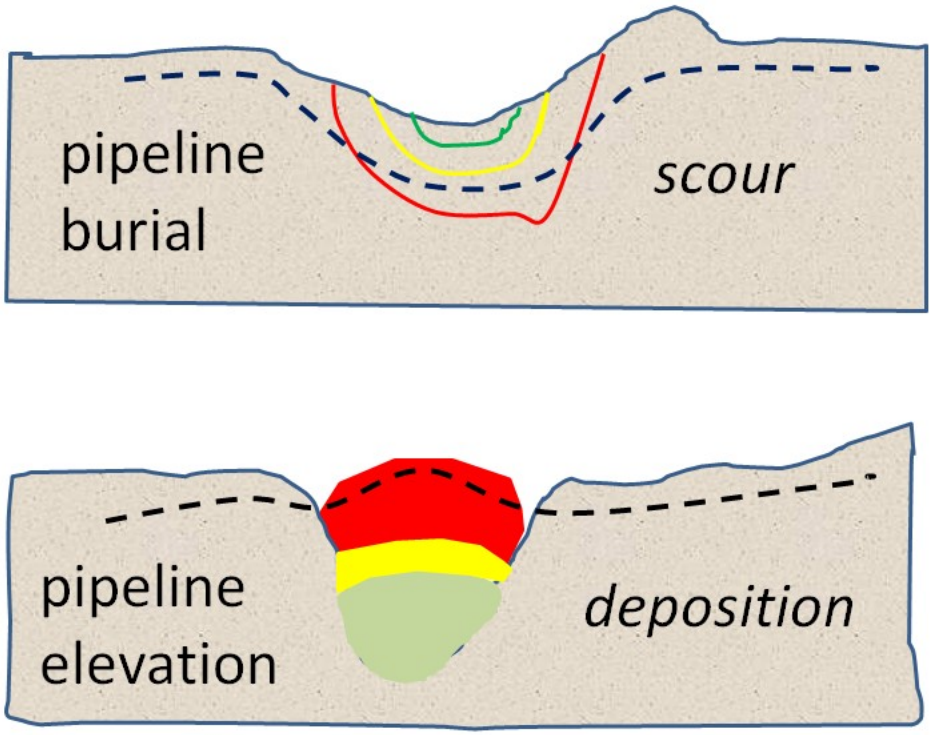
2004 10 6

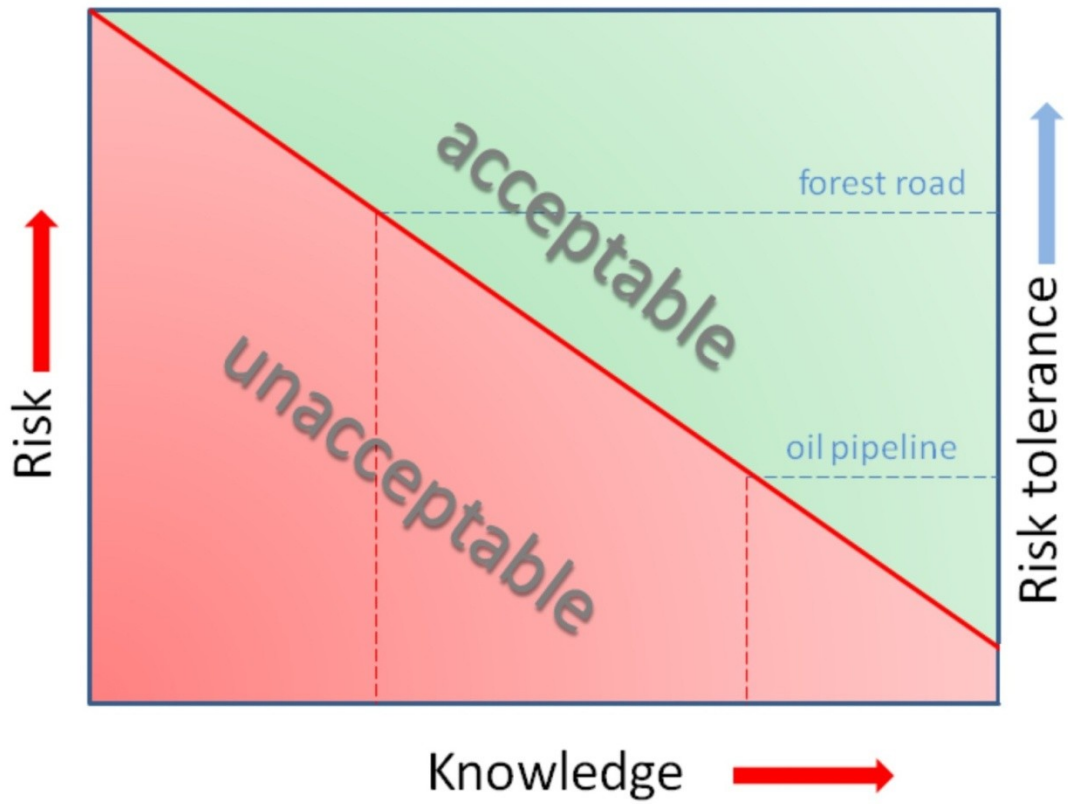
mitigating landslide hazard

- spatial avoidance (vertical, horizontal)
- temporal avoidance

scour > 5m

deposition


pipeline
burial
scour
pipeline
elevation
deposition



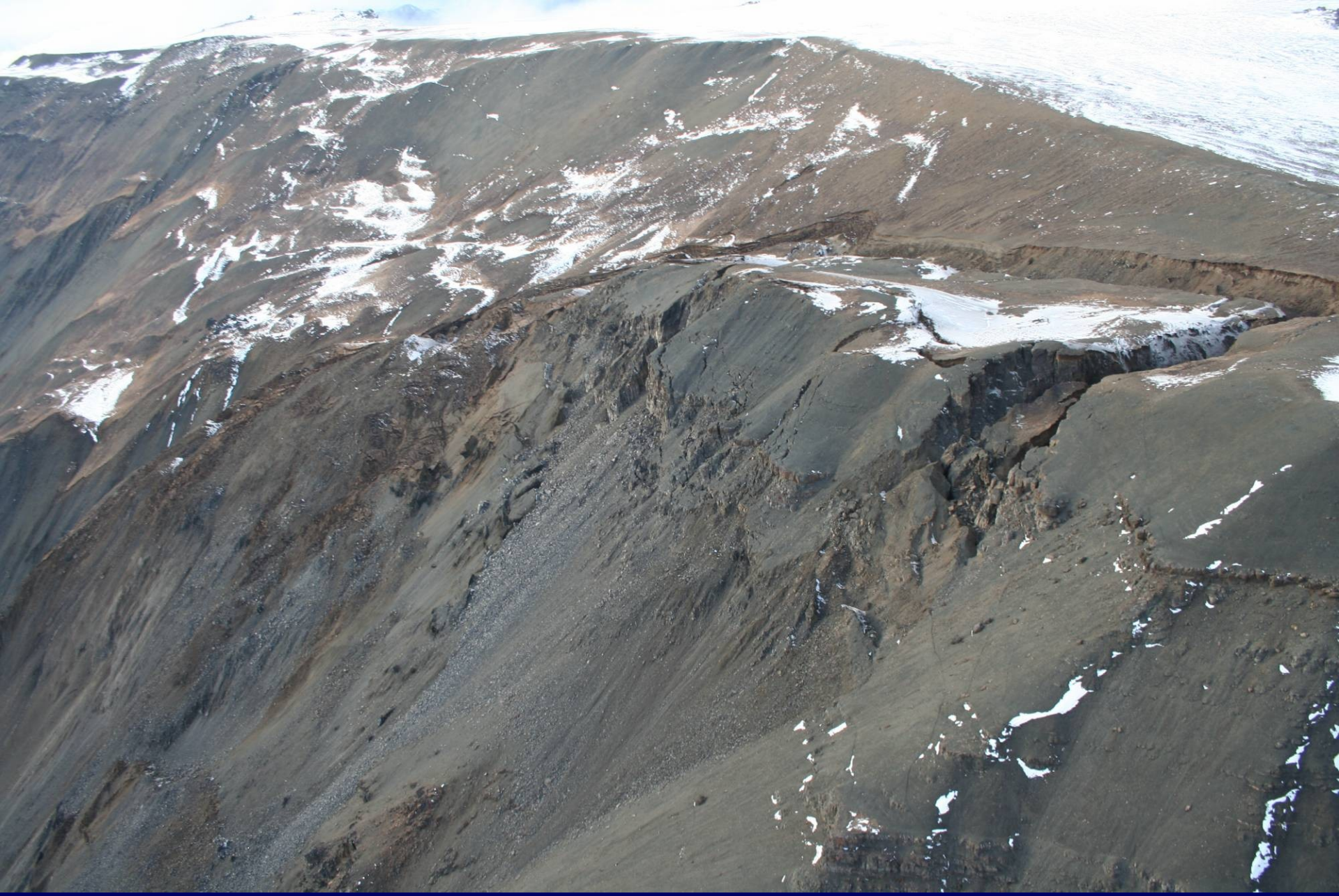
The more we know about potential landslides –
the more we can lower the risk of a potential pipeline rupture.

Conclusions

- Large landslides may continue to increase if climate further warms and becomes wetter (and don't forget about permafrost).
- Studies of landslide hazard for siting pipelines should consider the landscape context and not be bounded by an arbitrary distance from the centerline of the corridor. We recommend that such studies consider the adjacent height of land, including tributary valleys. (don't forget about transformation of one mode of failure to another – undrained loading)
- Travel distances of previous landslides may provide a useful constraint on the hazard, although a landslide larger than anything in the past could occur in the future.

Conclusions

- Given the multi-decadal operational life of pipelines and the serious consequences of oil spills, pipeline routing studies must make identification of potential landslides a priority. We recommend the use of high-resolution LiDAR imagery during such studies, because it is often the only imagery able to reveal features indicative of slope distress and imminent catastrophic failure.
- After areas that have a moderate to high likelihood of failure have been identified and characterized, they can be avoided, either by rerouting or by burial or elevation of the pipe.
- As a last resort, pipelines could be shut down during periods of expected landslide activity.



more to come . . .

Further reading

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