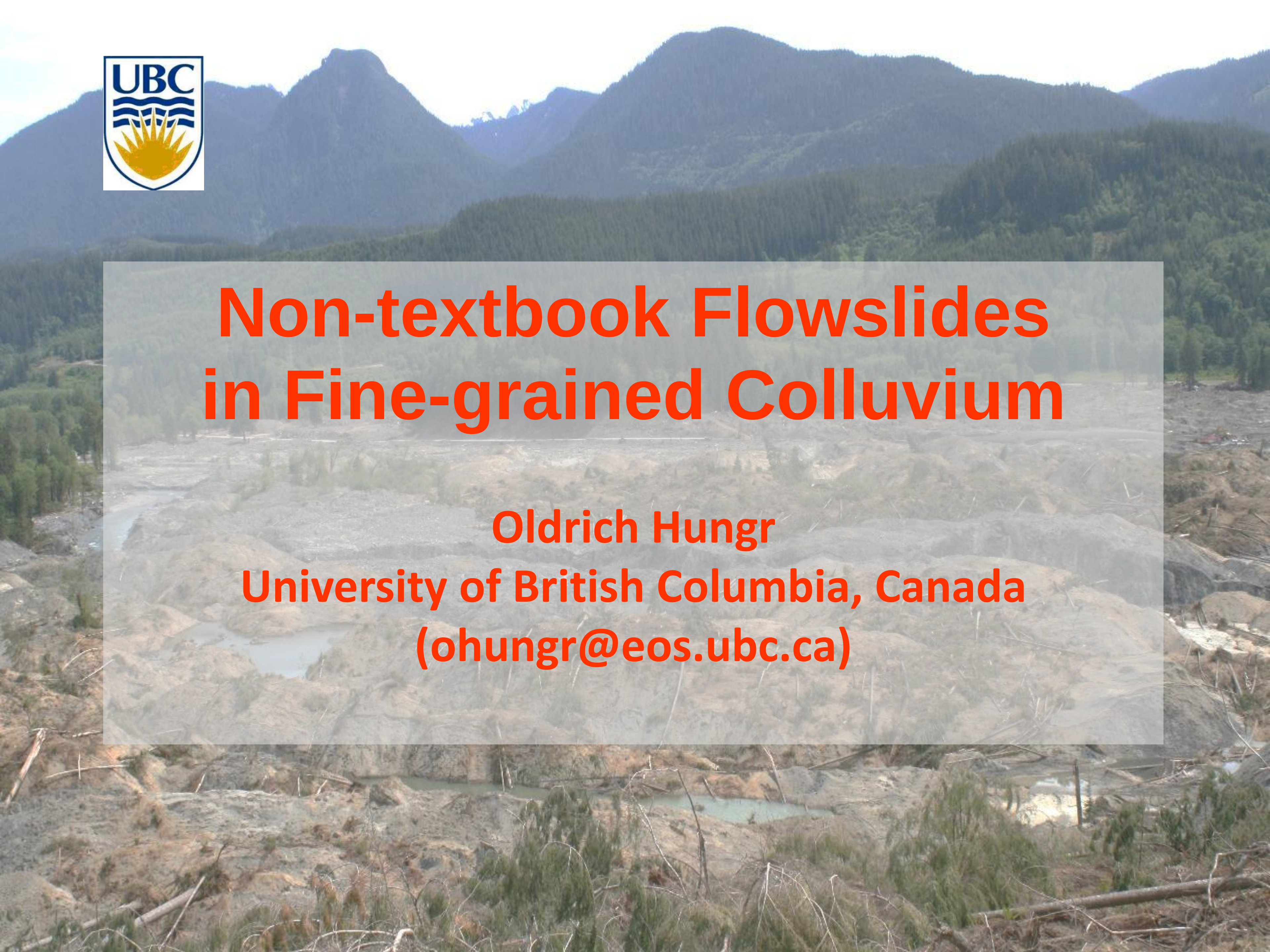

Non-textbook Flowslides in Fine-grained Colluvium

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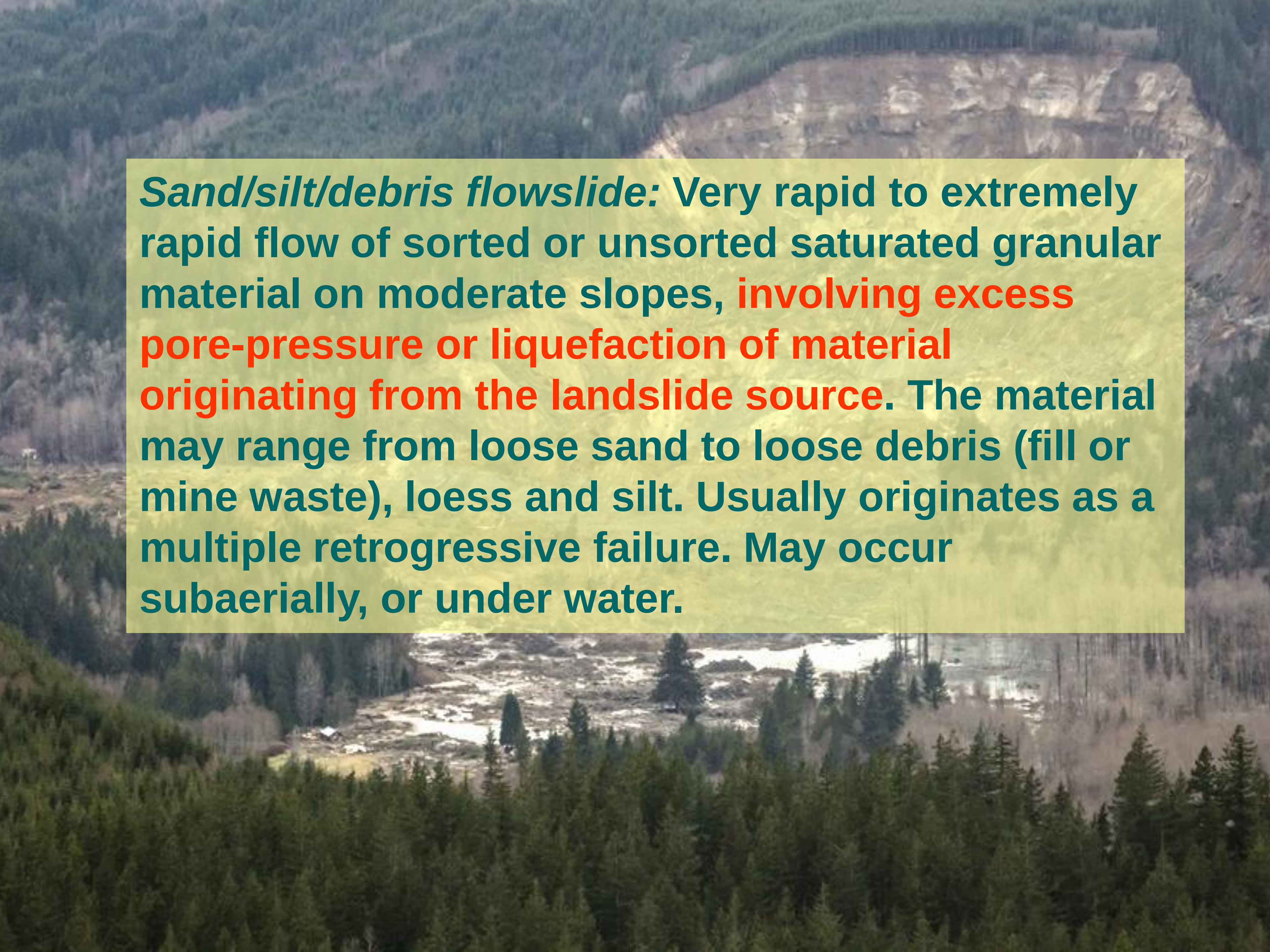
Hungr, O., Picarelli, L. and Leroueil, S., 2014.
The Varnes classification of landslides-an update. Landslides, 11:167-194.

Type of Movement	**Rock**	**Soil**
Fall	1* *Rock, Ice* fall	2* *Boulder, debris, silt* fall
Topple	3* Rock block topple 4 Rock flexural topple	5* *Gravel, sand, silt* topple
Slide	6 Rock rotational slide 7* Rock planar slide 8* Wedge slide 9 Rock compound slide 10* Rock irregular slide	11 *Clay, silt* rotational slide 12 *Clay silt* planar slide 13* *Gravel, sand, debris* slide 14 *Clay, silt* compound slide
Spread	15 Rock slope spread	16* *Sand, silt,* liquefaction spread 17* Sensitive clay spread
Flow	18* *Rock, Ice* avalanche	19 *Sand, silt, debris* dry flow 20* *Sand, silt, debris* flowslide 21* Sensitive clay flowslide 22* Debris flow 23* Mud flow 24 Debris flood 25* Debris avalanche 26 Earthflow 27 Peat flow
Slope Deformation	28 Mountain slope deformation 29 Rock slope deformation	30 Soil slope deformation 31 Soil creep 32 Solifluction

* Can be extremely rapid

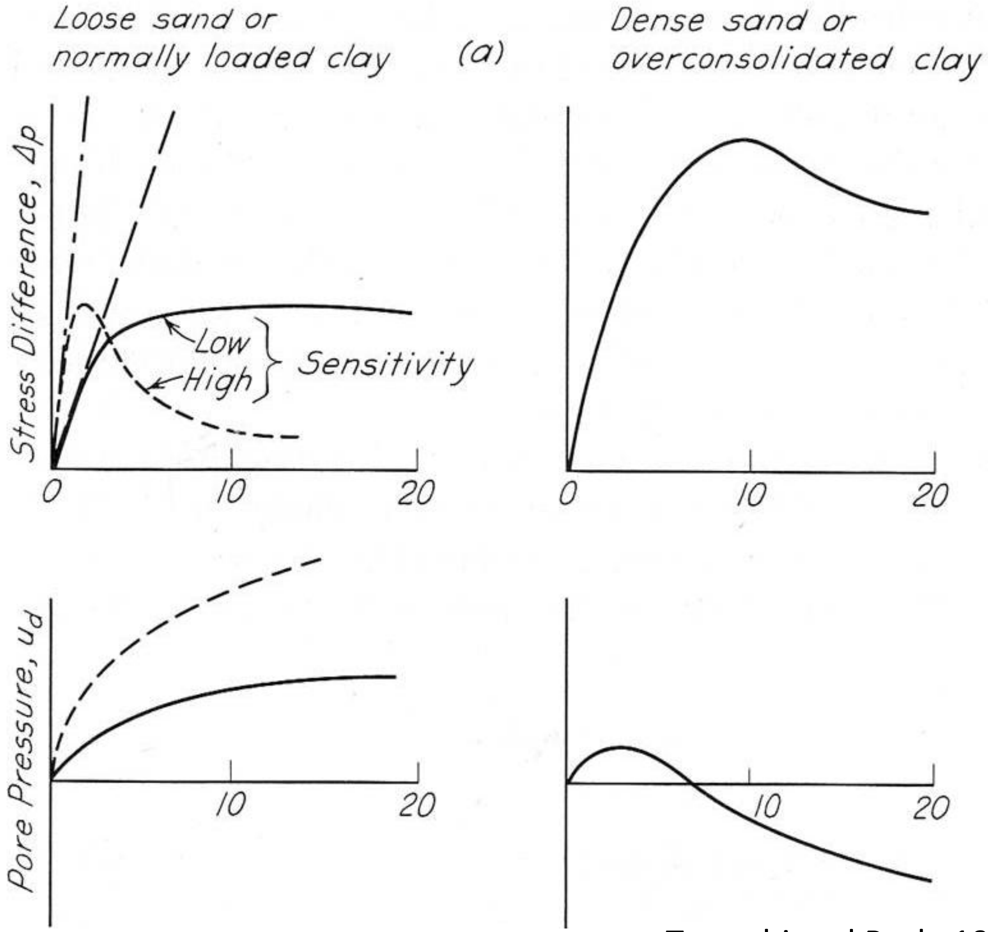


Sand/silt/debris flowslide: **Very rapid to extremely rapid flow of sorted or unsorted saturated granular material on moderate slopes, involving excess pore-pressure or liquefaction of material originating from the landslide source. The material may range from loose sand to loose debris (fill or mine waste), loess and silt. Usually originates as a multiple retrogressive failure. May occur subaerially, or under water.**

Flowslides in 2014 (Landslide Blog)

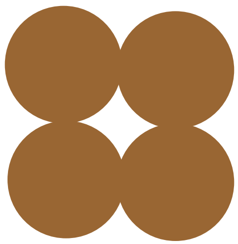
Liquefaction (Casagrande, 1976):

“The response of loose, saturated sand when subjected to strains or shocks that result in substantial loss of strength and, in extreme cases, lead to flowslides”

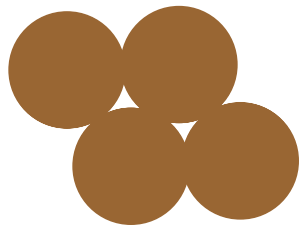


Terzaghi and Peck, 1967

1) Granular materials: Soil structure collapse

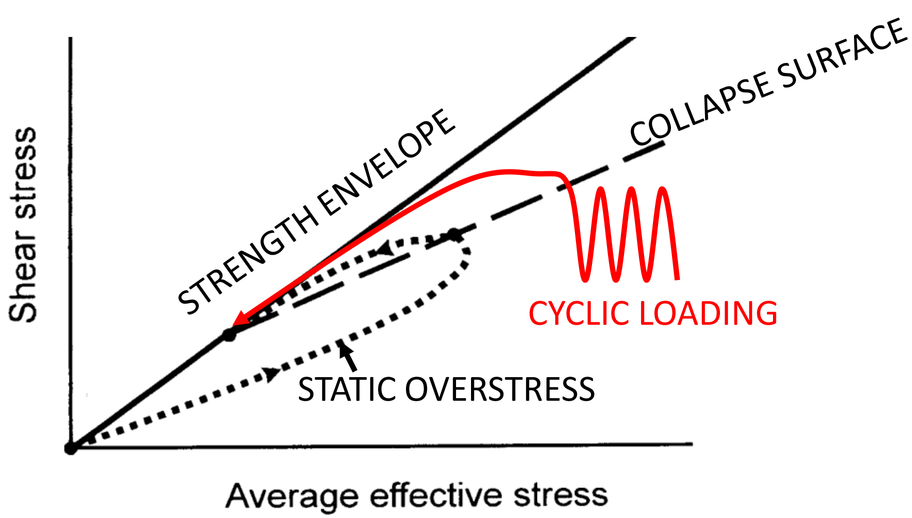


Loose packing



Dense packing

Soil collapse: sudden change from loose to dense packing, volume change. If soil is saturated, volume change cannot occur and pore-pressure increases, reducing effective stress ("liquefaction")



(Mc Roberts and Sladen, 1990)

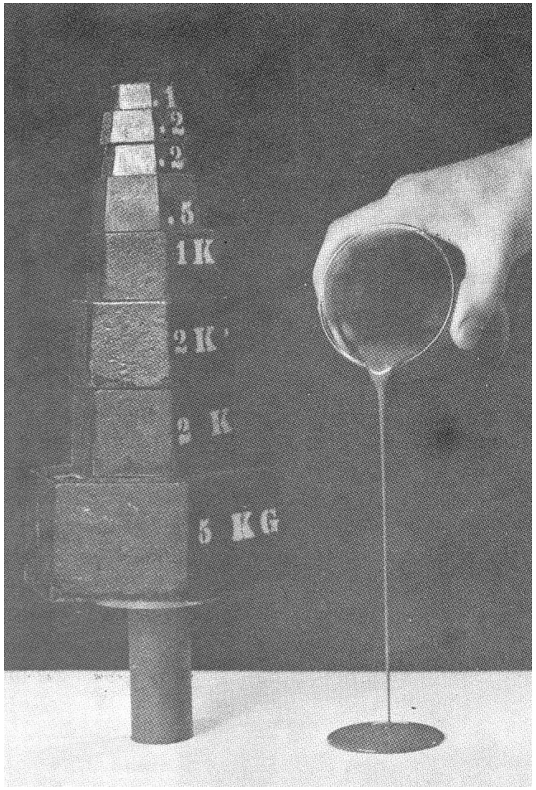
What causes collapse:

1) loose, saturated soil (N<8)
2) Static overstress (caused by added loading, or increase in pore pressure)
3) Earthquake shaking (cyclic loading)\

Effect more dramatic,
if accompanied by cohesion loss

2) Remolding of highly-sensitive ("quick") clays

Usually leached clays of marine origin, may be overconsolidated and of low plasticity



peak remoulded

(Photo: S.G. Evans)

Conclusion: Liquefaction requires a special type of material:

- ➢ Loose, “collapsive” sand or silt
- ➢ or Extra-sensitive (“quick”) clay

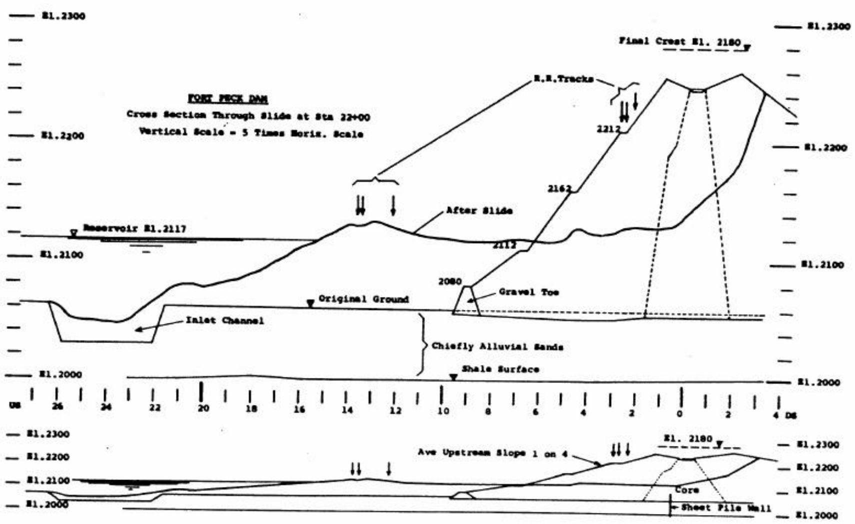
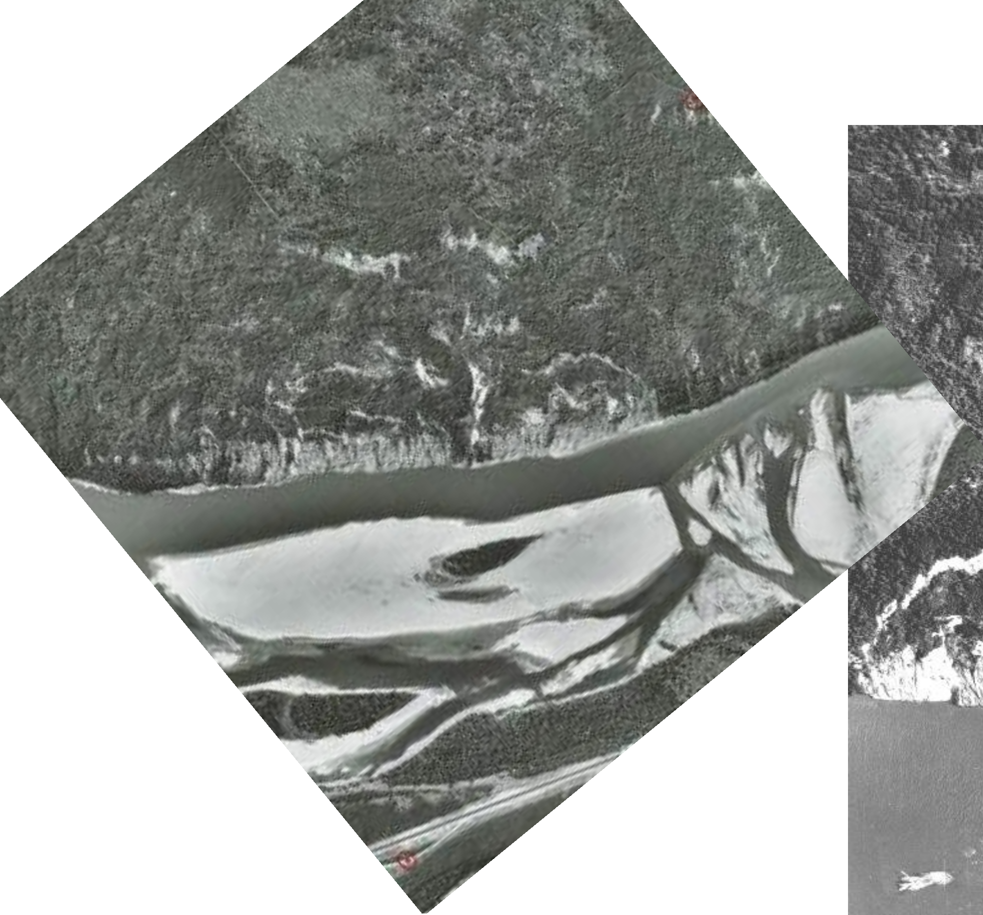


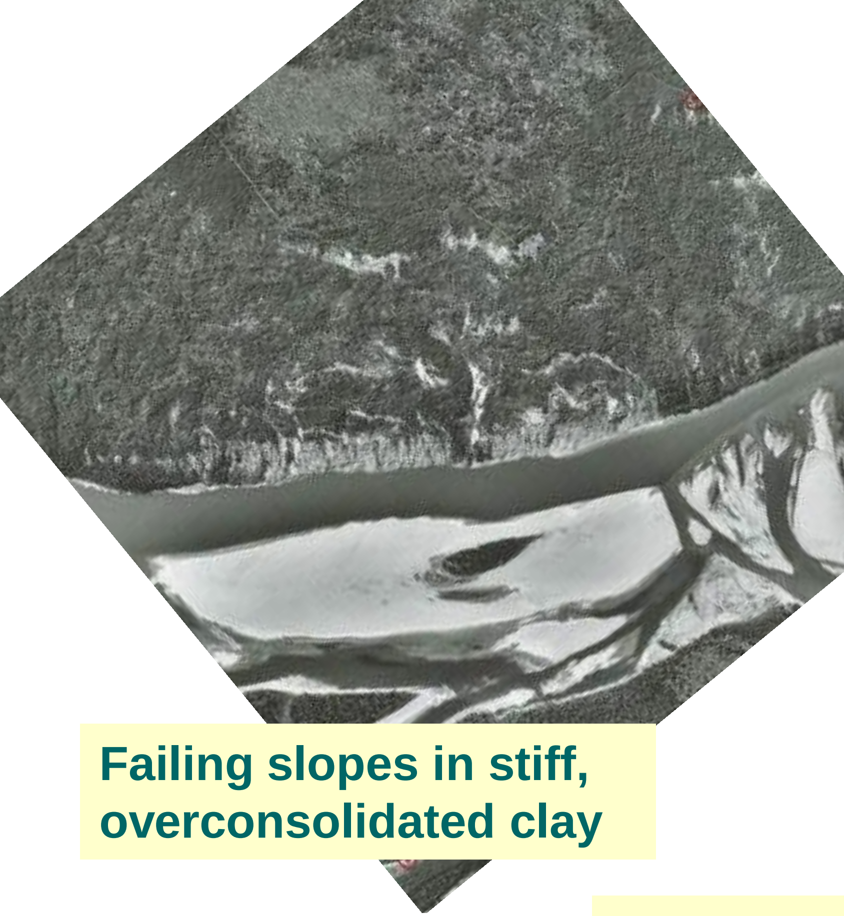
FIG. 2 - CROSS-SECTION THROUGH FLOW SLIDE IN FORT PECK DAM AT STATION 22+00

Fort Peck Dam flowslide, Casagrande (1976)

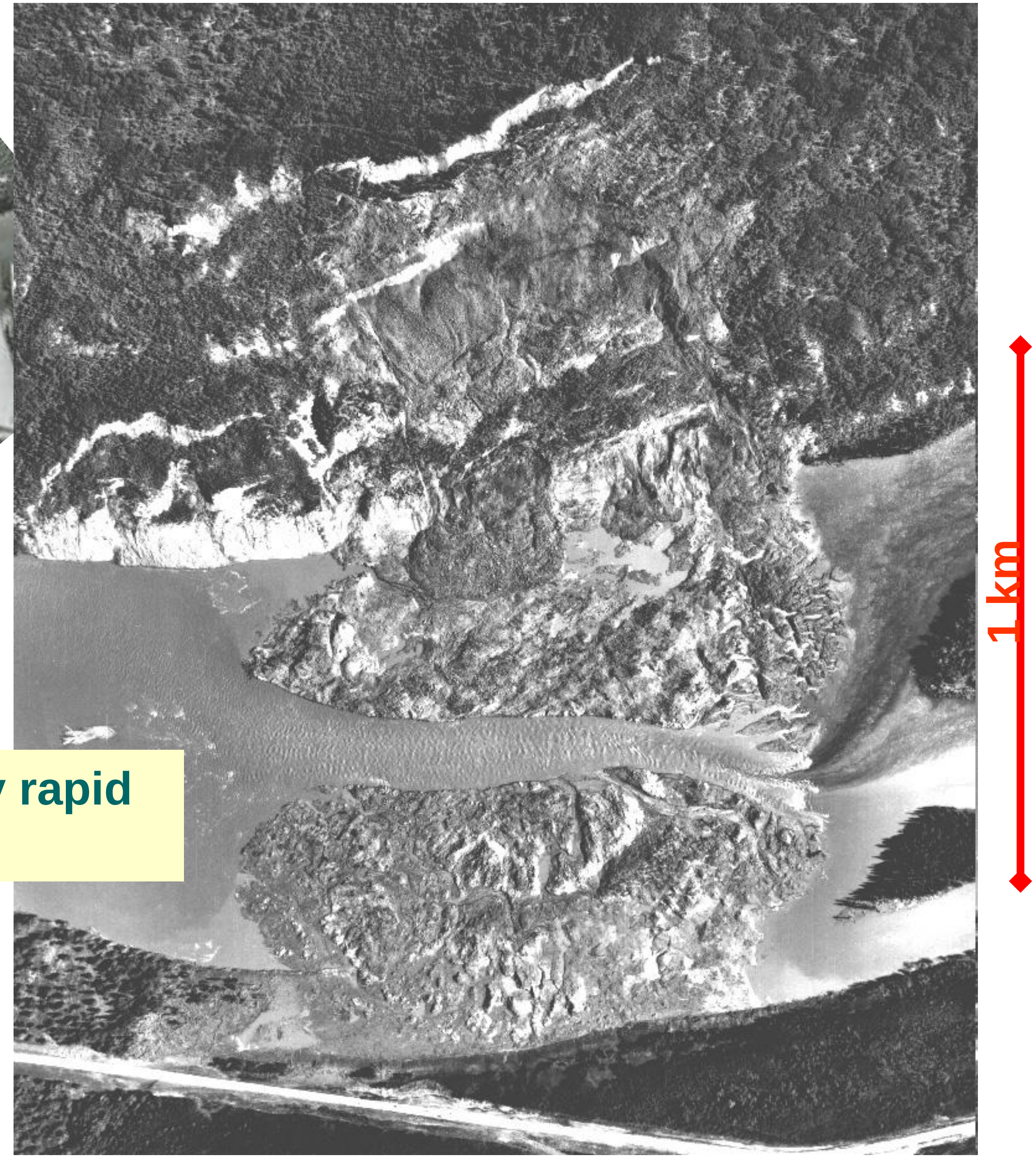


But what happened here?

Attachie Slide, NE British Columbia, May 1973



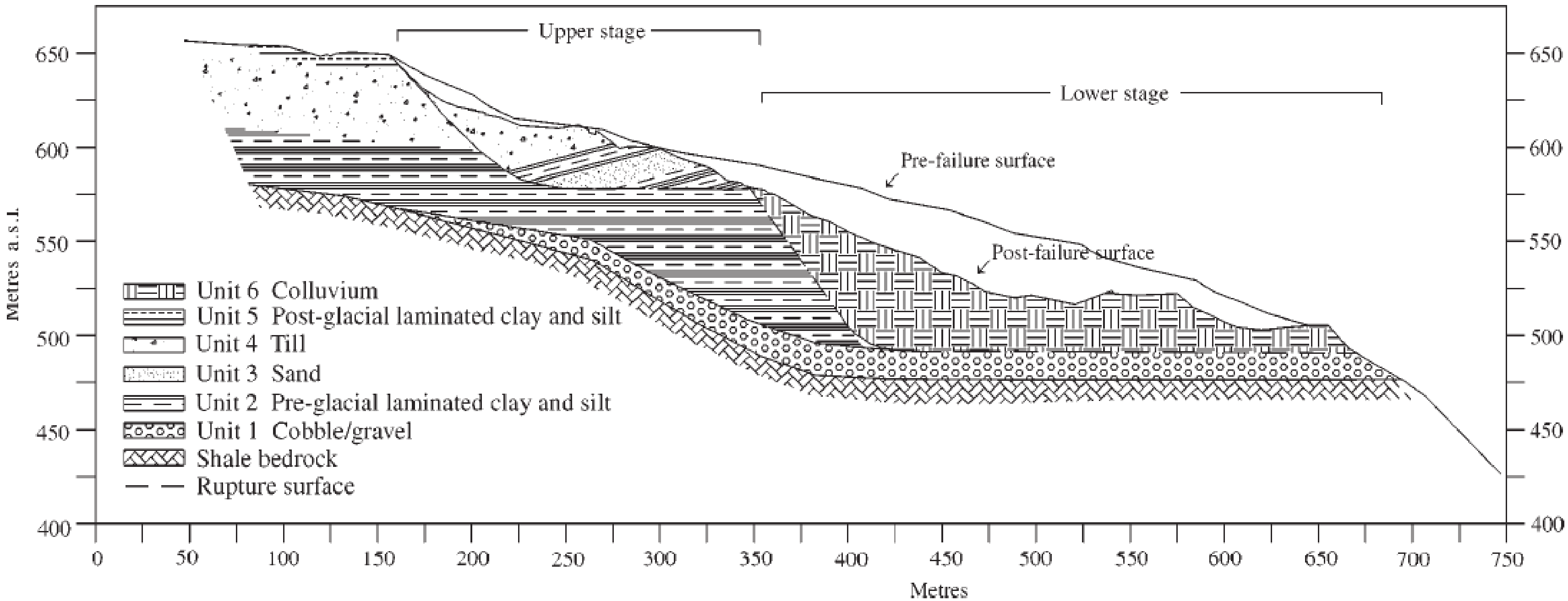
Failing slopes in stiff, overconsolidated clay



Extremely rapid flowslide

But what happened here?

Attachie Slide, NE British Columbia, May 1973



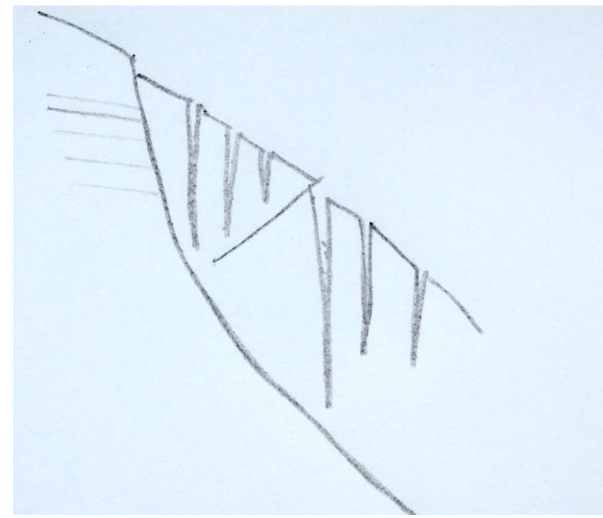
		Preglacial lake sediments	
Property	Till (n = 3)	Plastic (n = 38)	Silt (n = 7)
Natural water content (%)	24 (16–35)	31 (20–37)	—
Liquid limit (%)	38 (33–44)	41 (27–59)	30 (NP to 34)
Plastic limit (%)	17 (8–22)	21 (14–27)	21 (NP to 24)
Plasticity index (%)	17 (17–22)	18 (8–34)	9 (NP to 12)
Liquidity index (%)	0.27 (–0.01 to 0.57)	0.19 (–3.18 to 0.59)	—
Clay content (%)	31 (19–37)	46 (28–68)	16 (7–27)
Silt content (%)	46 (25–63)	54 (32–72)	84 (73–91)
Bulk density (kg/m^3)		1947* (1846–2171)	

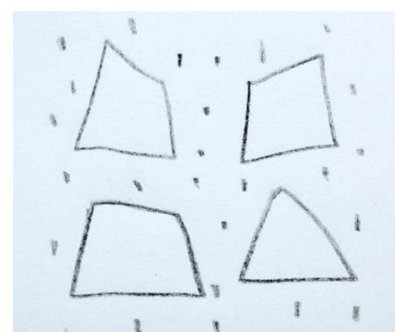
Note: NP, nonplastic; n, number of samples tested.
*n = 15.

These materials are neither collapsive nor sensitive (Fletcher et al., 2002)

“Macroscopic brittleness”?

(Fletcher et al., 2002)





Water ingress, softening

Blocks in loose matrix

Attachie Slide, 1973

La Conchita, California, 1996 and 2005 (Jibson, 2005)

Terrace of poorly indurated Tertiary marine sediment. Interlayered siliceous shale, siltstone, and sandstone.

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La Conchita, California, 1996 and 2005 (Jibson, 2005)

Terrace of poorly indurated Tertiary marine sediment. Interlayered siliceous shale, siltstone, and sandstone.

1995 event: earth flow

- Following spring with 100% above average precipitation.
- 1 month delay between precipitation and failure
- Moved “tens of metres in a few minutes” (slow-rapid)
- Houses damaged, but no injuries.

(Jibson, 2005)

2005 event: flowslide

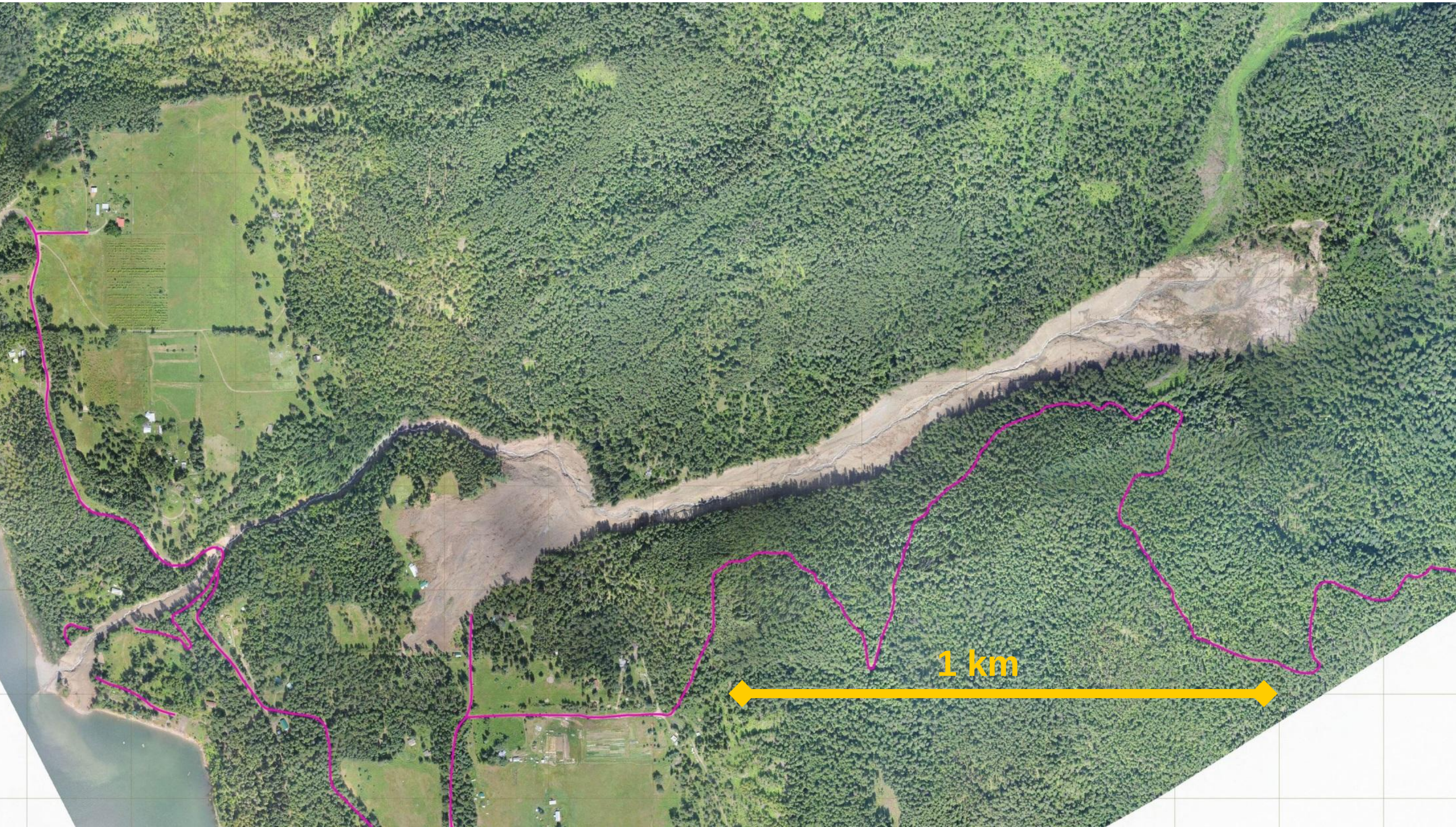
- **Remobilized 1995 debris**
- **Following the day with maximum daily precipitation.**
- **Moved "tens of metres in a few seconds" (extremely rapid)**
- **Several houses destroyed, 10 fatalities.**

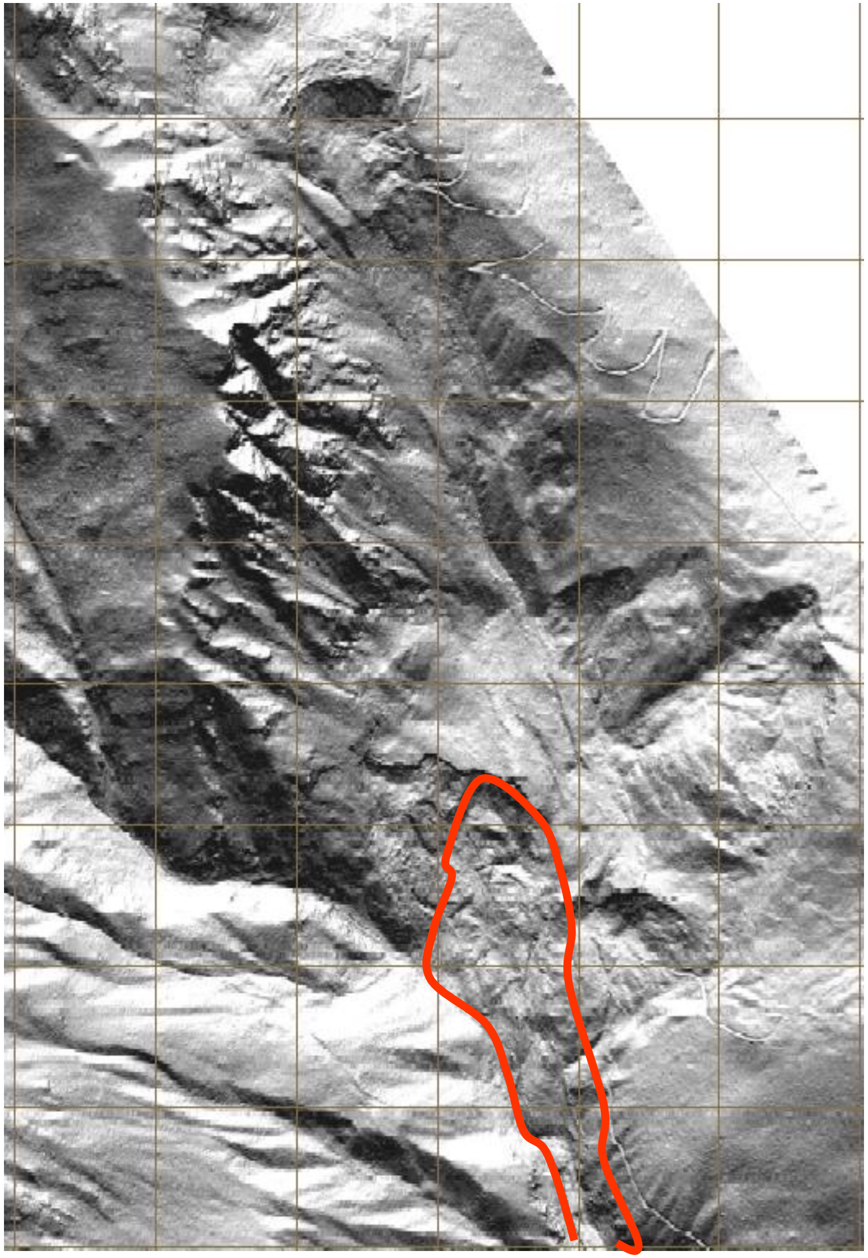
(Jibson, 2005)


1/11/2005 2:24pm

“A highly hazardous situation involving a two-phased landslide mechanism: (1) a saturated, highly fluid layer at depth on which the landslide mobilized that (2) carried a thick layer of drier, much more viscous material that effectively acted as a battering ram.” (Jibson, 2005)

Johnson's Landing Flowslide, British Columbia
May, 2012

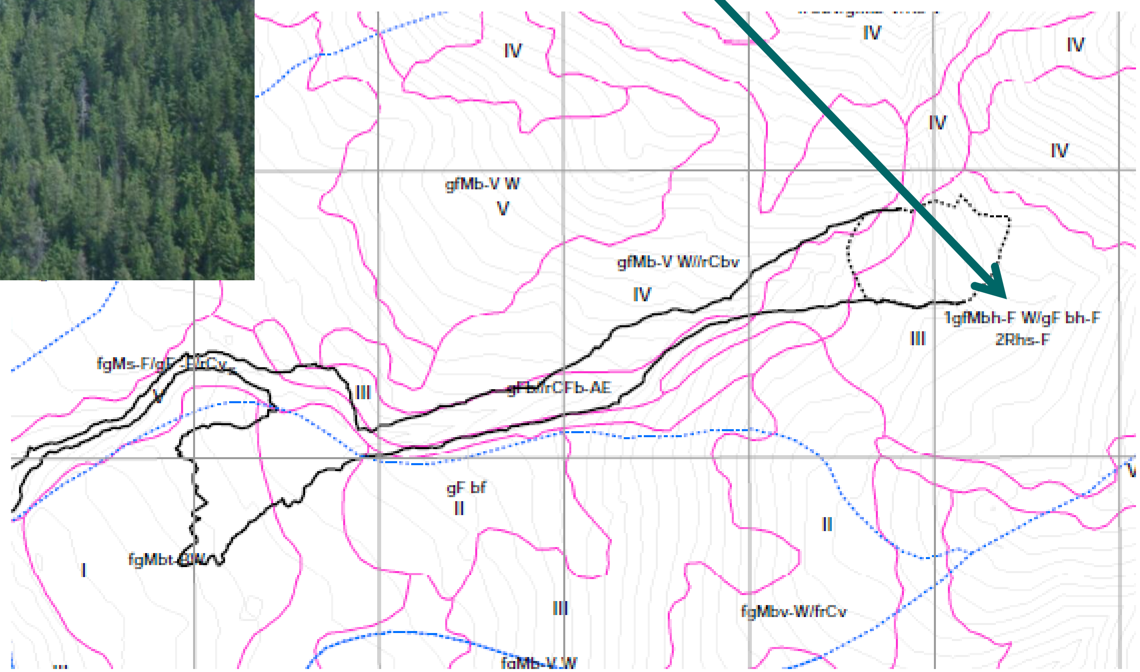




The source of the landslide is situated in a slope area disturbed by the instability of both the bedrock and the overburden.

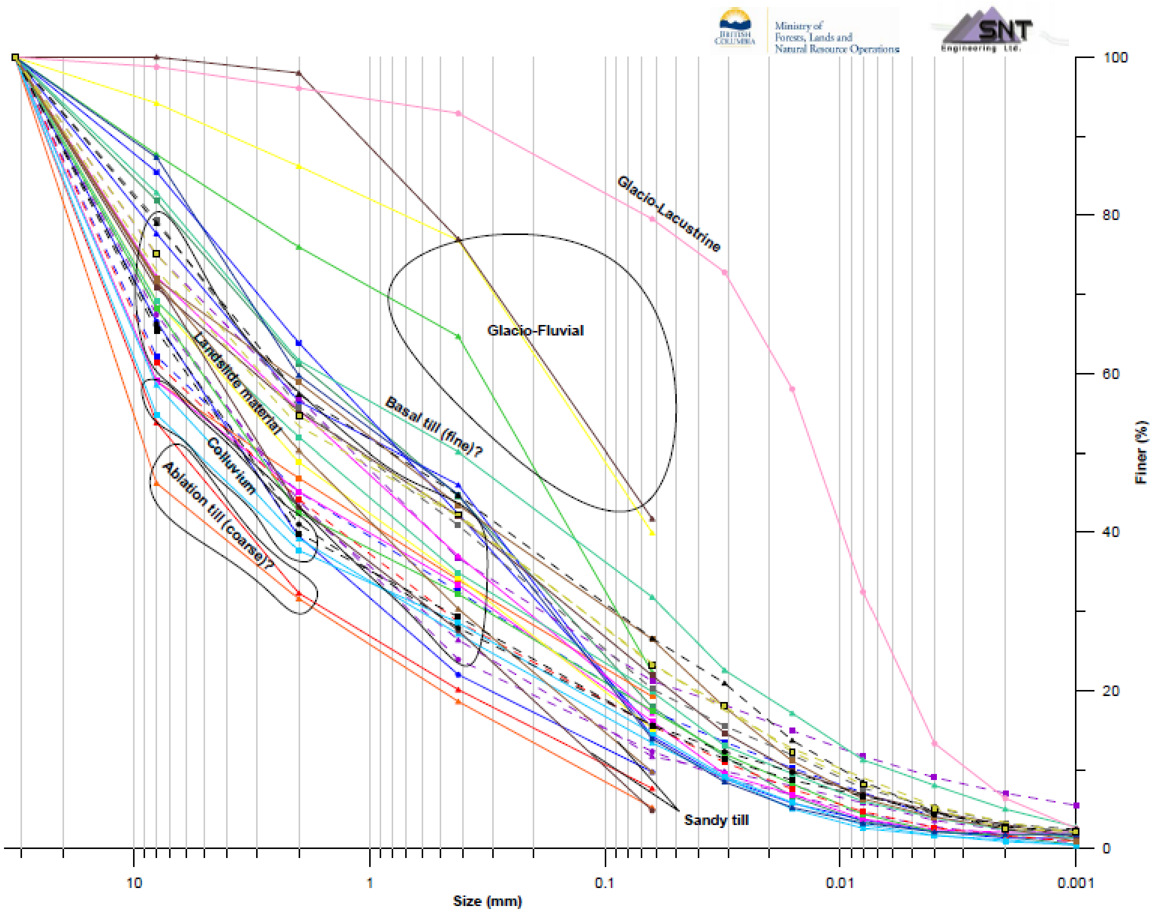
Pre-event geomorphological mapping:

Source area is situated in a geomorphological unit described as sandy moraine and glacio-fluvial soil (kame deposit) – Failing (i.e. in an unstable condition). Stability Class III (out of 5)



Deep-seated compound silt slide
320,000 m^3

1:500 year rain on snowmelt



Material: Interbedded glacial till and glacio-fluvial deposits, mostly silty sand in texture, mostly non-plastic, a few clayey silt interbeds, based on weak, unstable bedrock

Source volume: 320,000 m^3

Minor soil entrainment, large quantities of timber debris

Flow velocity from eyewitness accounts: > 20 m/s

Deposit:

6 houses destroyed,
4 fatalities

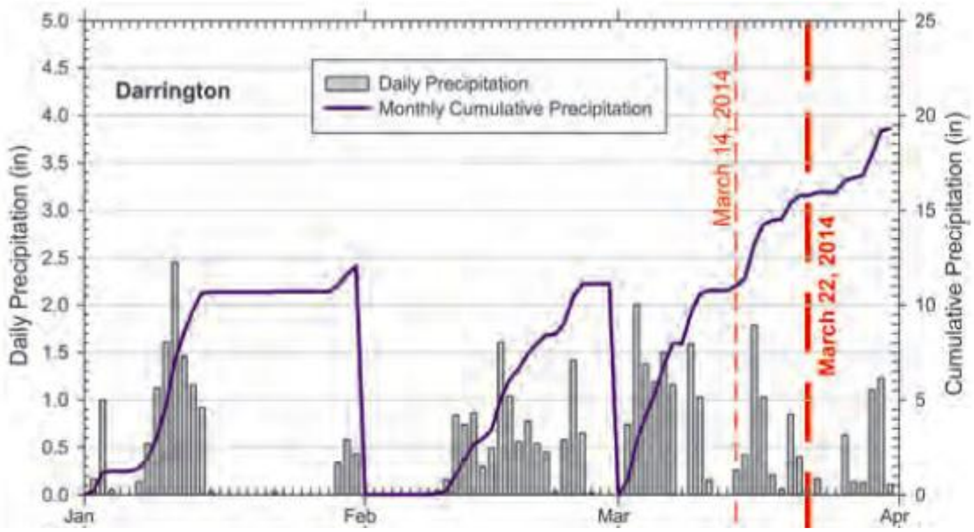
This is the first landslide deposit on top of a glacio-fluvial terrace surface, over 9,000 years old

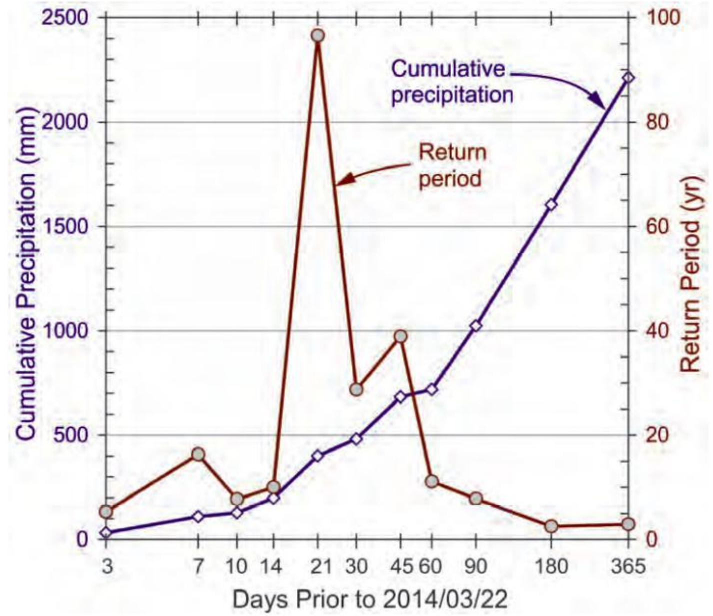
Oso Slide, Northern Washington, USA, March 22, 2014

Oso Slide, Northern Washington, USA, March 22, 2014

7.6 million m^3
Community destroyed, 43 fatalities, $50 million cost

Precipitation

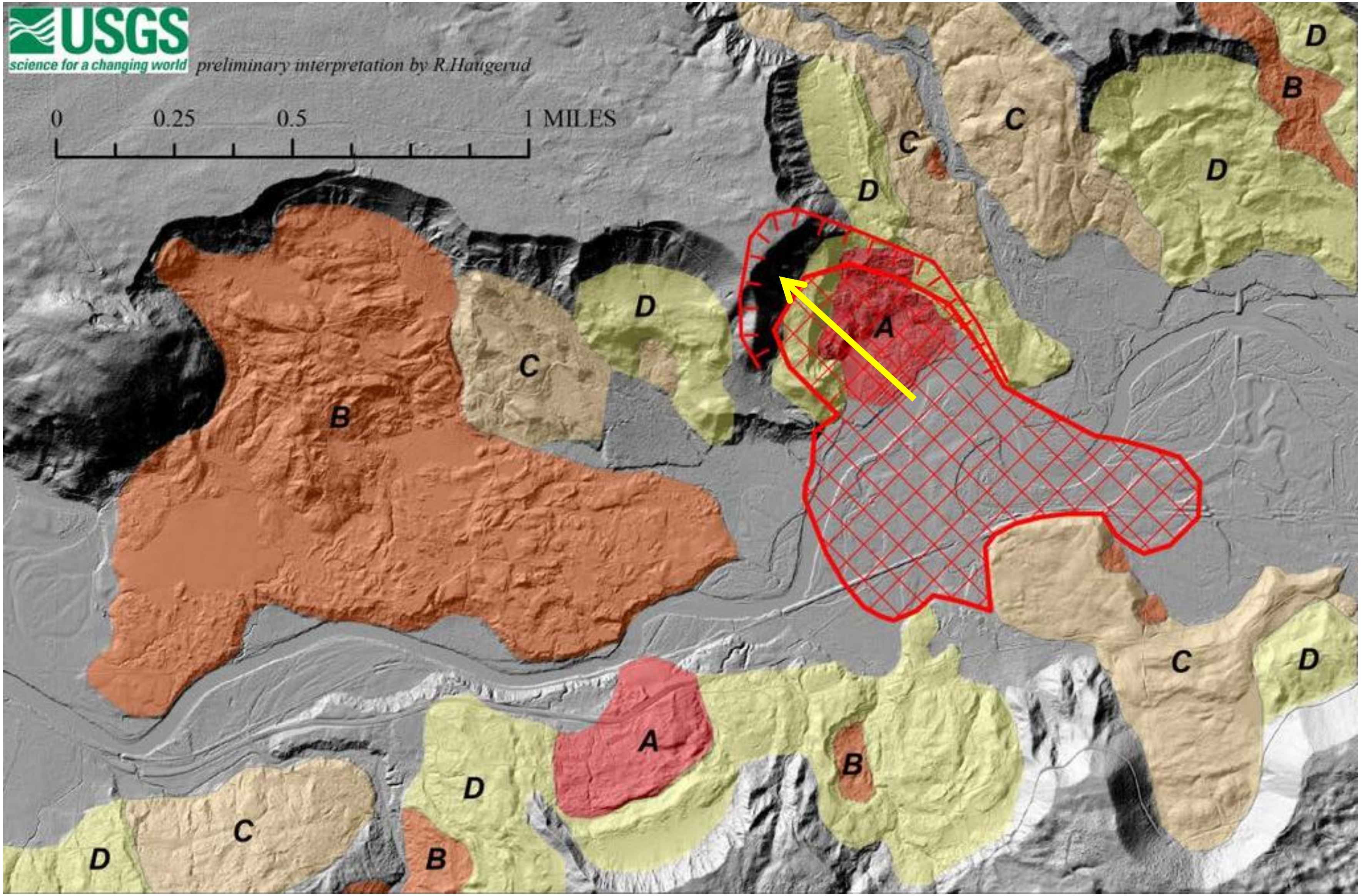




Daily and monthly precipitation
- 20 km away

Frequency/duration analysis
Radar indicates local precipitation could have been higher (NSF, 2014)

Previous landslides (A youngest, D older)

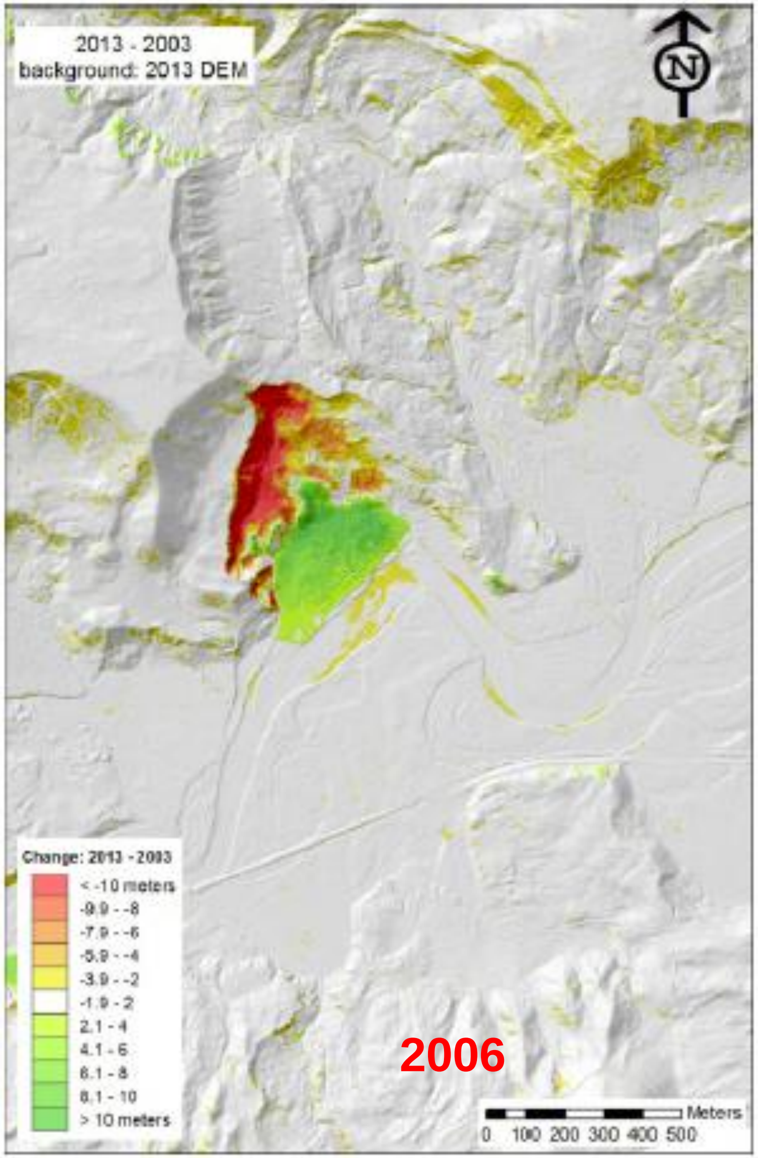


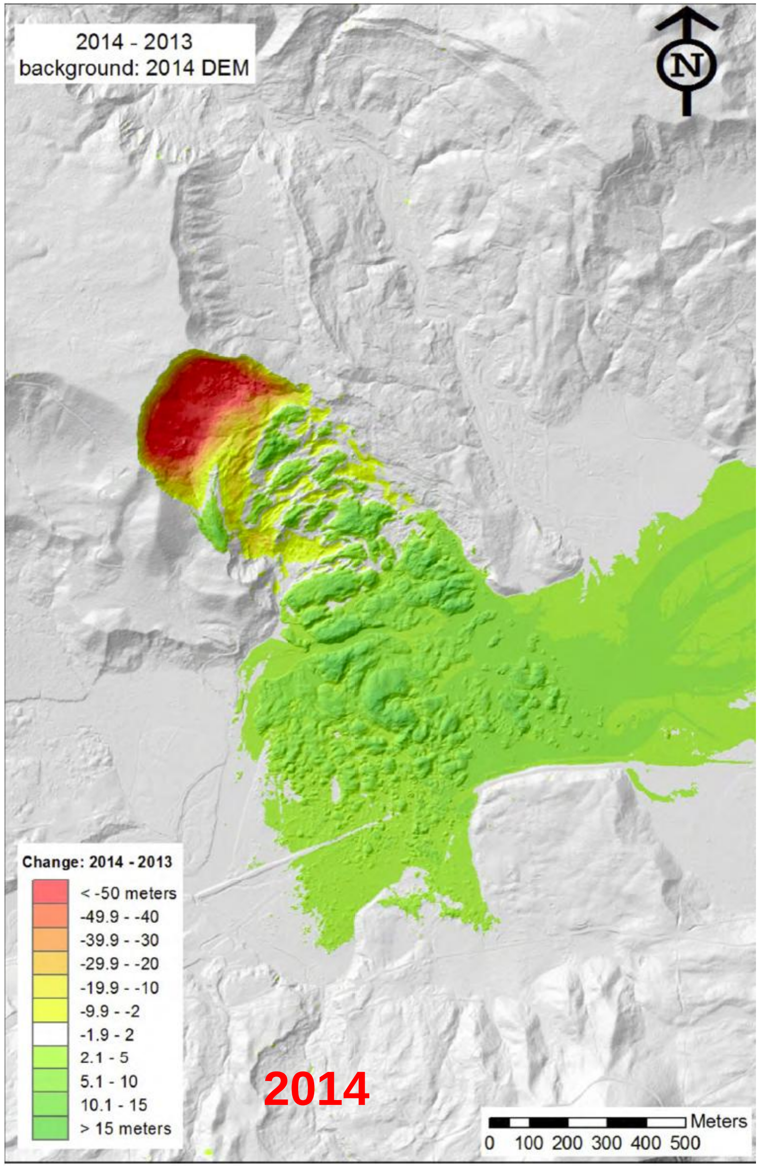

January, 2006 slide


Oso July 2013
Google earth
Imagery Date: 7/14/2013 10 U 585208.26 m E 5348071.46 m N elev 442 ft eye alt 8977 ft


Oso March 2014
Google earth
Imagery Date: 3/31/2014 10 U 585208.26 m E 5348071.46 m N elev 442 ft eye alt 8977 ft

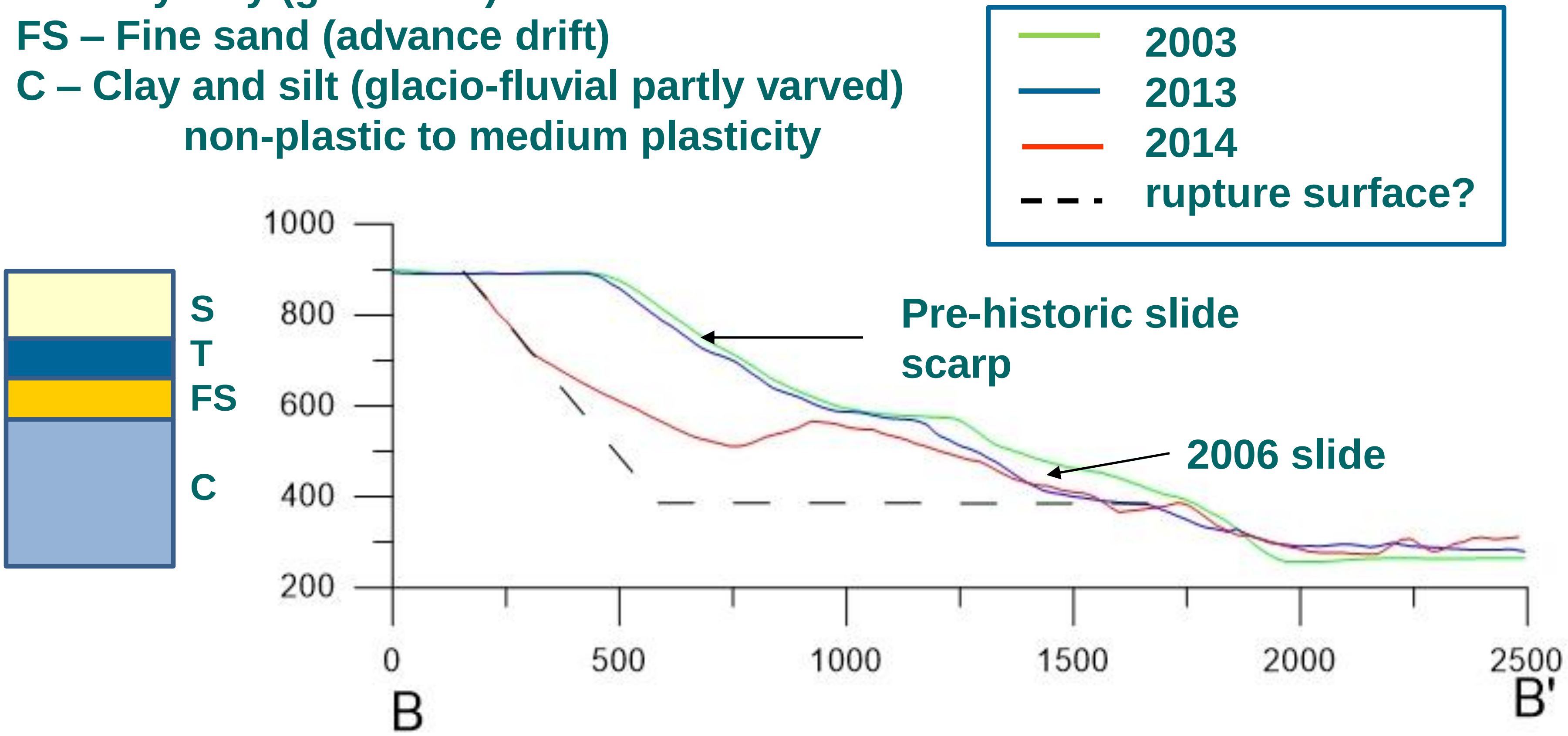
Comparison (NSF, 2014)





Stratigraphy (NSF, 2014)

S – Sand and gravel (recessional outwash)
T – Silty clay (glacial till)
FS – Fine sand (advance drift)
C – Clay and silt (glacio-fluvial partly varved) non-plastic to medium plasticity



Material:

Glacio-lacustrine clay and silt
Described as “hard” in drillholes
Collapsive??

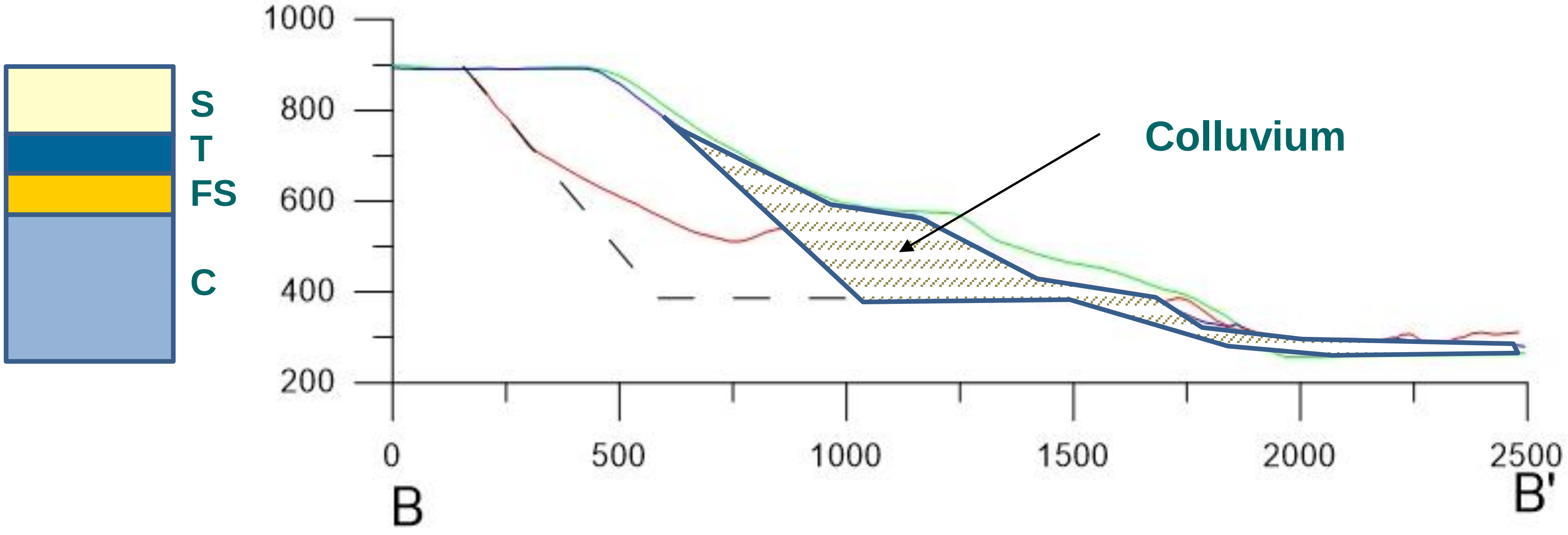
Overlying sand and glacial till

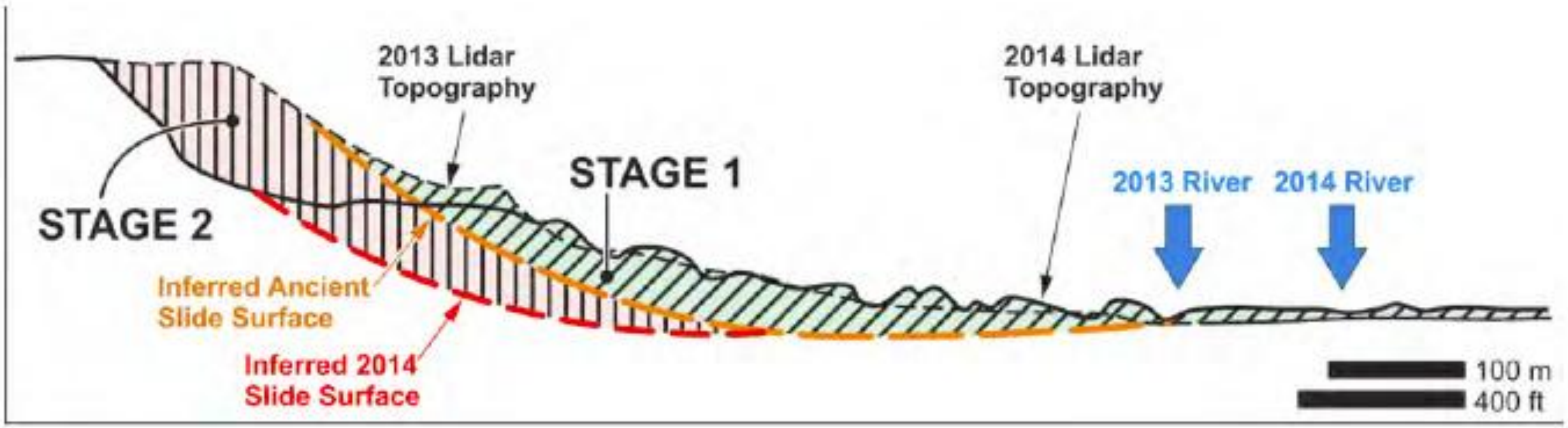
Material:

Colluvium from the 2006 and earlier slides. Liquefiable?

Alternative mechanism

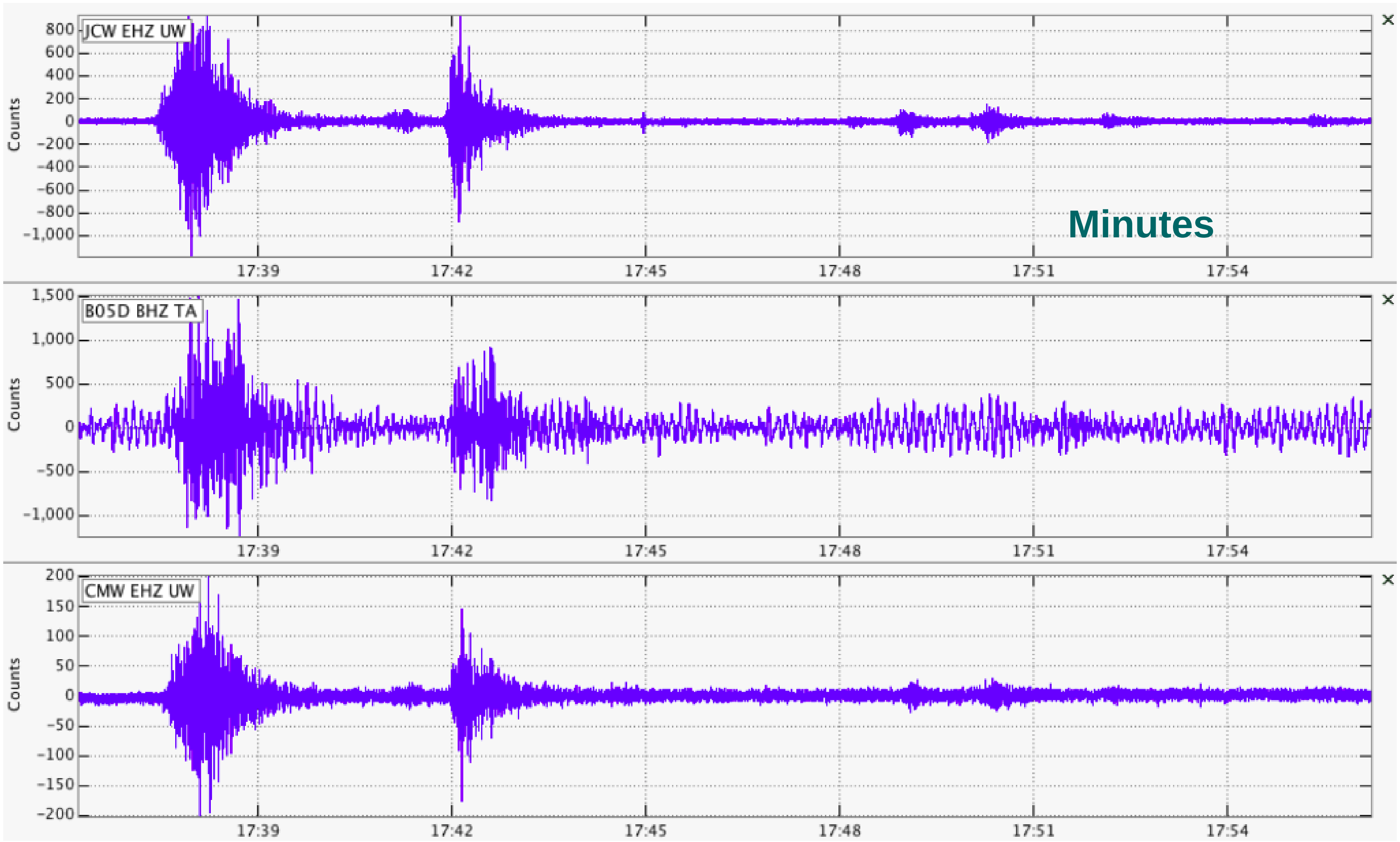
- 2003
- 2013
- 2014
- rupture surface?





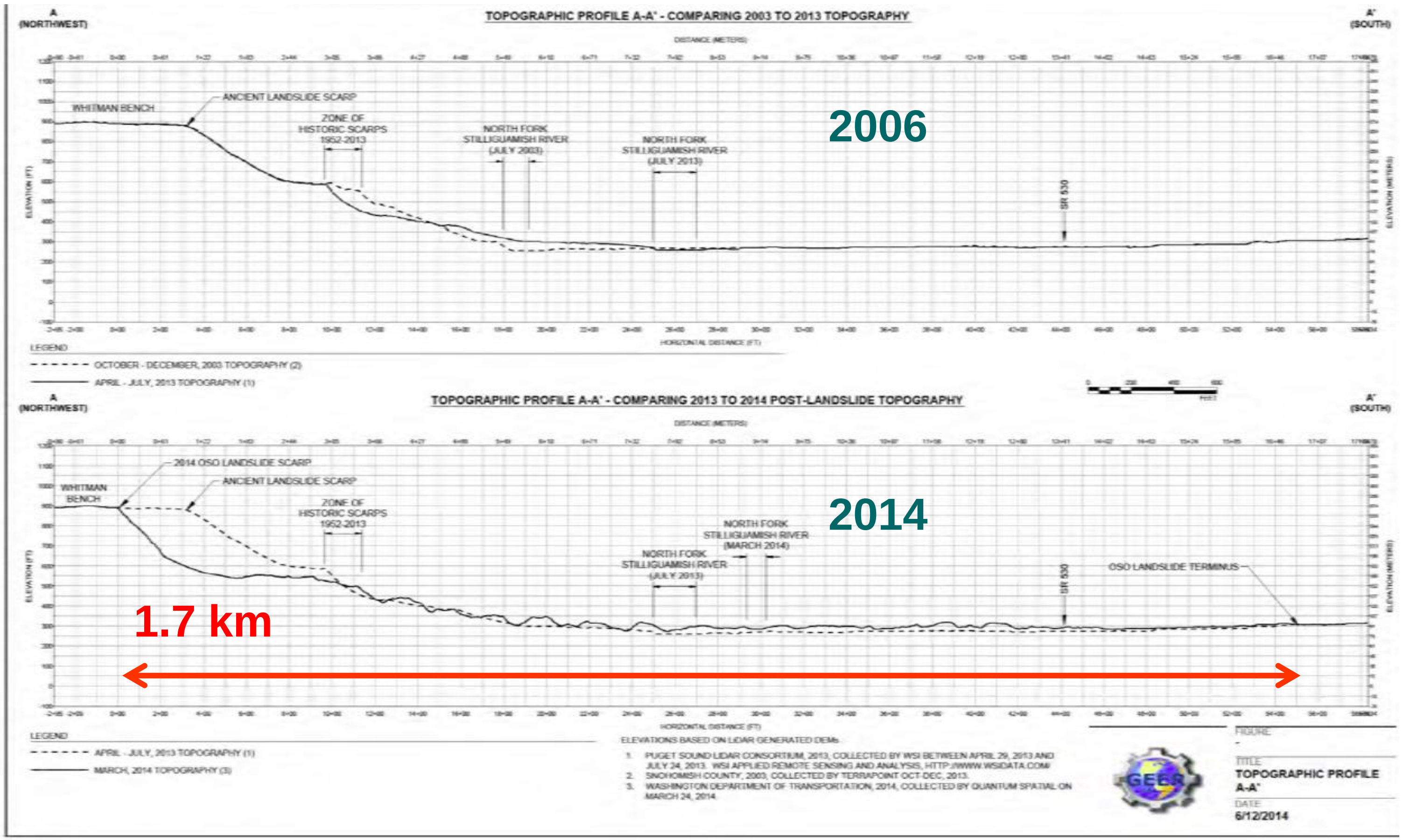
GEER report reconstruction of the slide mechanism (NSF, 2014)

Seismic records (USGS)



Runout:

1.2 km in about 1.5 min >> 13 m/s avg. velocity



Flowslide in Papua New Guinea?

Flowslide in Hong Kong?

Conclusion:

- Not only lose saturated sands and sensitive clays are liquefiable. Many other materials may be.
- Softening of disturbed soils (“colluvium”) may induce liquefaction susceptibility.
- There is no routine methodology to identify such materials

References:

Casagrande A (1976) Liquefaction and cyclic deformation of sands; a critical review. Harvard Soil Mechanics Series, No 88, p. 51.

Fletcher L, Hungr O, Evans SG (2002) Contrasting failure behaviour of two large landslides in clay and silt. Canadian Geotech J 39:46–62.

Hungr, O., Picarelli, L. and Leroueil, S., 2014. The Varnes classification of landslides-an update. Landslides, 11:167-194.

Hutchinson JN (1992b) Flow slides from natural slopes and waste tips, in Proceedings, 3rd National Symposium on Slopes and Landslides. La Coruna, Spain, pp 827–841

National Science Foundation , 2014. The 22 March 2014 Oso Landslide, Snohomish County, Washington. Geotechnical Extreme Events Reconnaissance Report.