EARTH 270 – DISASTERS AND NATURAL HAZARDS (v. 2017)

Kensennuma City, Miyagi Prefecture , Japan, March 2011

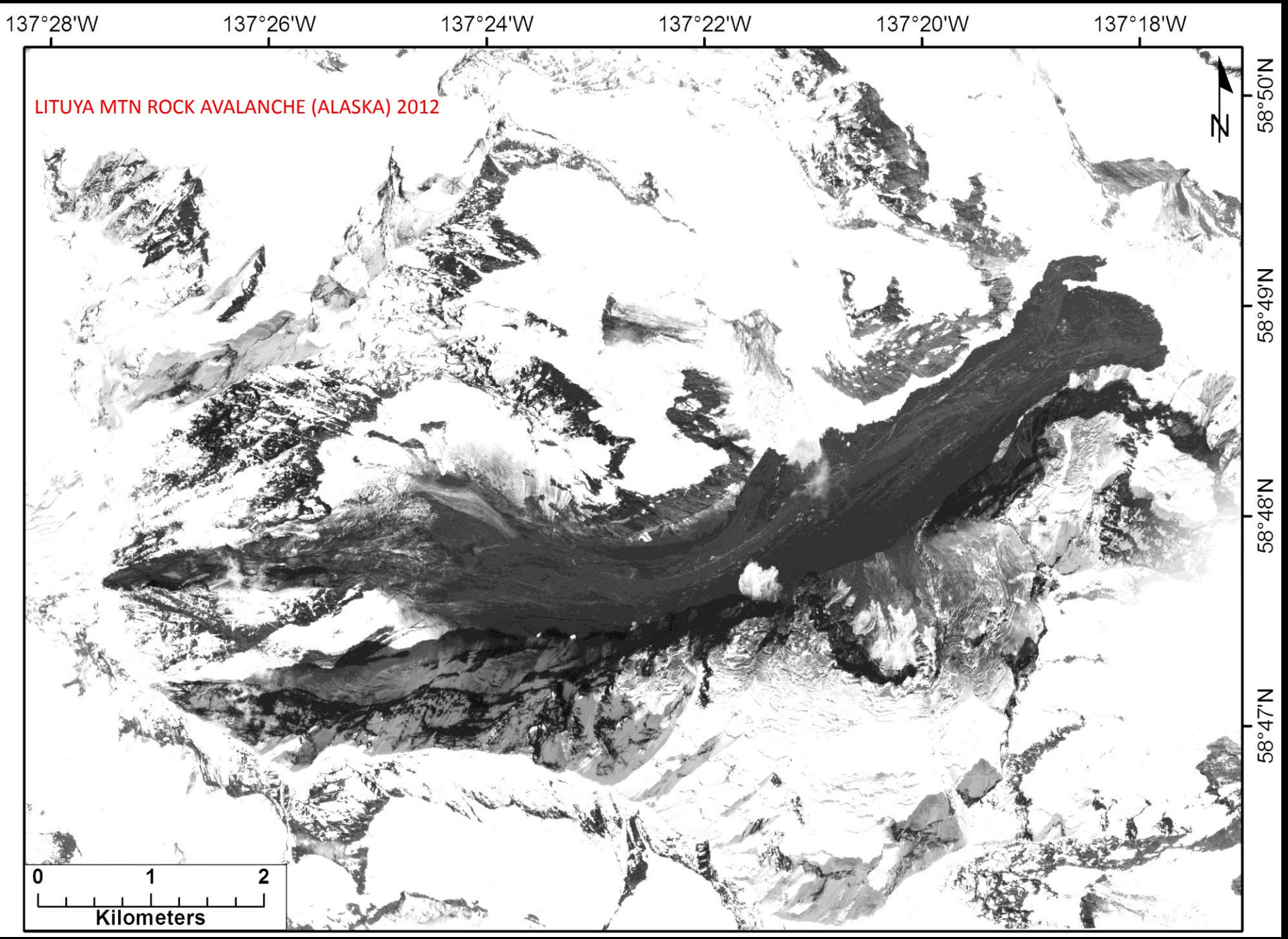
PROFESSOR S.G. EVANS, PhD, PEng (Room 303, Earth Science and Chemistry (ESC) Building)

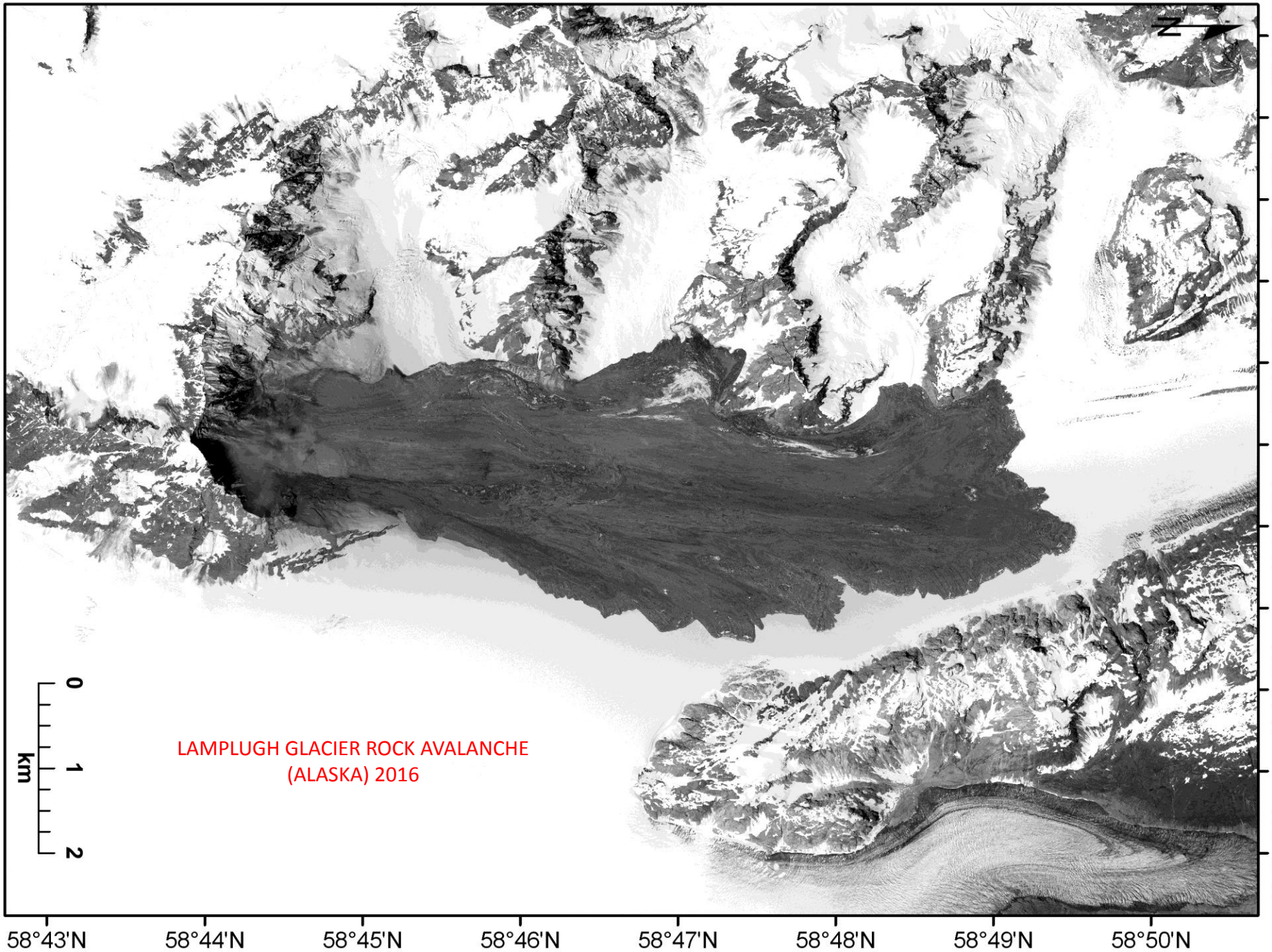
UNIVERSITY OF WATERLOO

LANDSLIDES

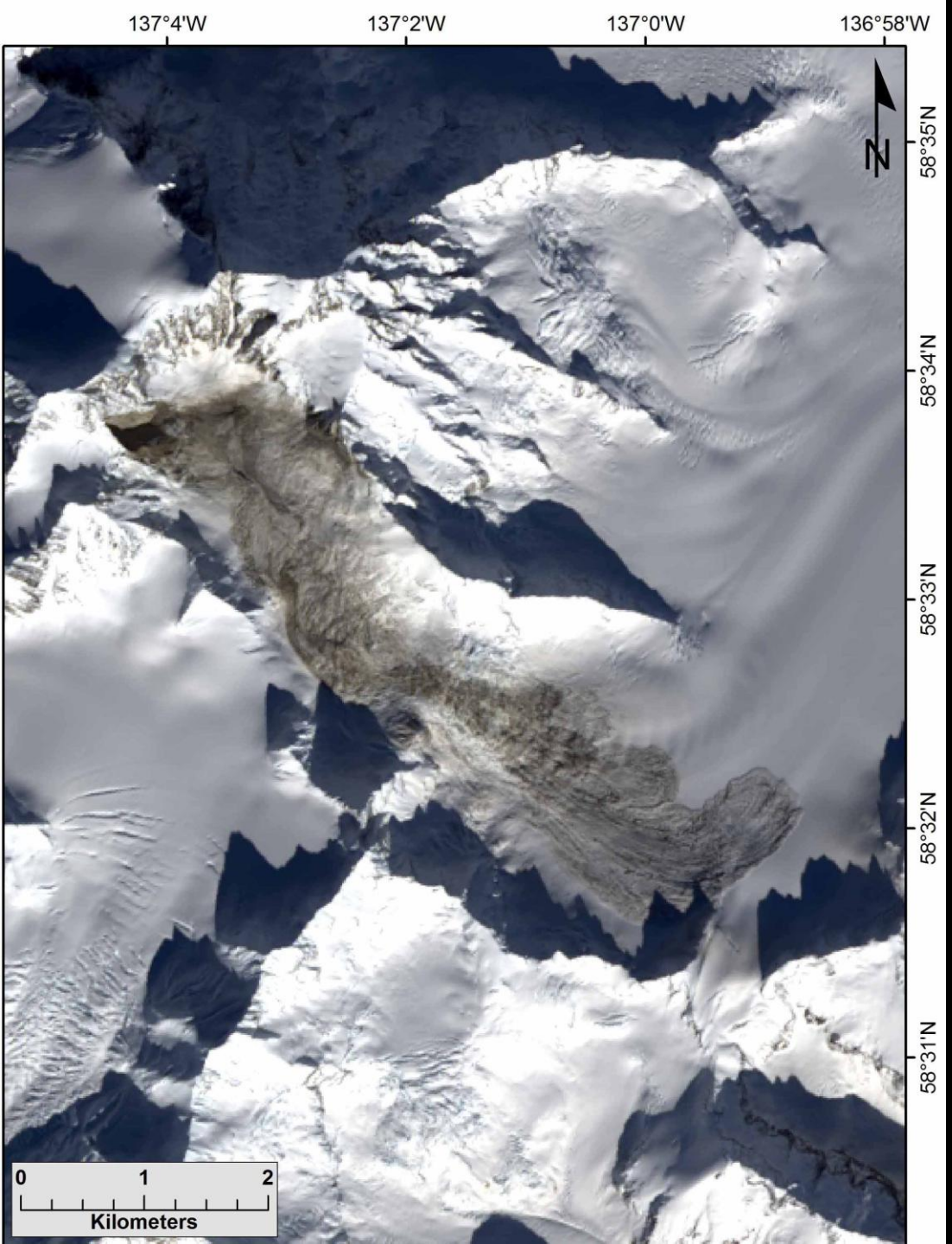
OFFICE HOURS: TUESDAY 10:30 AM – NOON

1949 KHAIT LANDSLIDE, TAJIKISTAN

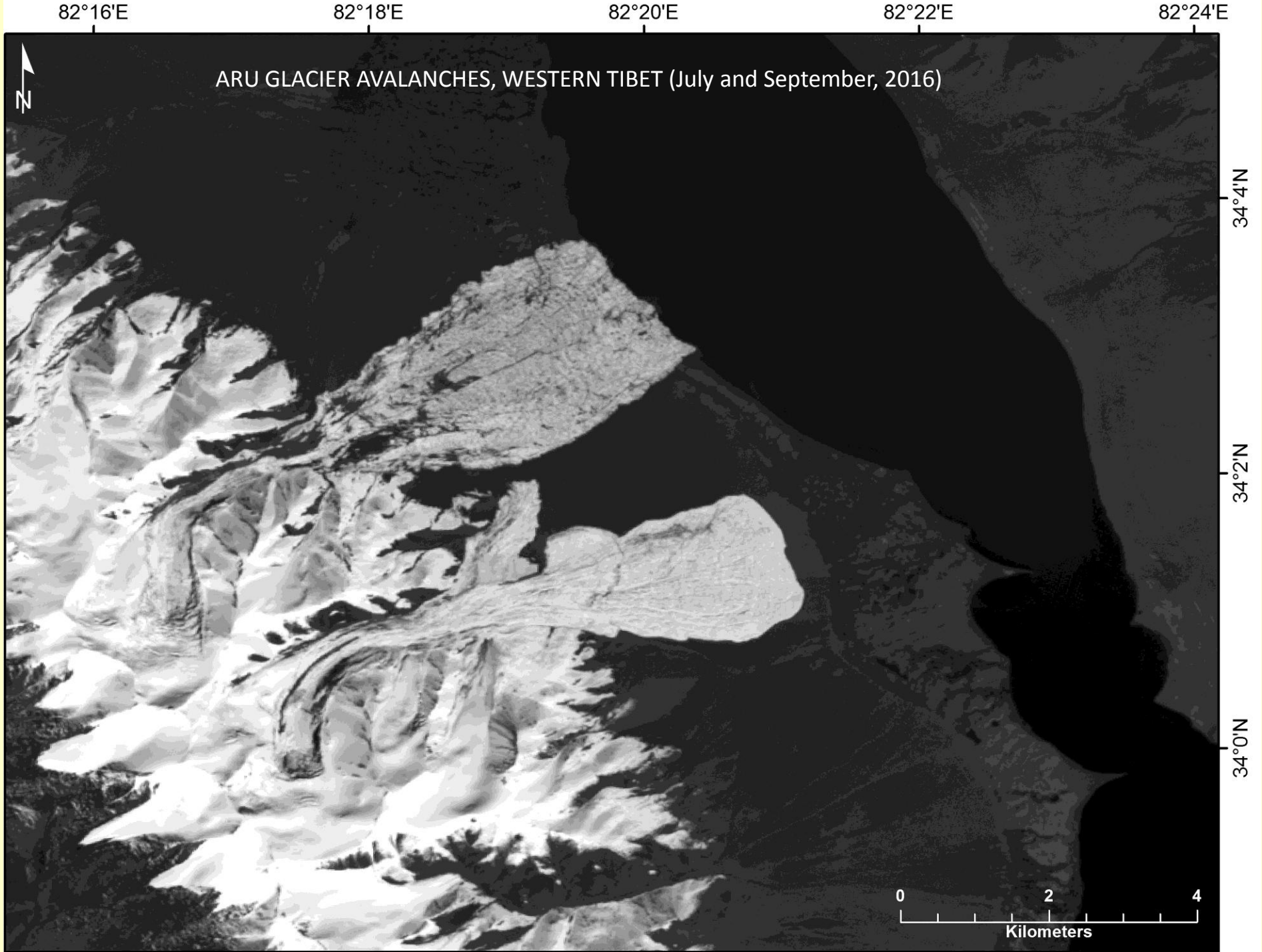

LITUYA MTN ROCK AVALANCHE (ALASKA) 2012
137°28'W
137°26'W
137°24'W
137°22'W
137°20'W
137°18'W
58°50'N
58°49'N
58°48'N
58°47'N
N
0
1
2
Kilometers

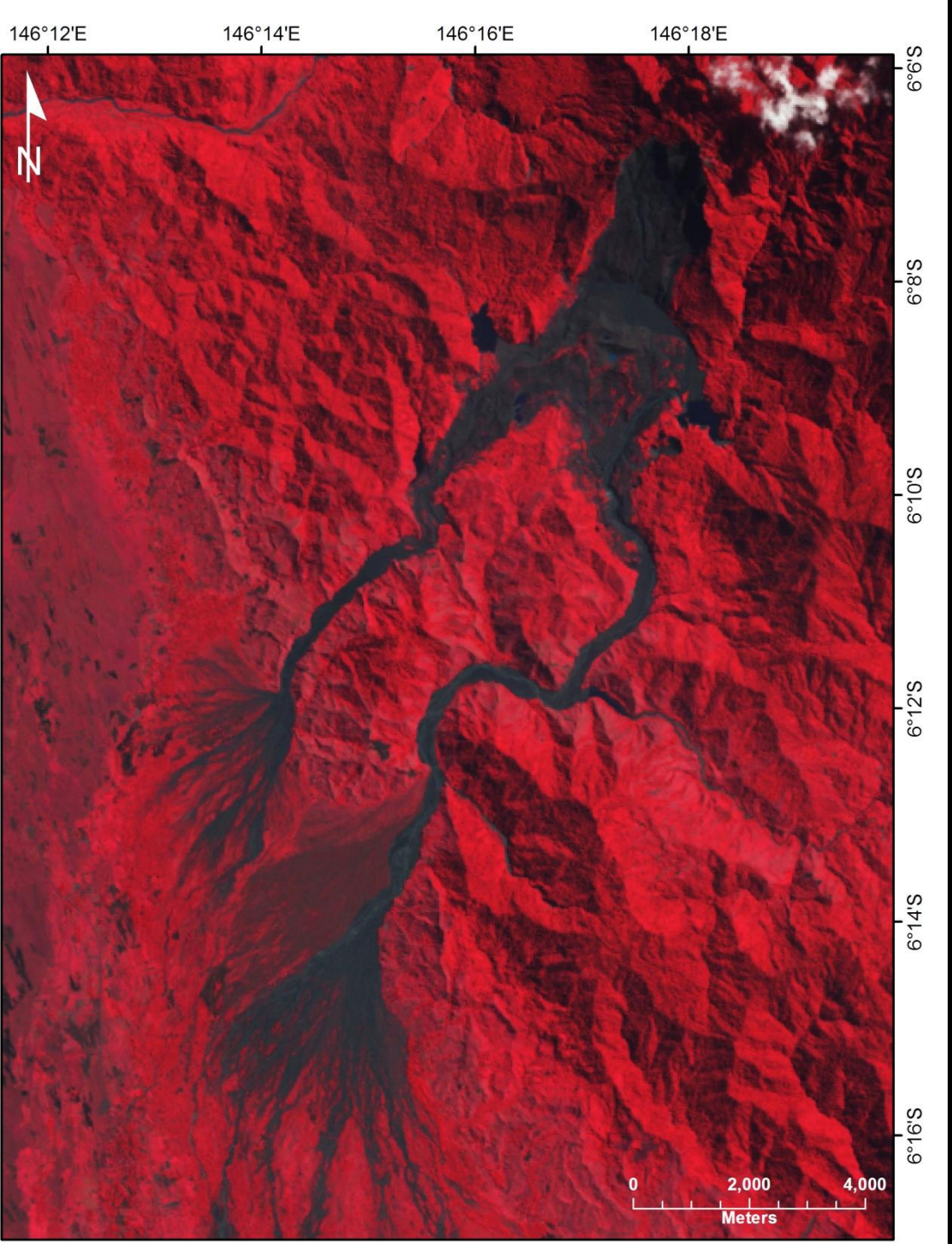

LAMPLUGH GLACIER ROCK AVALANCHE
(ALASKA) 2016
N
0
1
2
km
136°59'W
136°57'W
136°55'W
136°53'W
136°51'W
136°49'W
58°43'N
58°44'N
58°45'N
58°46'N
58°47'N
58°48'N
58°49'N
58°50'N

MOUNT DIXON ROCK AVALANCHE, SOUTHERN ALPS, NEW ZEALAND – JANUARY 2013



LA PEROUSE ROCK AVALANCHE, ALASKA – FEBRUARY 2014


ARU GLACIER AVALANCHES, WESTERN TIBET (July and September, 2016)
82°16'E
82°18'E
82°20'E
82°22'E
82°24'E
34°4'N
34°2'N
34°0'N
N
0
2
4
Kilometers

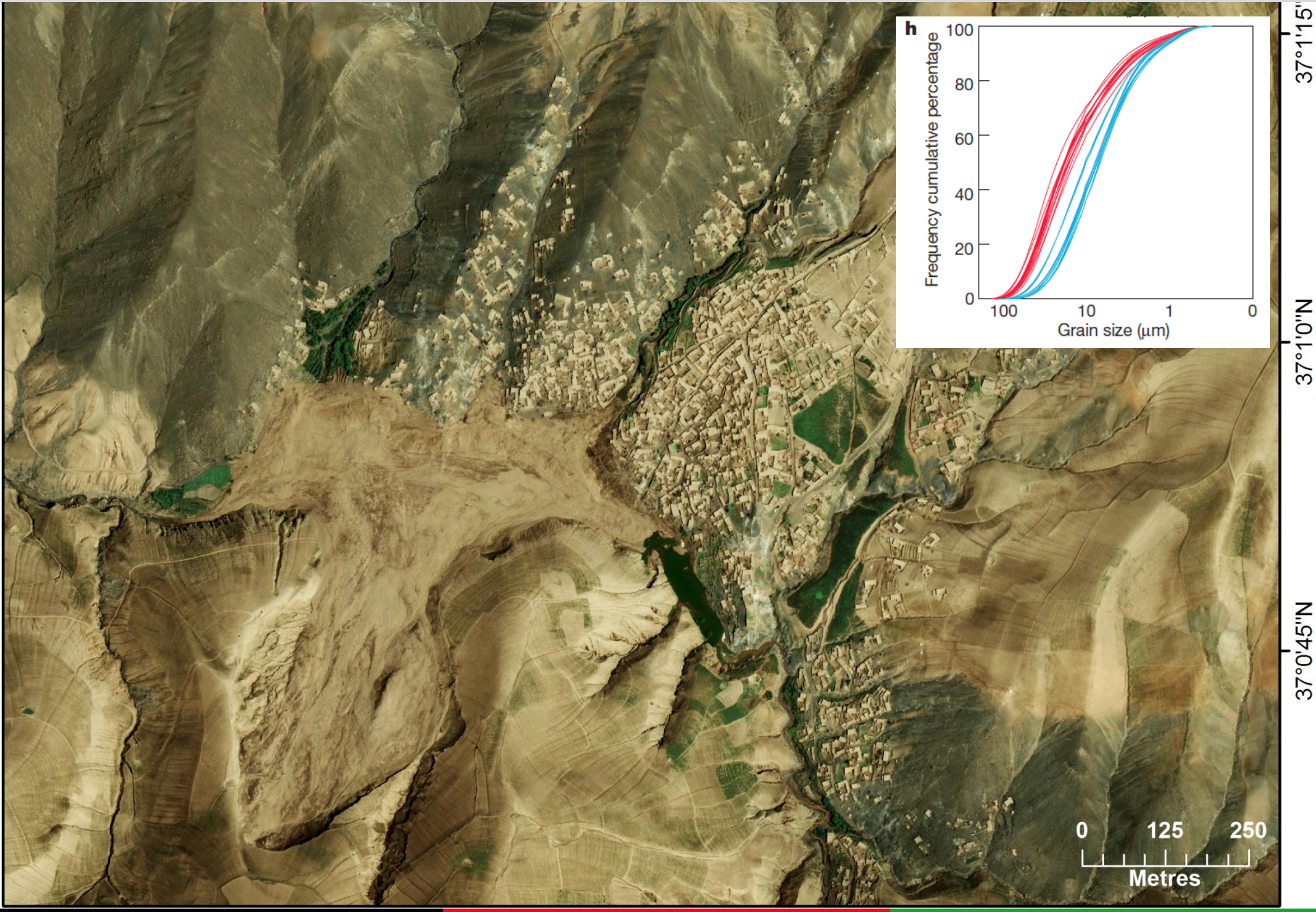


1988 KAIAPIT LANDSLIDE, PAPUA NEW GUINEA

SUNKOSHI LANDSLIDE, NEPAL (August 2, 2014) : 5.5Mm^3 / 156 deaths /debris blocked Sunkoshi River/ impacted Sunkoshi hydropower station.

AB BAREK LANDSLIDE, BADAKHSHAN PROVINCE, NE AFGHANISTAN (May 2, 2014)

AB BAREK LANDSLIDE, BADAKHSHAN PROVINCE, NE AFGHANISTAN (May 2, 2014)



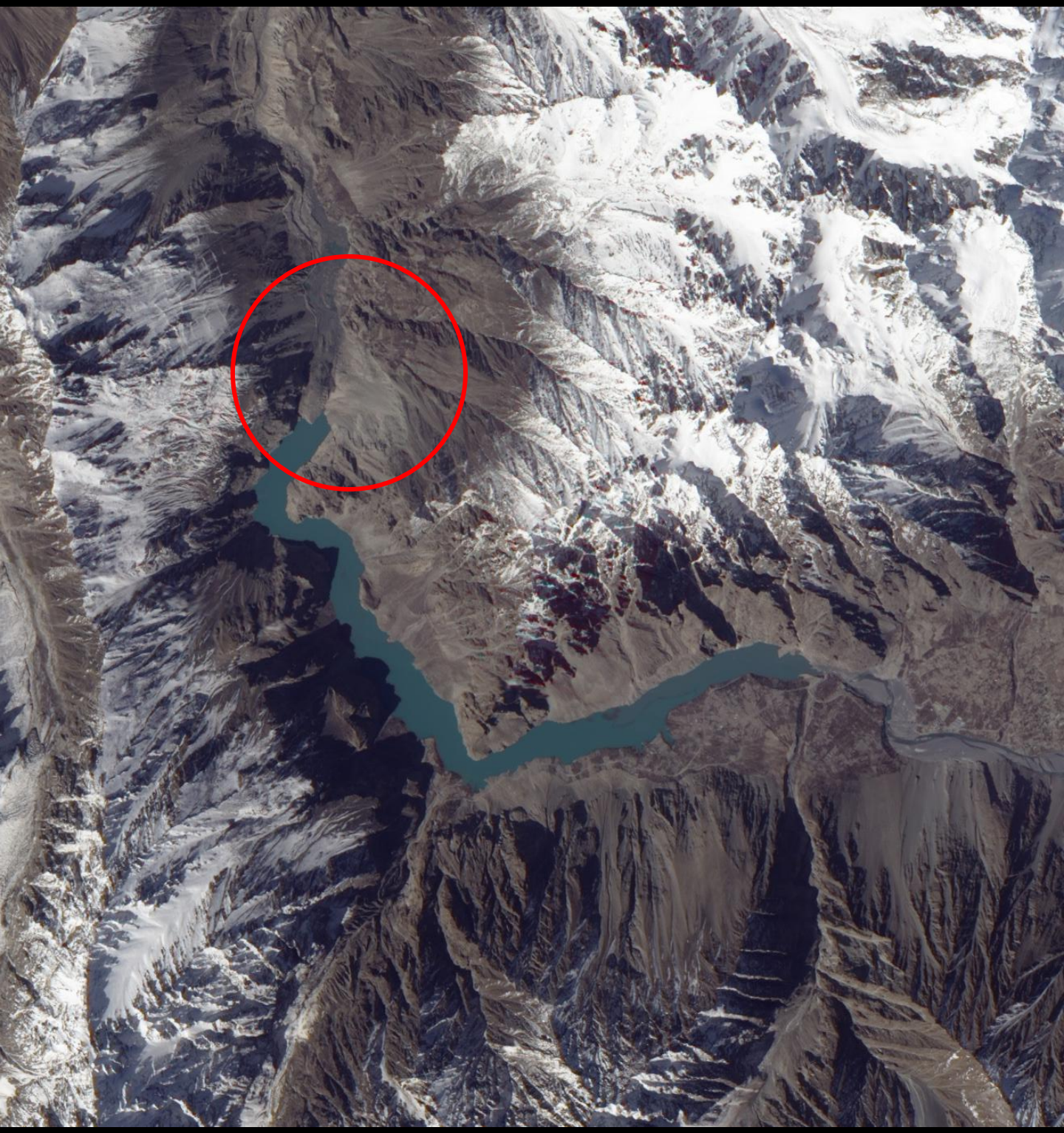
2010 – THE YEAR OF LANDSLIDES

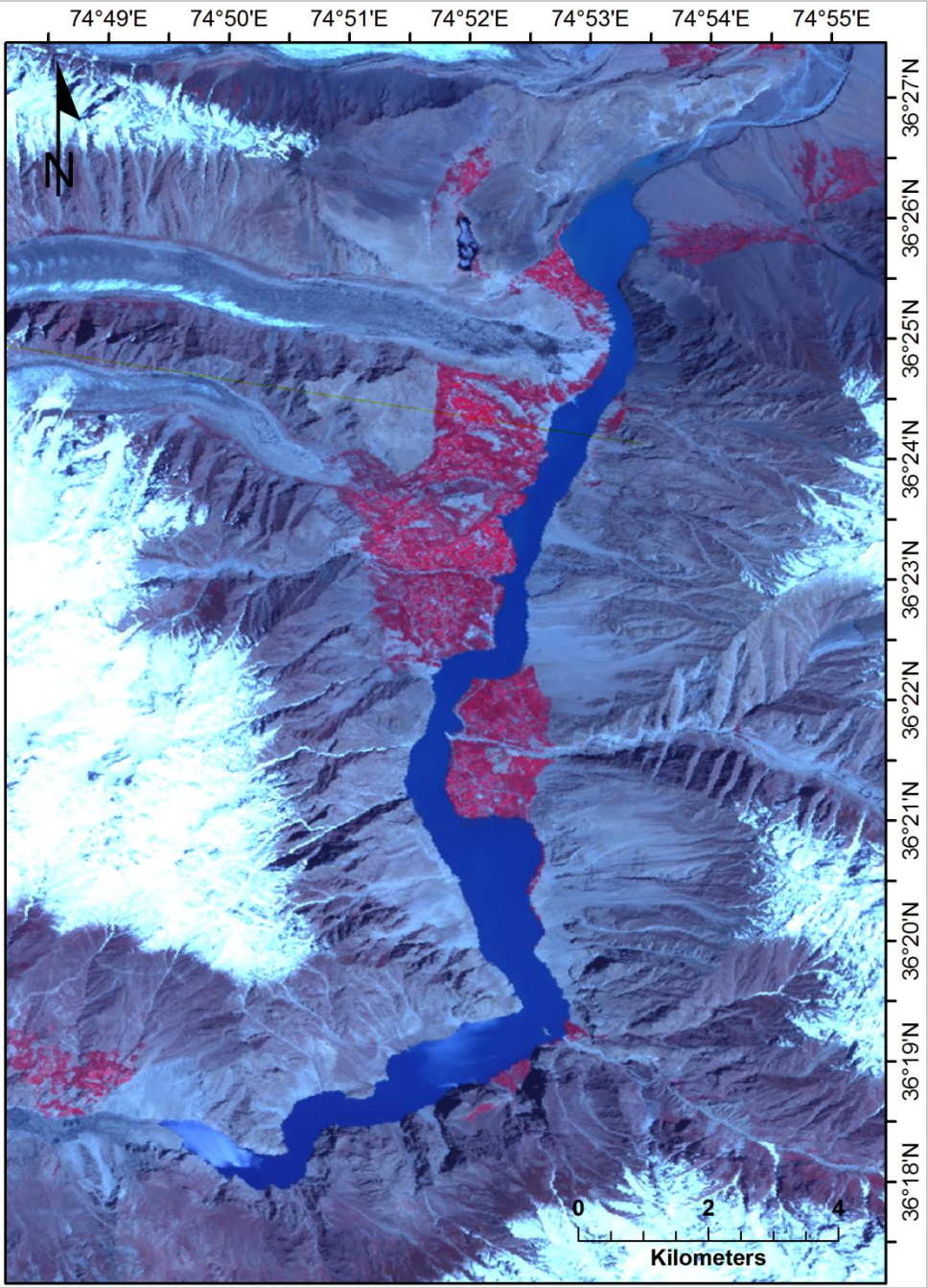
Landslide in residual soil triggered by heavy rains, Ilha Grande, State of Rio de Janeiro, Brazil, January 1, 2010 – 60 deaths (23.112°S/44.250°W)

January 2010 Hunza River rock avalanche , Pakistan

Rockslide blocked the Hunza River, northern Pakistan in early January 2010 to form landslide-dammed lake that overflowed in May 2010; it is still full

ADA ABAD ROCKSLIDE AND ROCKSLIDE-DAMMED LAKE, HUNZA RIVER, PAKISTAN - SATELLITE IMAGE ACQUIRED MARCH 16 , 2010




74°49'E
74°50'E
74°51'E
74°52'E
74°53'E
74°54'E
74°55'E
36°27'N
36°26'N
36°25'N
36°24'N
36°23'N
36°22'N
36°21'N
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36°19'N
36°18'N
N
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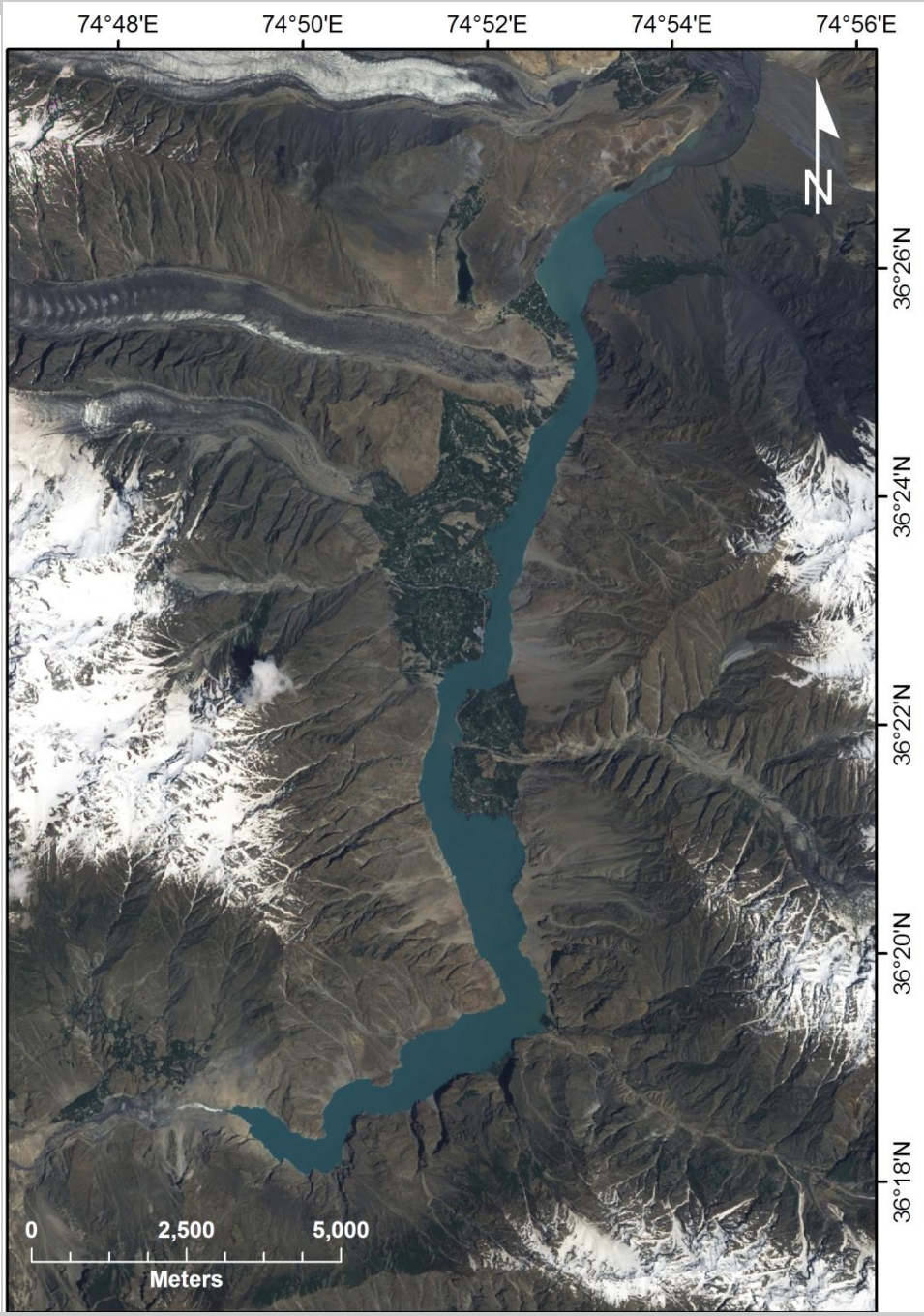
2
4
Kilometers


74°48'E
74°50'E
74°52'E
74°54'E
74°56'E
36°26'N
36°24'N
36°22'N
36°20'N
36°18'N
N
0
2,500
5,000
Meters

Landslide triggered by heavy rains in Bududa District , Uganda – March 3, 2010 (>300 deaths)

ST. JUDE LANDSLIDE, QUEBEC, APRIL 2010 – 4 deaths

HIGHWAY 3 LANDSLIDE, TAIWAN, APRIL 2010

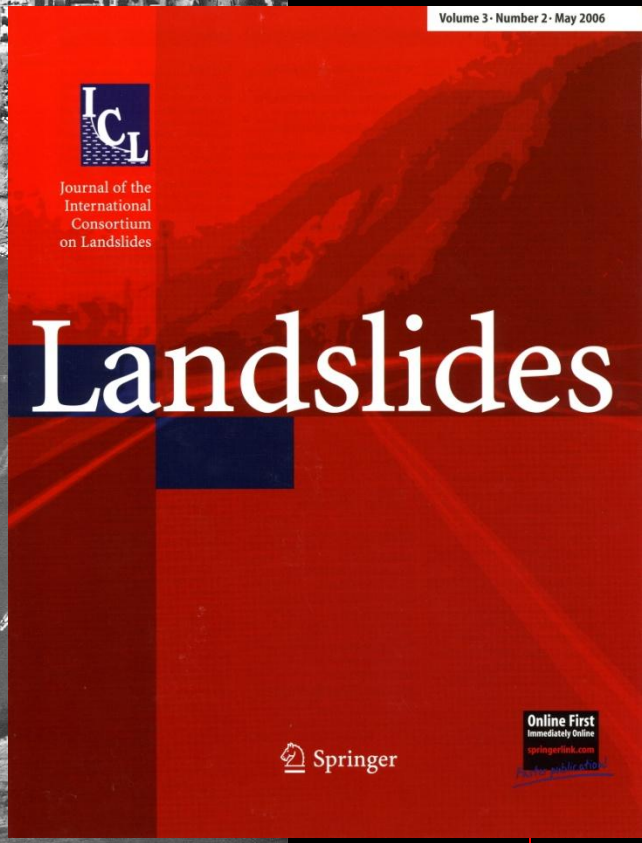
Wangong landslide (Sichuan) triggered by heavy rains, July 27, 2010

MOUNT MEAGER ROCK AVALANCHE, BRITISH COLUMBIA, AUGUST 6, 2010

2010 Mount Meager rock avalanche – estimated volume 45 Mm^3

MOUNT MEAGER IN 1988

ZHOUQU LANDSLIDE, GANSU, CHINA; Aug. 8, 2010 [1744 deaths]



MASS MOVEMENTS AND LANDSLIDES

EXAMPLES OF LANDSLIDES AT THE 1st NORTH AMERICAN LANDSLIDE CONFERENCE

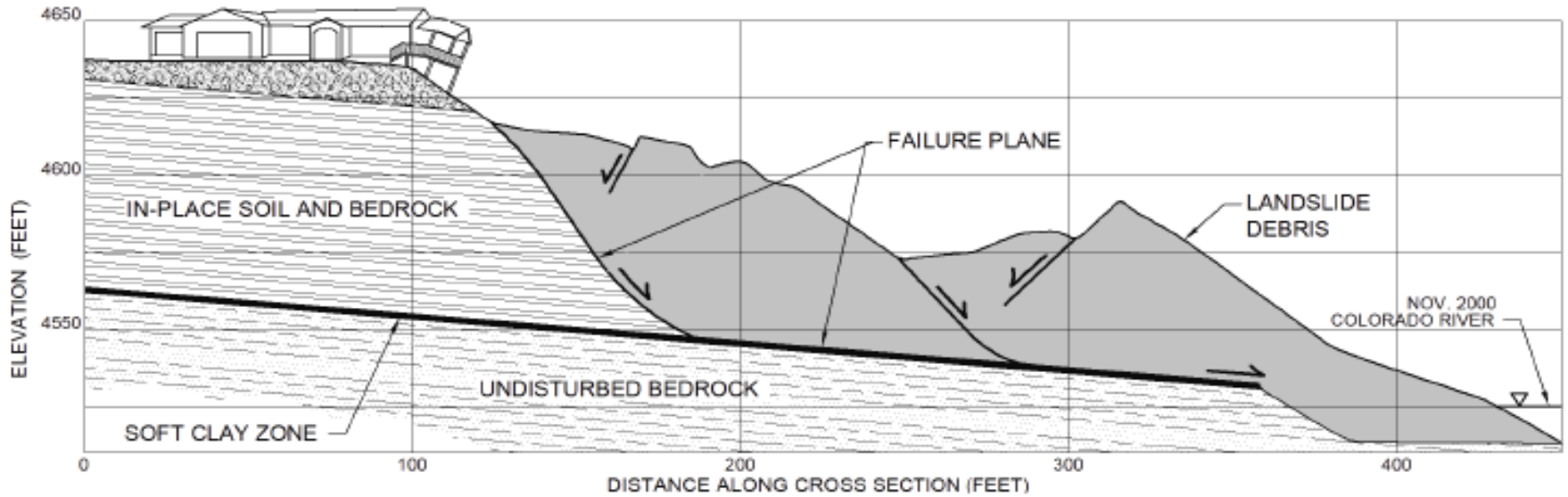


Figure 6. Topography resulting from subsequent failure. 1998 topography.

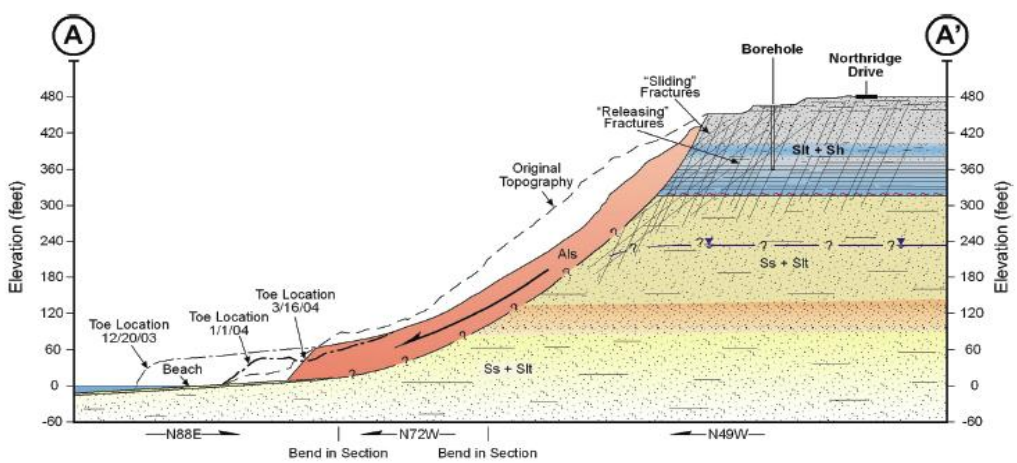
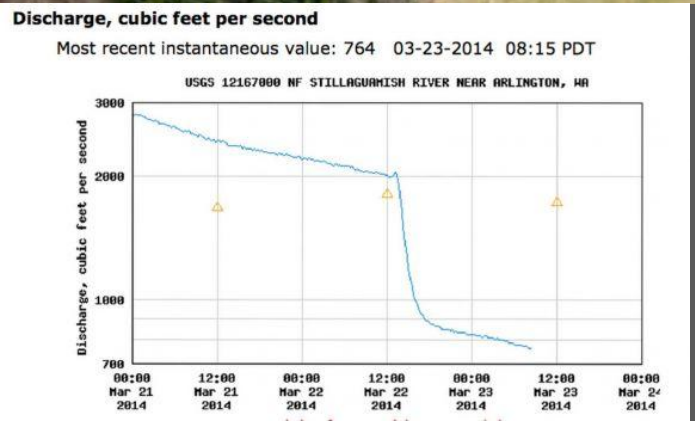


Figure 9. Engineering geologic cross section A-A' through the Northridge bluff Landslide.

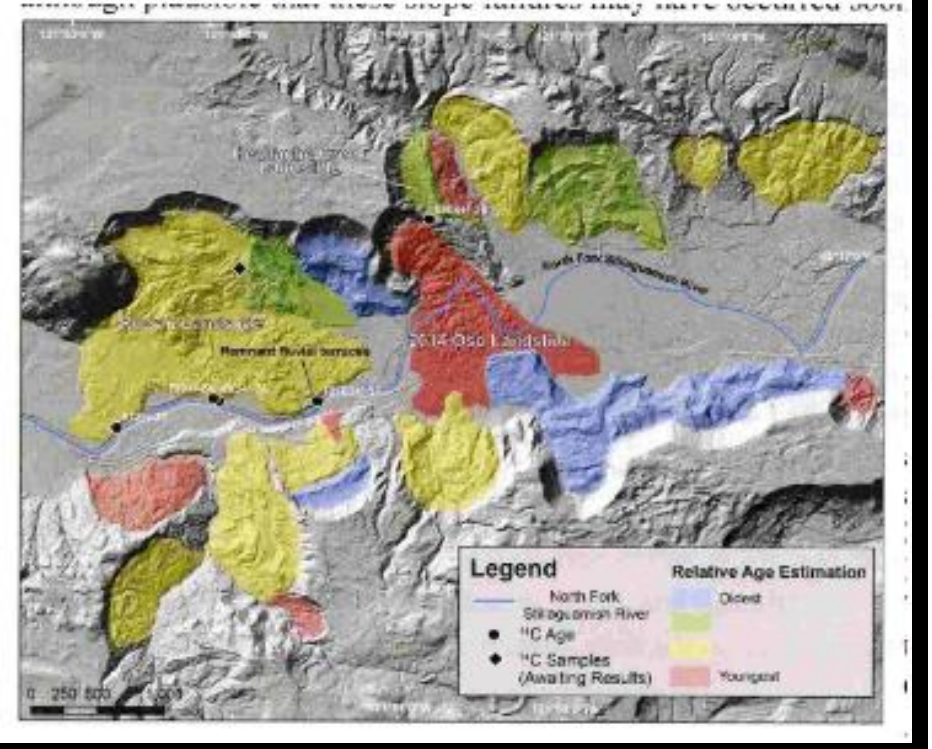
Figure 1. Oblique aerial photograph of the Northridge Bluff Landslide taken within two weeks after the December 2003 failure.

FEBRUARY 17, 2006, LANDLSIDE, LEYTE ISLAND, PHILIPPINES

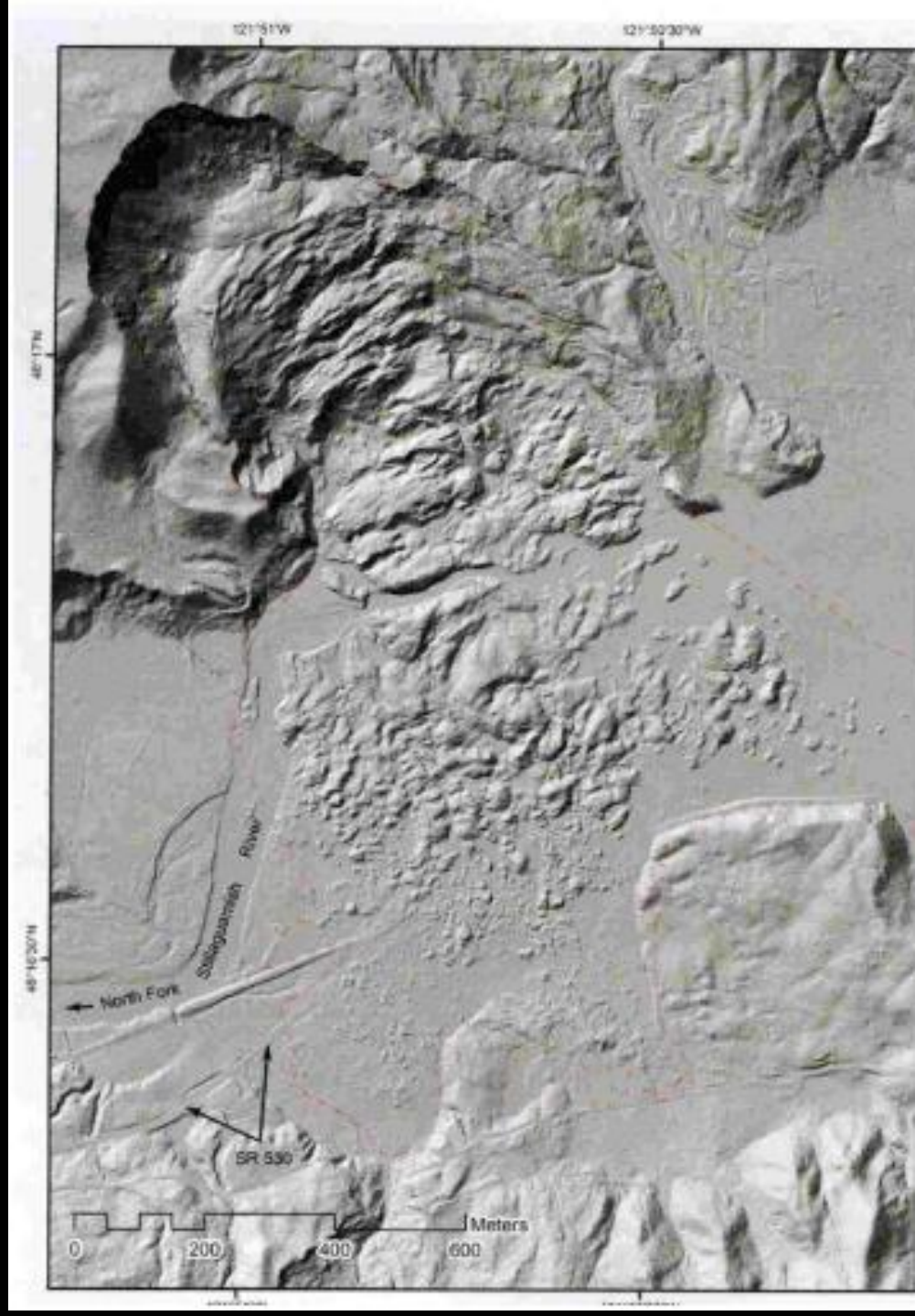
OSO LANDSLIDE, WASHINGTON STATE, USA : MARCH 22, 2014



OSO LANDSLIDE, WASHINGTON STATE, USA
MARCH 22, 2014

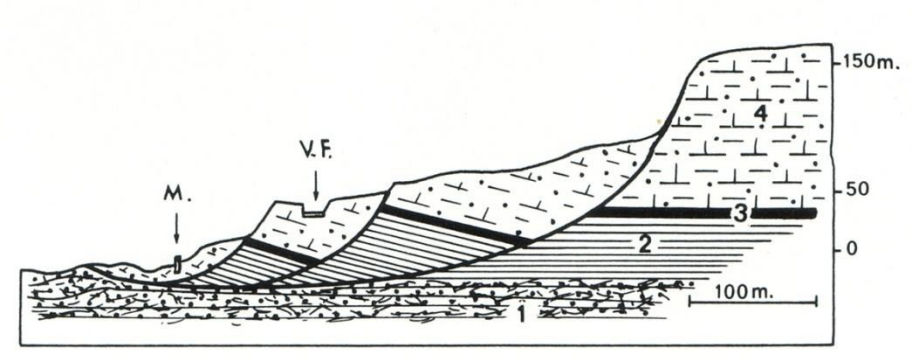


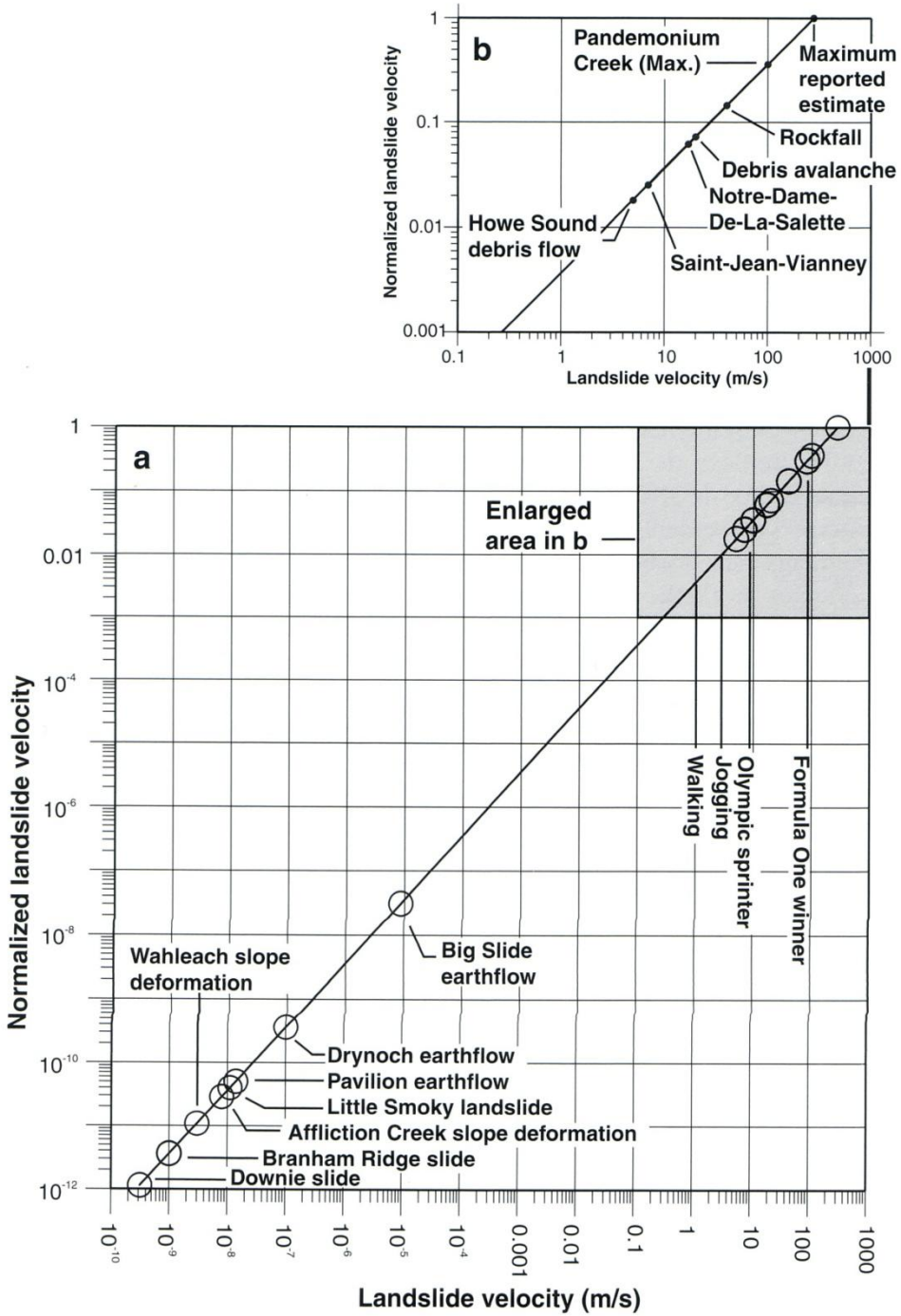
- Volume ~ 7 Mm
- Fatalities – 43 (second deadliest landslide in US history)
- Dammed river for short period of time
- LIDAR technology vital in landslide investigation
- Site of previous landslide (s)
- Liability issues being settled in ongoing court cases (previously zoned as residential)



Mass Movements and Landslides

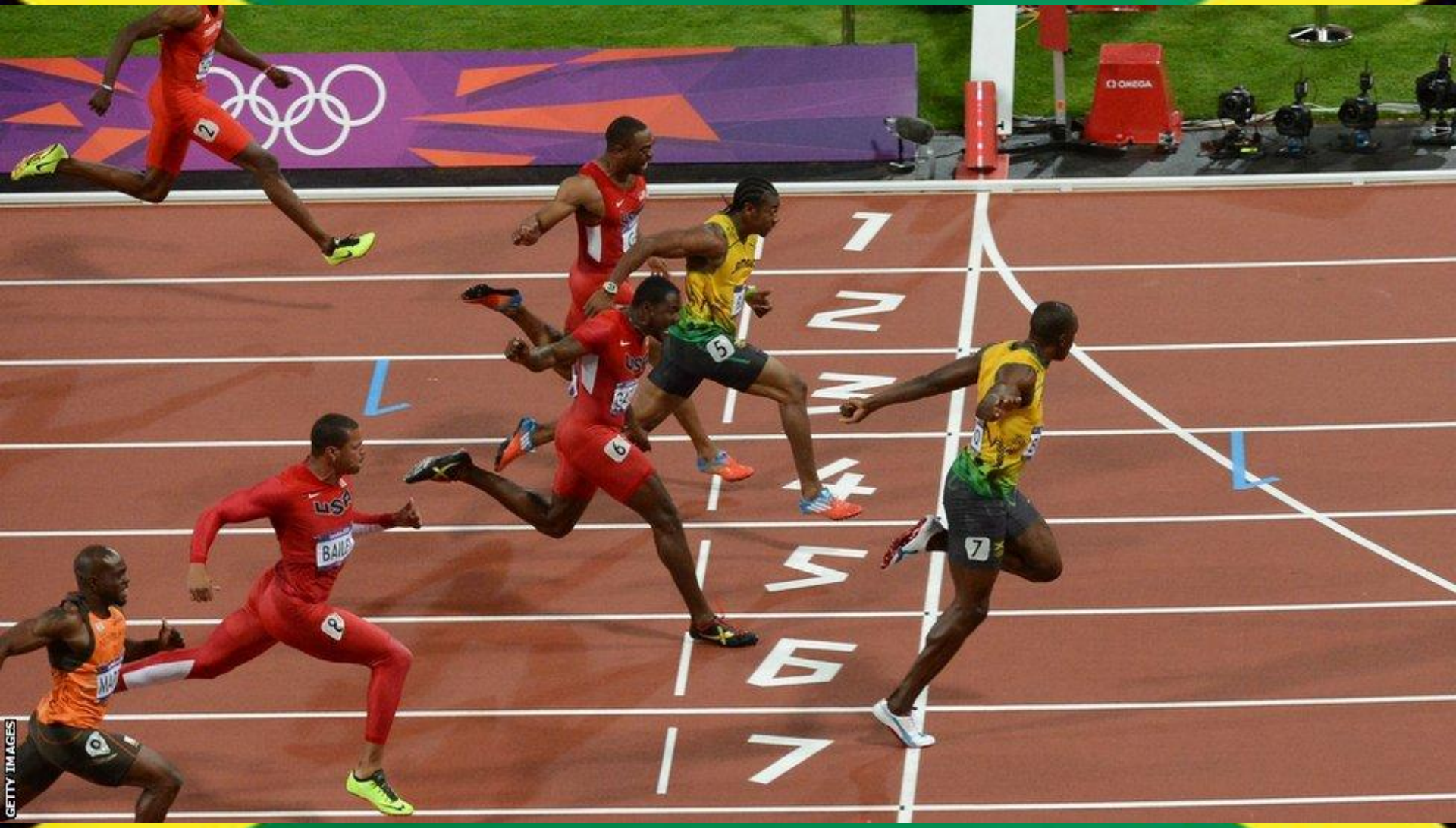
- Mass movements: general term to describe a group of natural processes that result in downslope movement of material under the direct influence of gravity. Material may be soil or rock.
- Landslide: individual mass movement event. May involve little deformation of the sliding mass or its complete disintegration.
- Rates range from very slow: creep to extremely fast: rockfall or slide.
- Human risk is highest for sudden and fast events
- Landslides also involve built slopes



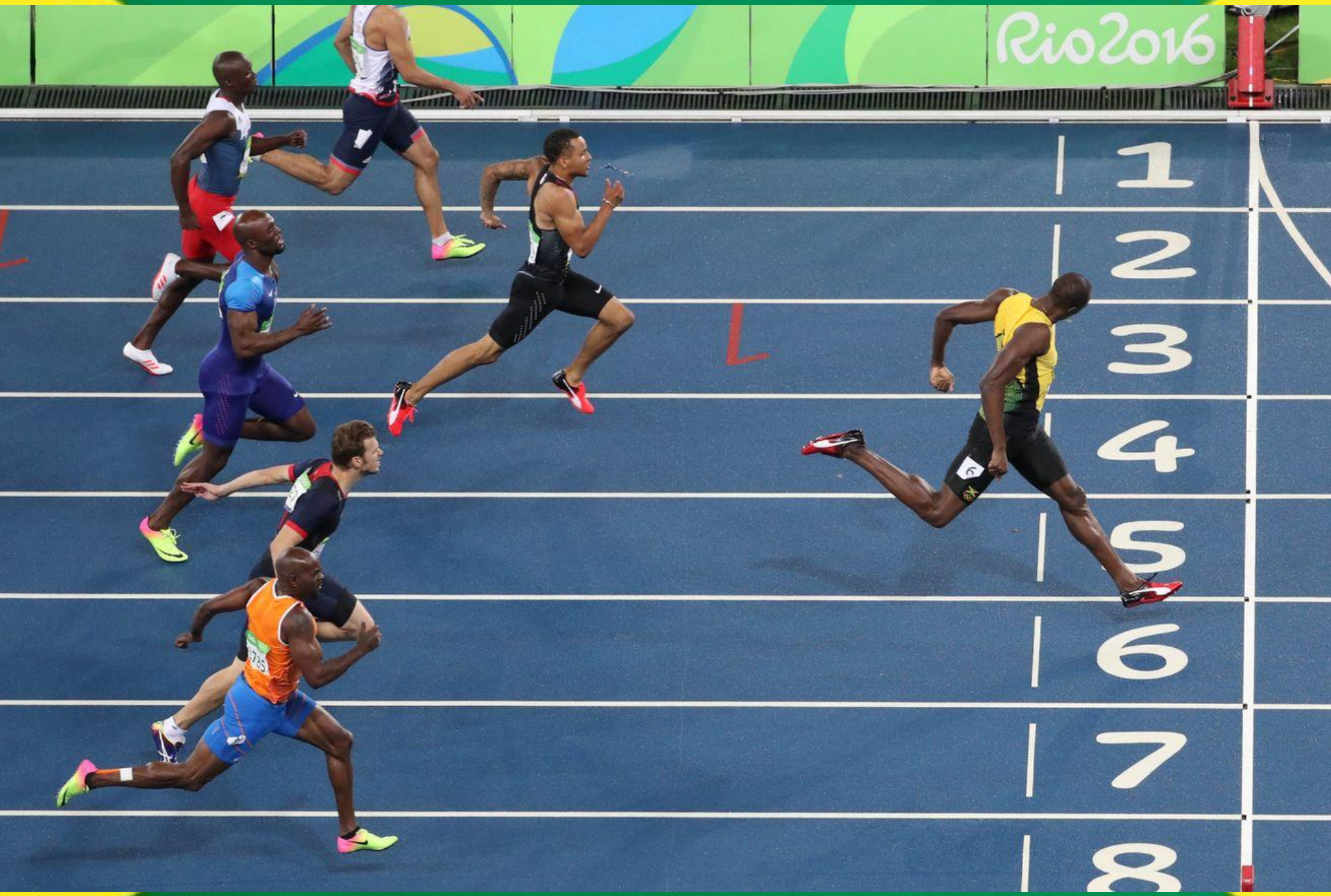


LANDSLIDE VELOCITY

Catastrophic landslides faster than 5 m/s



USAIN BOLT – 100 m GOLD MEDAL WINNER AT 2012 LONDON OLYMPICS (10.38 m/s)



USAIN BOLT – 100 m GOLD MEDAL WINNER AT 2016 RIO OLYMPICS (10.19 m/s)

JENSON BUTTON (McLAREN-MERCEDES) WINS 2012 AUSTRALIAN F1 GP (AVGE. SPEED 54 m/s)

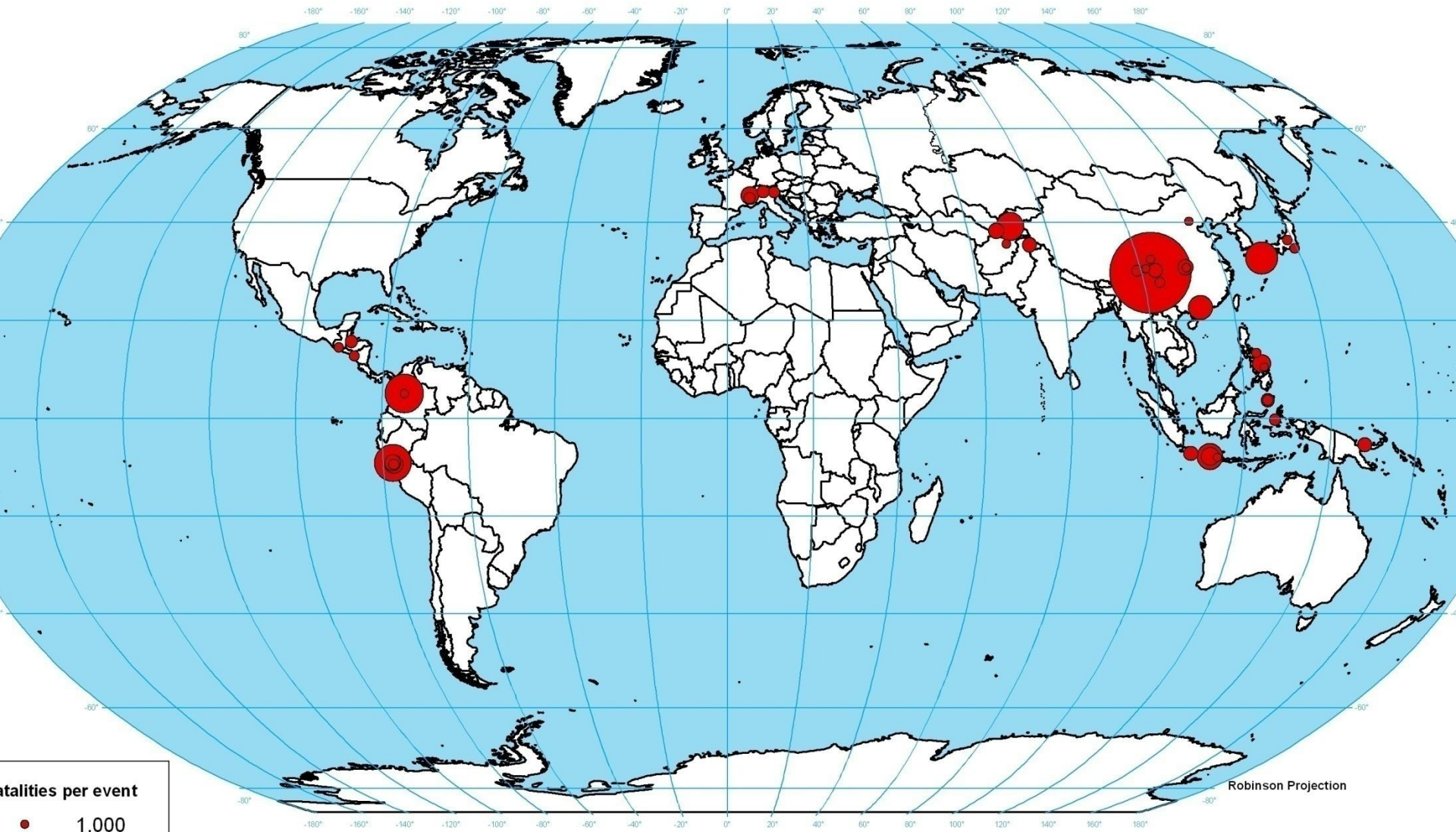
NICO ROSBERG (MERCEDES) WINS 2016 AUSTRALIAN GRAND PRIX
(AVERAGE SPEED – 46.53 m/s)

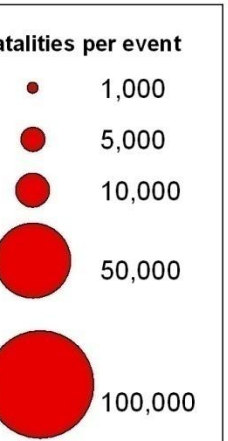
MUNICH TAXI RIDE (TO THE AIRPORT) JULY 2012

w.draxysoft.com

Earthquake-triggered 1970 Huascaran rock avalanche, Peruvian Andes

1962 AND 1970 HUASCARAN EVENTS – ANDES OF PERU





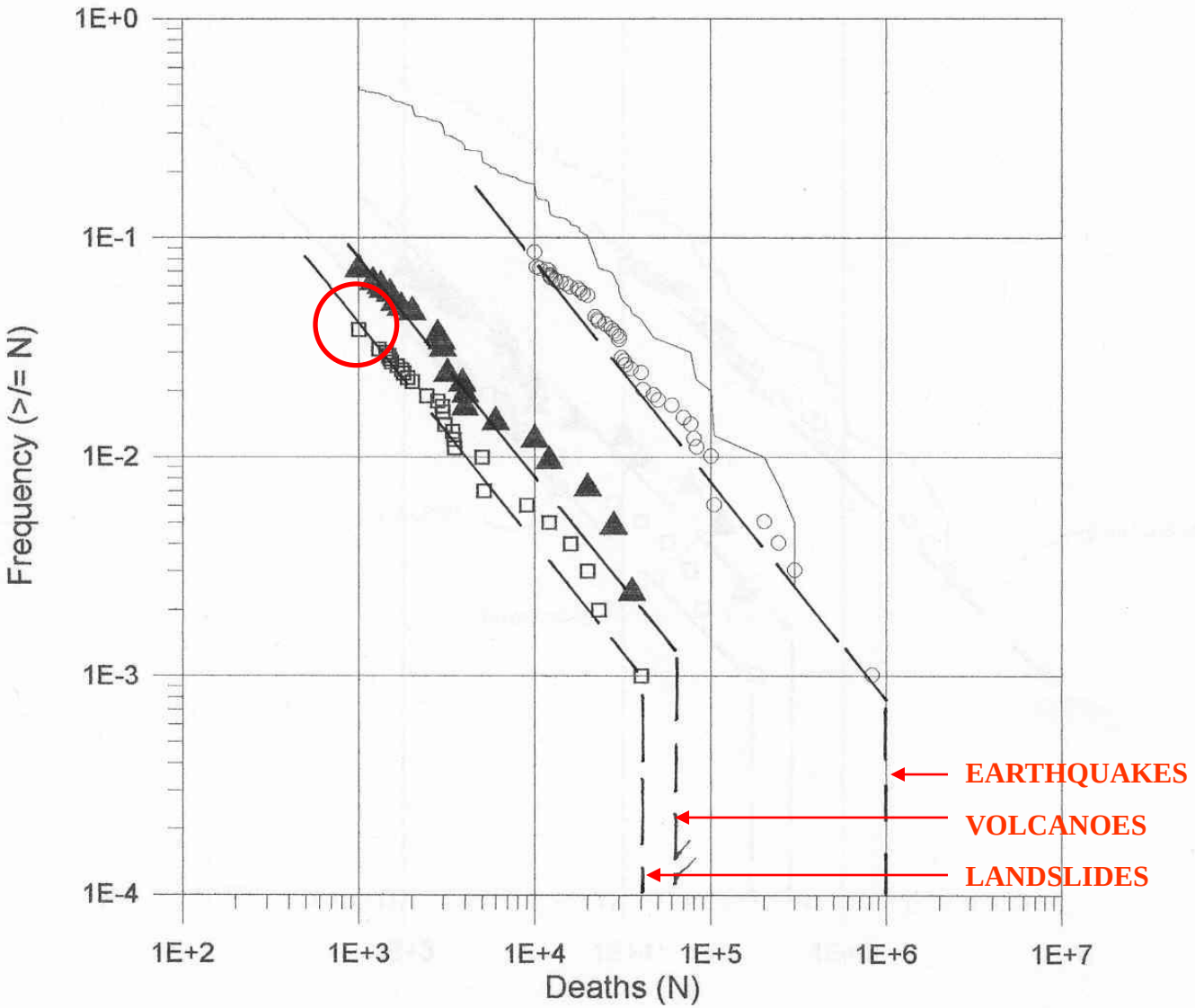
Landslide Catastrophes (1000 -2006 AD)

(over 1000 deaths per single event)

Landslide Research Program
Department of Earth Sciences
University of Waterloo

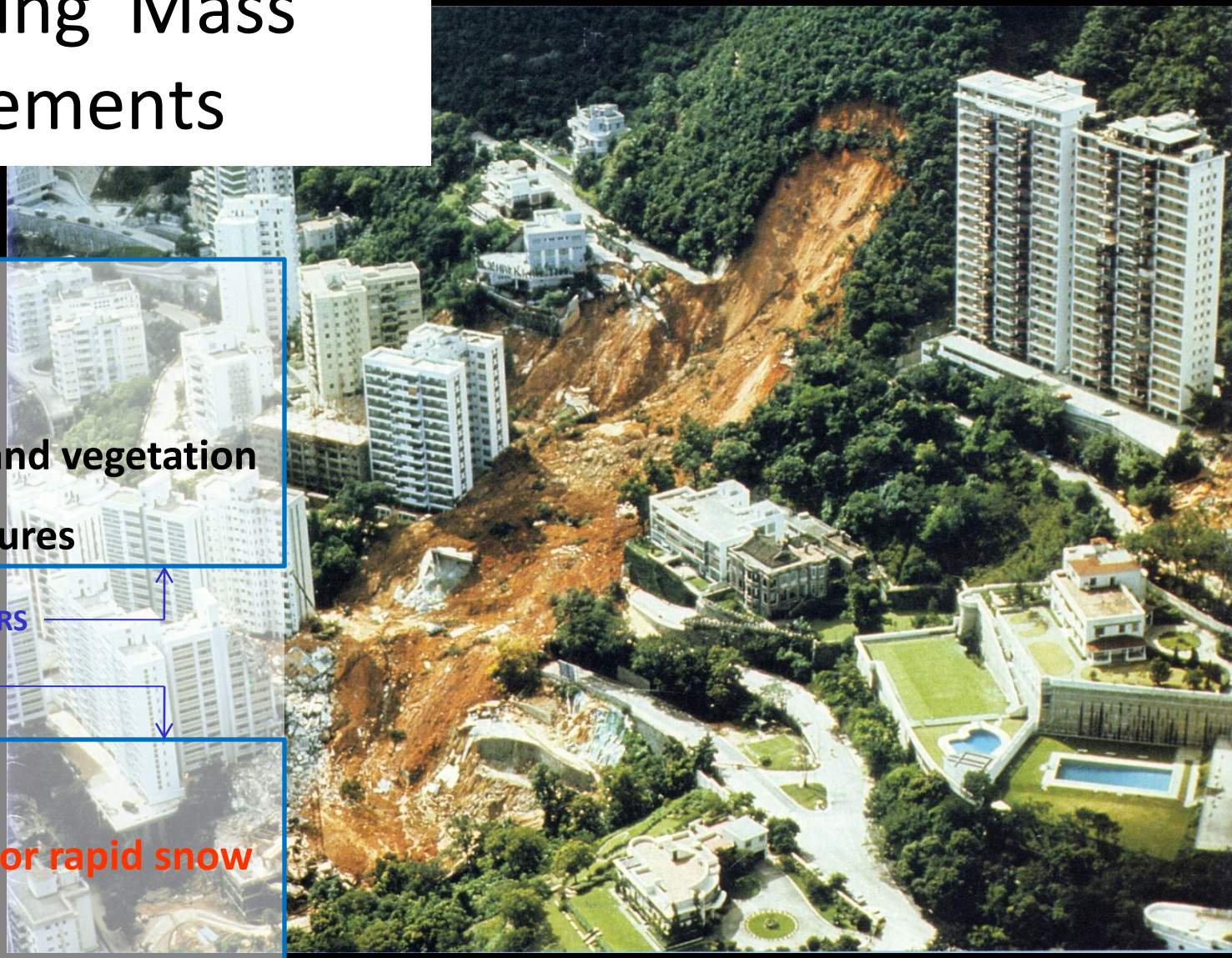
University of Waterloo

GLOBAL RISK ENVELOPES FOR GEOLOGICAL HAZARDS



Factors Influencing or Triggering Mass Movements

1972 Po Shan Road Landslide, Hong Kong



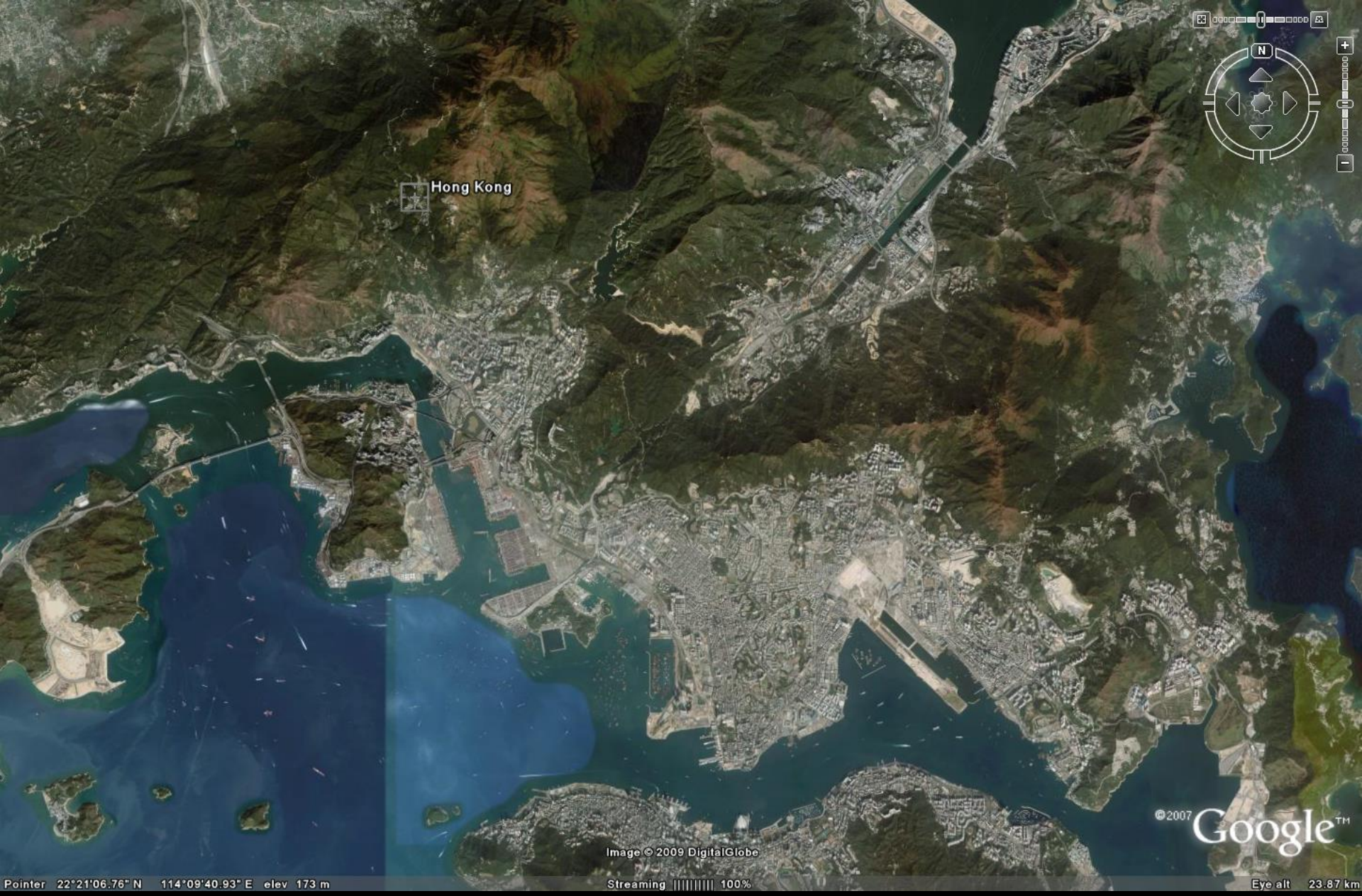
- **Slope angle**
- **Water**
- **Slope materials and vegetation**
- **Geological structures**

PRE-CONDITIONING FACTORS

TRIGGERRING FACTORS

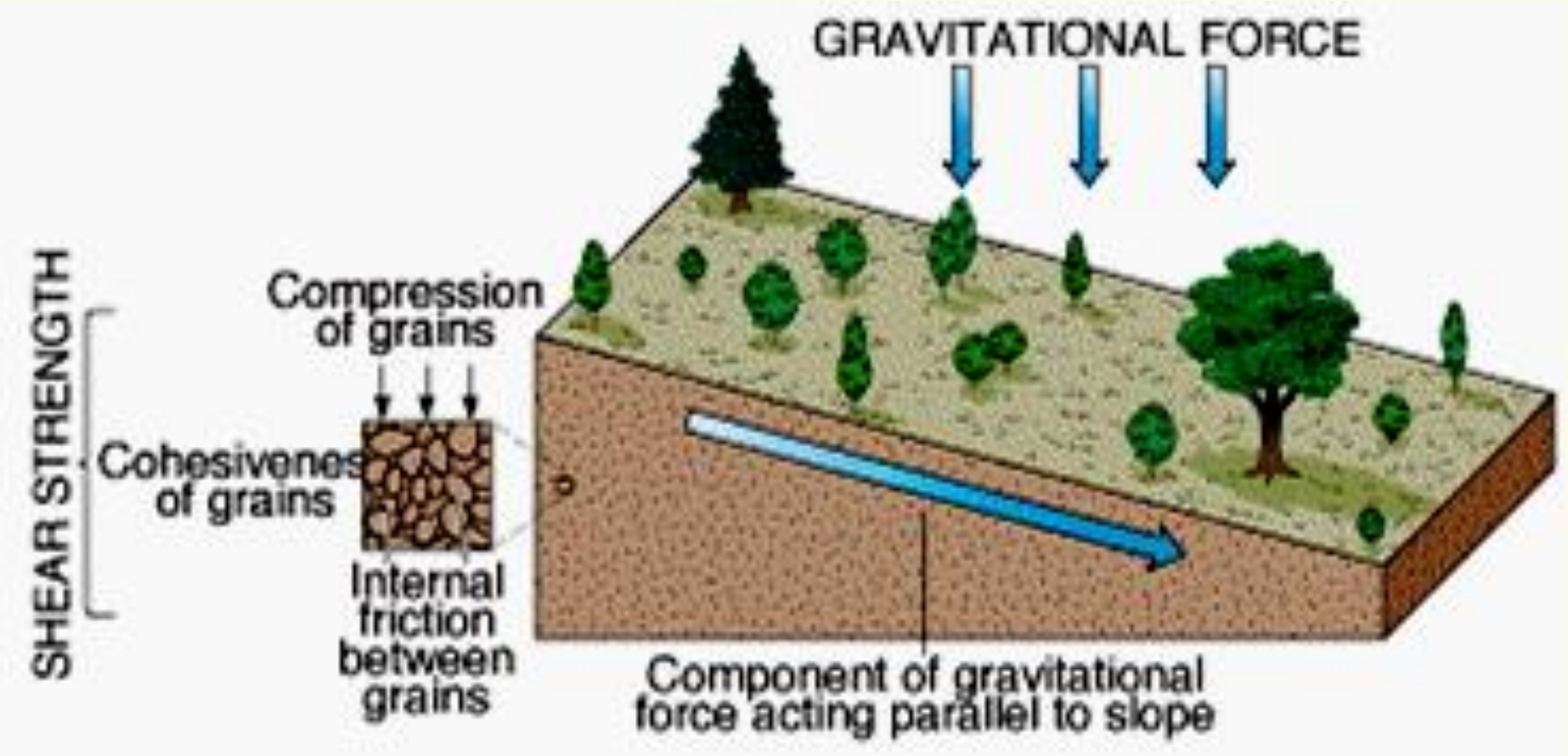
- **Earthquakes**
- **Heavy rains and/or rapid snow melt**
- **Human activity**

1972 Po Shan Road Landslide, Hong Kong



HONG KONG : STEEP SLOPES, TROPICAL WEATHERING, HEAVY RAINFALL = LANDSLIDES

Gravity Overcomes Resistive Forces



FACTOR OF SAFETY (FS)

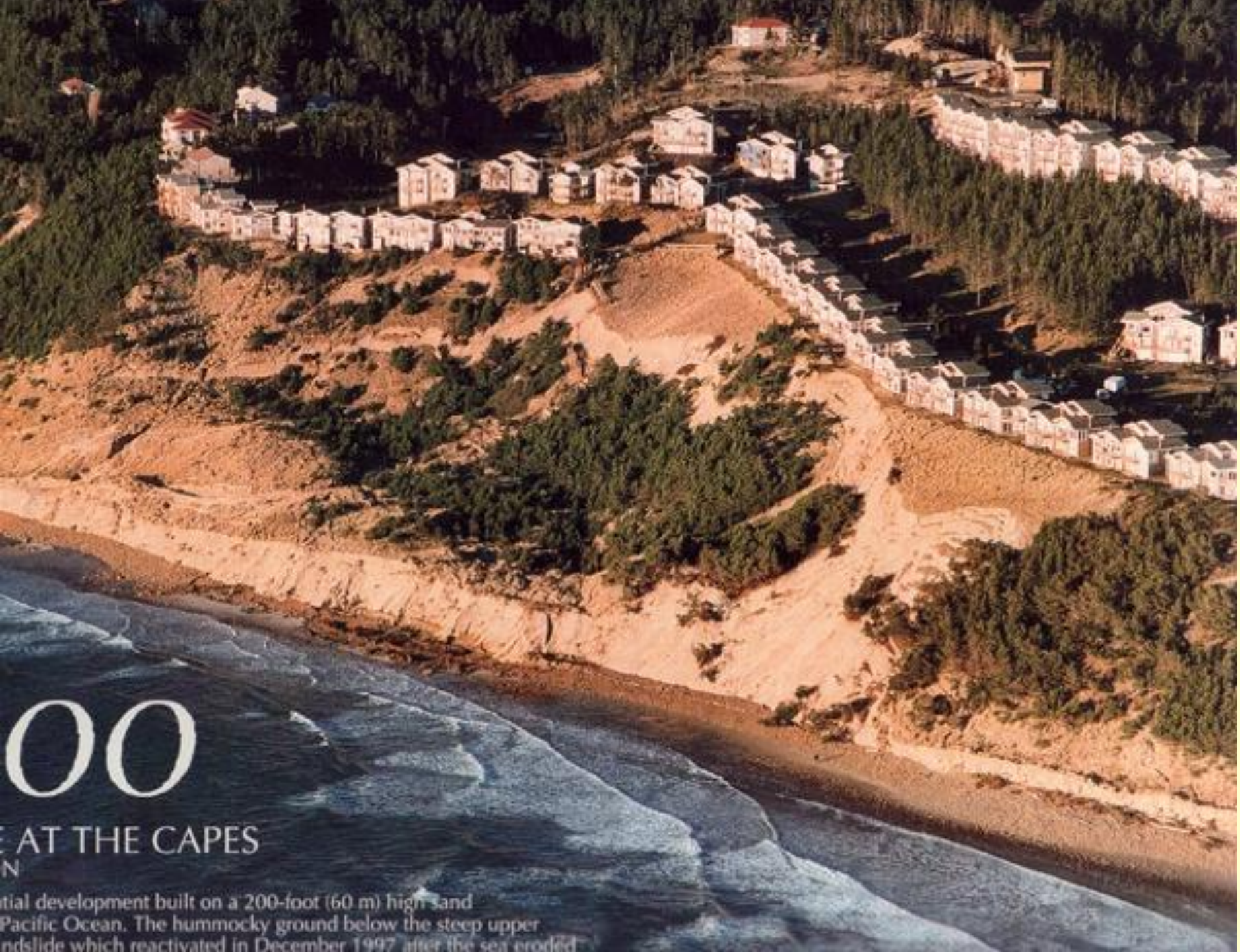
RATIO OF RESISTING FORCES (R) TO DISTURBING FORCES (D)

$$FS = R/D$$

WHEN FS IS EQUAL OR LESS THAN UNITY FAILURE ENSUES

FACTOR 1: Slope Angle

- Slope angle is probably the major reason for mass movements
- Angle of repose: steepest angle a material will maintain. Here the shear strength of the material exactly matches the forces of gravity.
  - Unconsolidated material = 25° to 40°.
  - Slopes > 40 ° generally comprise rock masses.
- A number of processes can oversteepen a slope:
  - undercutting by stream or wave action, removing the slope's base and increasing the component acting parallel to the slope
  - excavations for road cuts or foundations, increasing the stress in the soil or rock until it is no longer steep enough to remain at the steeper angle



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E AT THE CAPES
N

tial development built on a 200-foot (60 m) high sand
Pacific Ocean. The hummocky ground below the steep upper
ndslide which reactivated in December 1997 after the sea eroded

FEBRUARY 17, 2006, LEYTE ISLAND LANDSLIDE,
PHILIPPINES [1,250 deaths]

SEA CLIFFS IN ALLUVIAL FAN DEPOSITS, LIMA, PERU (DECEMBER 2005)

ODDICOMBE BEACH, TORBAY, DEVON, UK - Postcard from 1935

ODDICOMBE BEACH, TORBAY, DEVON, UK - June 2013

ODDICOMBE BEACH, TORBAY, DEVON, UK - June 2013

FACTOR 2 : Influence of water

- Amount of water in rock or soil influences slope stability significantly
- Source of water - rainfall, snowmelt, irrigation, leakage
- Presence of water within slope materials reduces the inter-grain frictional resistance (effective stress)
- Water saturation of moving debris increases runout and mobility

Jizukiyama landslide, Japan, July 1985

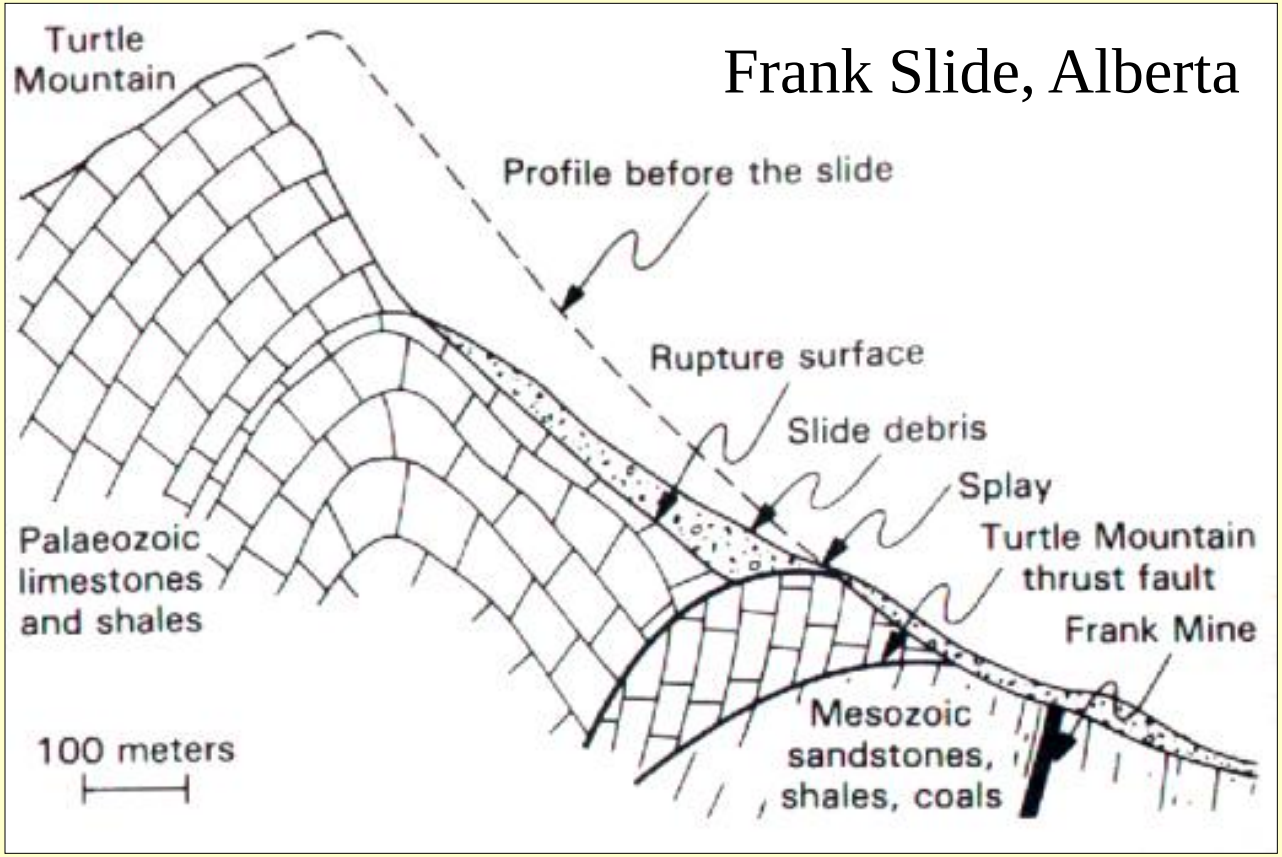
FACTOR 3: Material Properties

- Strength of slope forming materials determines resistance
- Mass wasting occurs in transported soils, loose or poorly consolidated slope material (residual soil), and bedrock.
- As soon as rock is exposed at the surface, weathering begins to disintegrate and decompose it, thus reducing its shear strength and increasing its susceptibility to mass wasting. The deeper the weathered zone, the greater the likelihood of some type of mass wasting.
- Tropical climates - temperature is high and considerable rainfall occurs, weathered zone may be very deep and mass movements generally occur in this deeper zone.

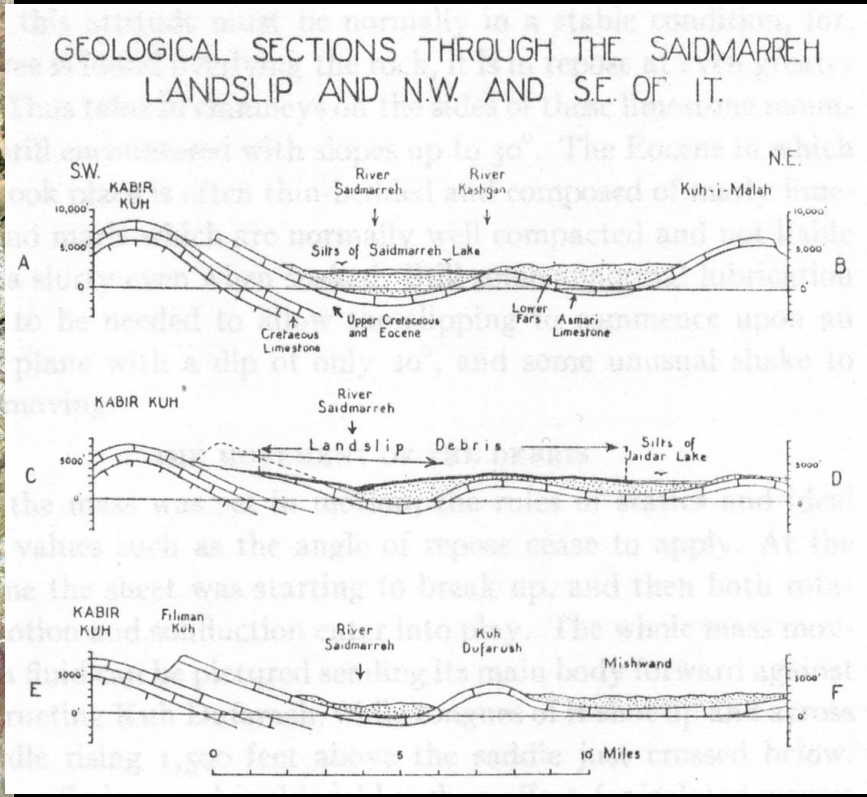
FACTOR 4 : Geological Structure

Rocks dipping in the same direction as the hill's slope are particularly susceptible to mass wasting. Undercutting of the base of the slope by a stream removes support and steepens the slope at the base. Water percolating through the soil and into the underlying rock increases its weight and, if clay layers are present, wets the clay, making them slippery.

Fractures dipping in the same direction as a slope are enlarged by chemical weathering, which can remove enough material to cause mass wasting.



1903 FRANK SLIDE



SAIDMARREH ROCK AVALANCHE, ZAGROS MOUNTAINS, IRAN (40 km³)

Tertiary Limestone sequence

SEYMAREH ROCK AVALANCHE, ZAGROS MOUNTAINS, IRAN

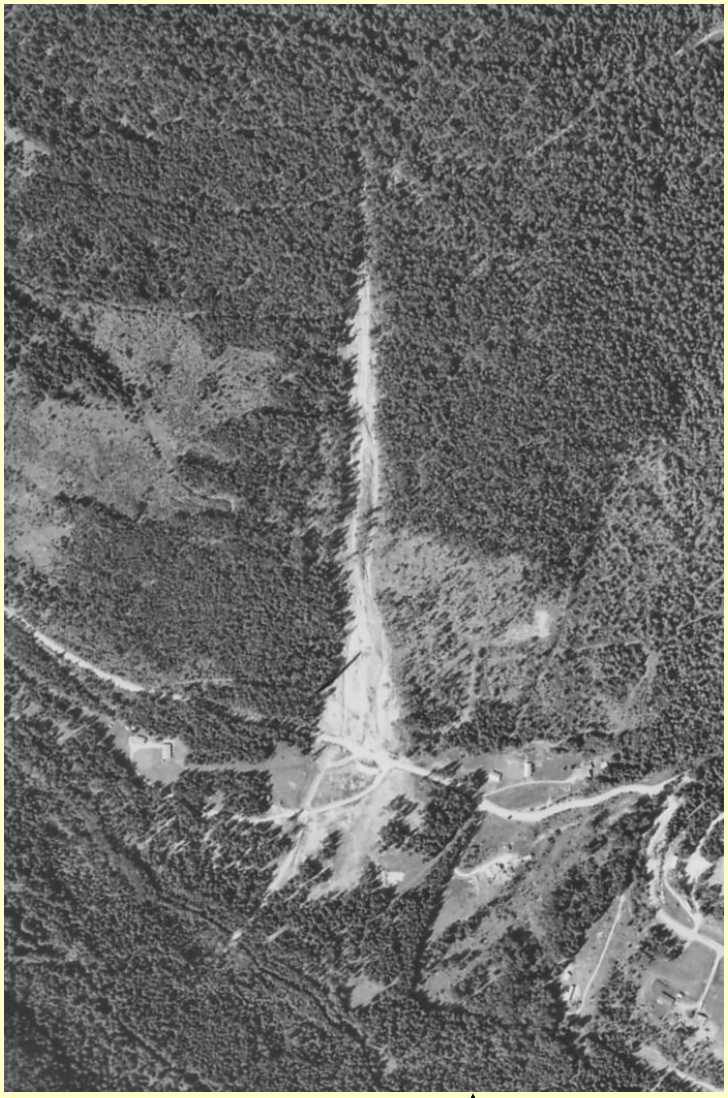
VOLUME ~40 cu km

RUNOUT 20 km

WIDTH OF SCARP 15 km

AGE~10,000 y BP

TRIGGER 1 : DEBRIS AVALANCHES TRIGGERED BY HEAVY RAINS



1973 Harbour Breton, Newfoundland – 4 deaths

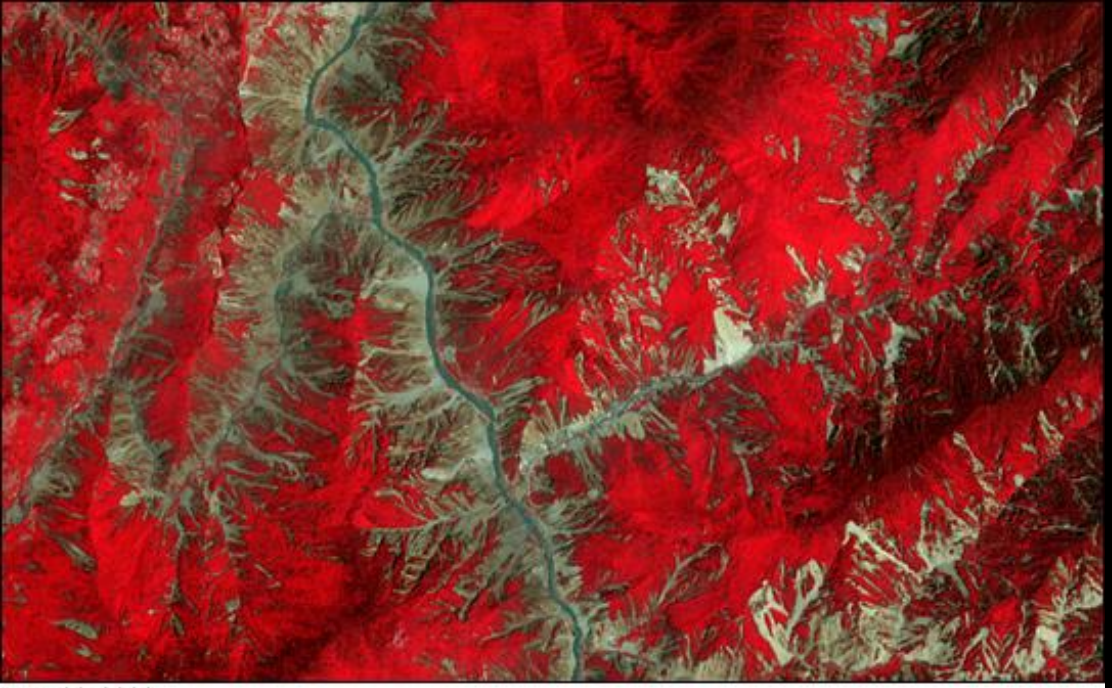
1990 Belgo Creek landslide, British Columbia – 3 deaths

Landslides in Yunnan Province, China in November, 2008 after 10 days of heavy rain

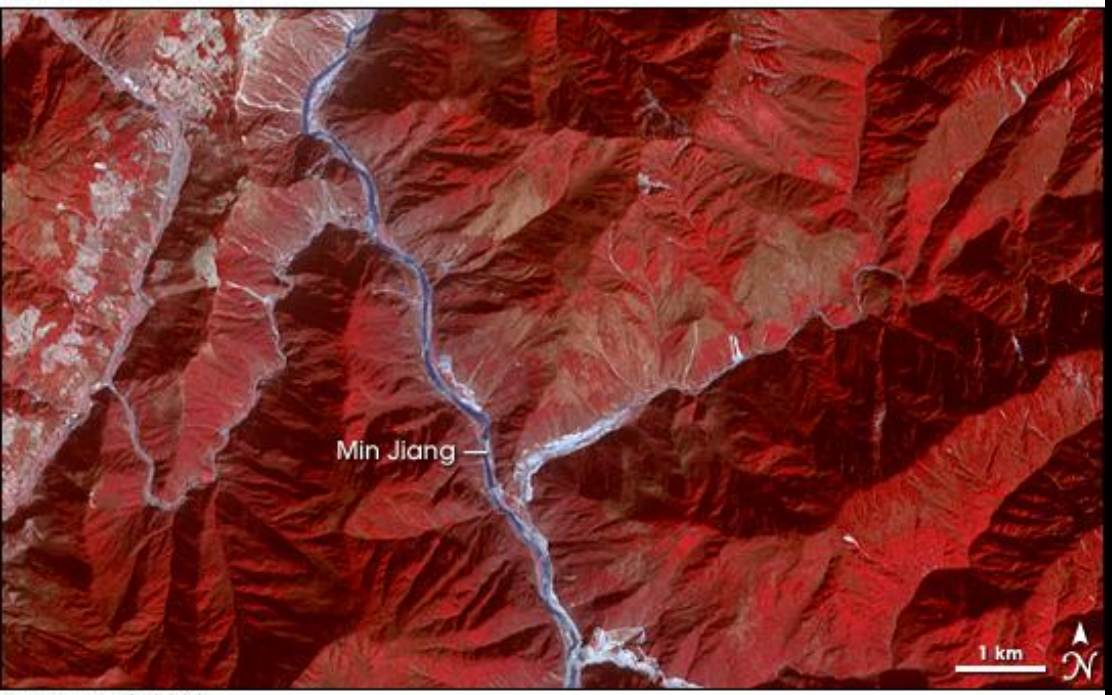
TRIGGER 2 : EARTHQUAKES

Las Colinas flowslide, El Salvador, January 2001

This 4 km long tongue of debris was deposited on Alaska’s Sherman Glacier by a rock avalanche. The event was triggered by the Great Alaska Earthquake in March 1964.



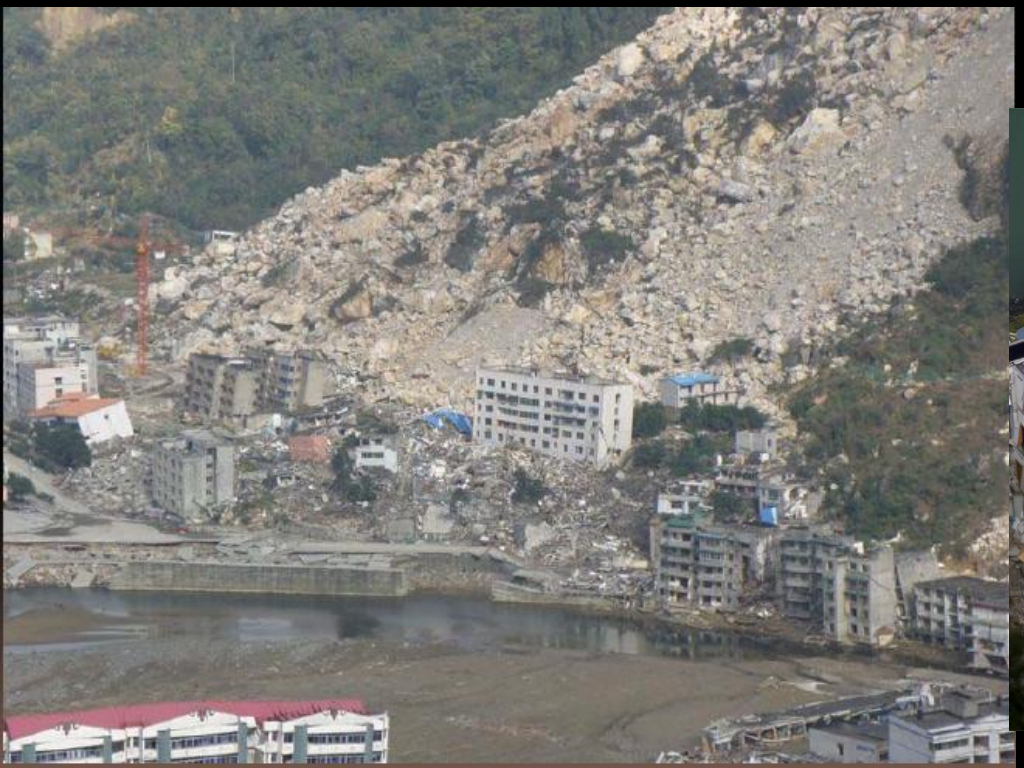
May 23, 2008



February 19, 2003

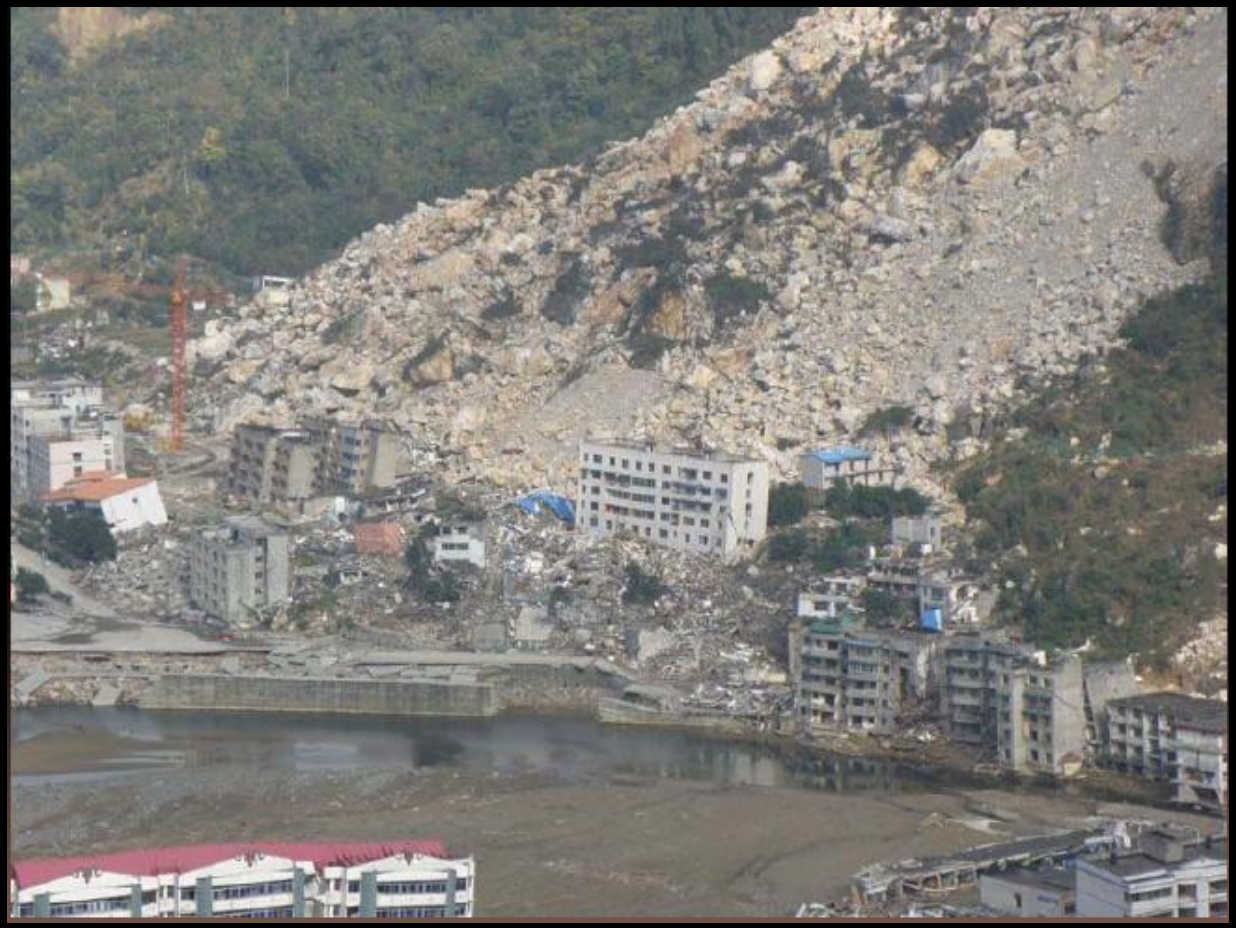
Landslides triggerred by May 2008 Sichuan Earthquake, China

LANDSLIDES IN BEICHUAN, 2008



2008 M8.0 Wenchuan Earthquake Wangjiayan Landslide (4.8 Mm^3 -1,600 fatalities) and Jingjiashan Landslide ; Data and image from Yin et al. 2009 and F. Wang)

FATALITIES IN 2008 WENCHUAN EARTHQUAKE CHINA ~ 69,497



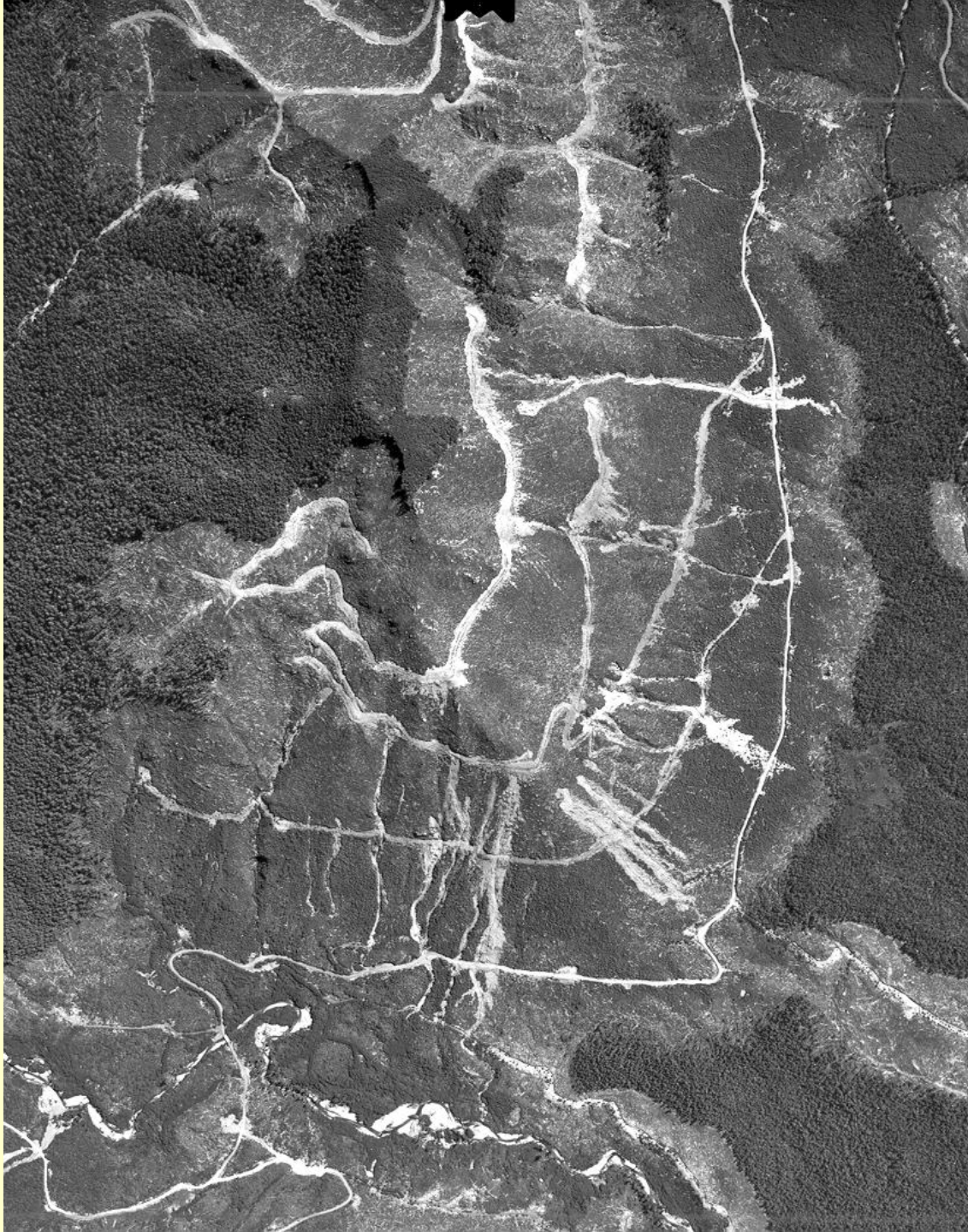
APPROXIMATE FATALITIES IN LANDSLIDES = 20,000 (Yin et al. 2009)

TRIGGER 3 : HUMAN ACTIVITY

1889 Rockslide in Champlain Street, Quebec; 50 people were crushed in houses at the base of the rockslope. V = 53,000 m^3

VEGETATION REMOVAL

- Vegetation will decrease water saturation of the slope material by absorbing water during a rainfall.
- The roots help to stabilize the slope by binding soil particles together and holding the soil to the bedrock.
- Examples of logging in British Columbia



Landslide Classification

- Mass movements are classified on the basis of three major criteria:
  - type of material involved (rock, soil or debris)
  - type of motion (falling, toppling, sliding or flowing)
  - rate of movement (rapid or slow)
- **Rapid mass movements** involve a visible movement of material: potentially very dangerous and may result in loss of life and/or property damage. Generally occur on relatively steep slopes, and can involve rock, soil or debris.
- **Slow mass movements** advance at an imperceptible rate and are usually only detectable by the effects of their movement (tilted trees, cracked foundations).

WHY CLASSIFY LANDSLIDES ?

Monsoon-triggered landslide, Mumbai, India, July 2005

Classification schemes based on morphology, type(s) of movement, materials, and velocity

1. Common and meaningful language of communication for discussion, mapping, and research
2. Mechanism-sensitive for understanding process and developing ideas to mitigate
3. Material-sensitive for understanding spatial distribution
4. Leads into ideas of hazard assessment
5. Further leading to risk assessment for use in risk management

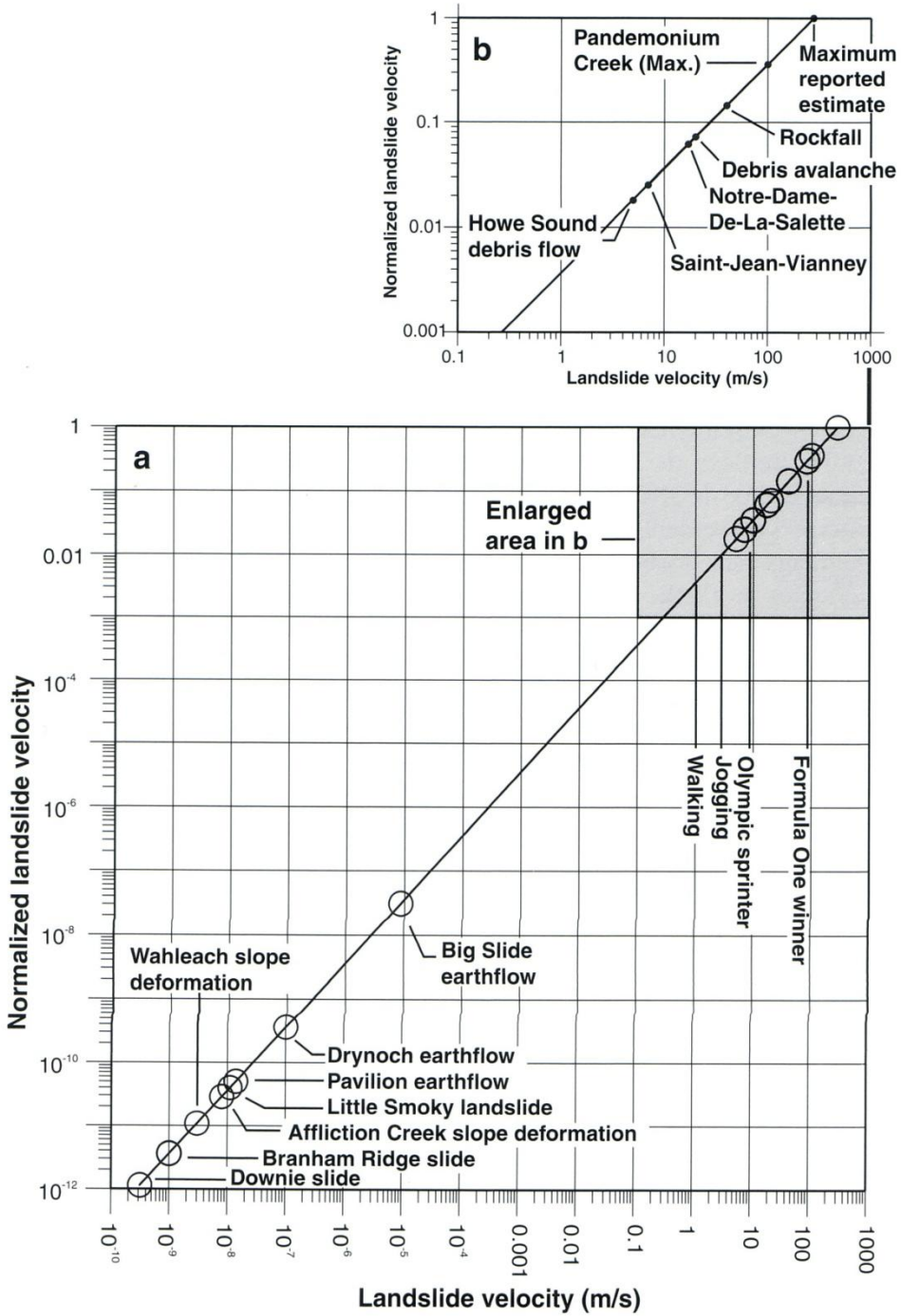
THE CLASSIFICATION SYSTEM SUGGESTED BY VARNES (1978); AN EXAMPLE OF A CURRENT CLASSIFICATION OF LANDSLIDES IN USE

MATERIALS →

TYPE OF MOVEMENT

TYPE OF MOVEMENT	BEDROCK	COARSE SOILS - DEBRIS (>20% OF GRAVEL AND COARSER)	FINE SOILS - EARTH (<20% OF GRAVEL AND COARSER)
FALLS	ROCK FALL	DEBRIS FALL	EARTH FALL
TOPPLES	ROCK TOPPLE	DEBRIS TOPPLE	EARTH TOPPLE
SLIDES TRANSLATIONAL	ROCK BLOCK SLIDE	DEBRIS BLOCK SLIDE	EARTH BLOCK SLIDE
ROTATIONAL	ROCK SLIDE	DEBRIS SLIDE	EARTH SLIDE
LATERAL SPREADS	ROCK SPREAD	DEBRIS SPREAD	EARTH SPREAD
FLOWS	ROCK FLOW (DEEP CREEP)	DEBRIS FLOW	EARTH FLOW (SOIL CREEP

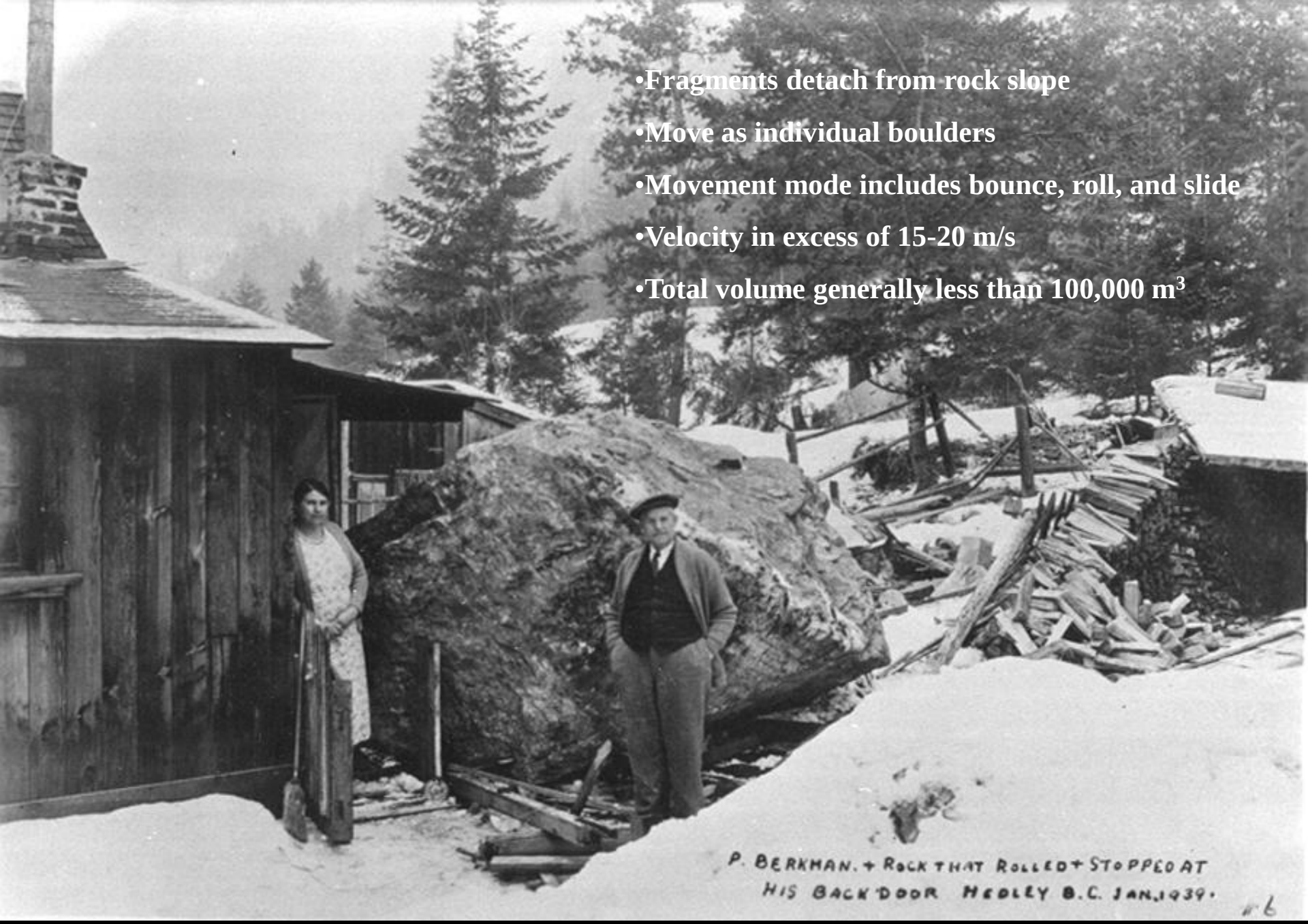
A COMPLEX LANDSLIDE IS ONE WHICH HAS COMBINATION OF TWO OR MORE TYPES OF MOVEMENT (e.g., SLUMP-EARTHFLOW, ROCK AVALANCHE); WITHIN EACH CLASS, LANDSLIDE TYPE DIFFERENTIATED WITH RESPECT TO VELOCITY (EXTREMELY SLOW TO EXTREMELY RAPID)



LANDSLIDE VELOCITY

Catastrophic landslides faster than 5 m/s

Type of Motion – Fall



- Fragments detach from rock slope
- Move as individual boulders
- Movement mode includes bounce, roll, and slide
- Velocity in excess of 15-20 m/s
- Total volume generally less than 100,000 m^3

1939 ROCKFALL, HEDLEY, B.C.

1983 SUNNYBRAE ROCKFALL

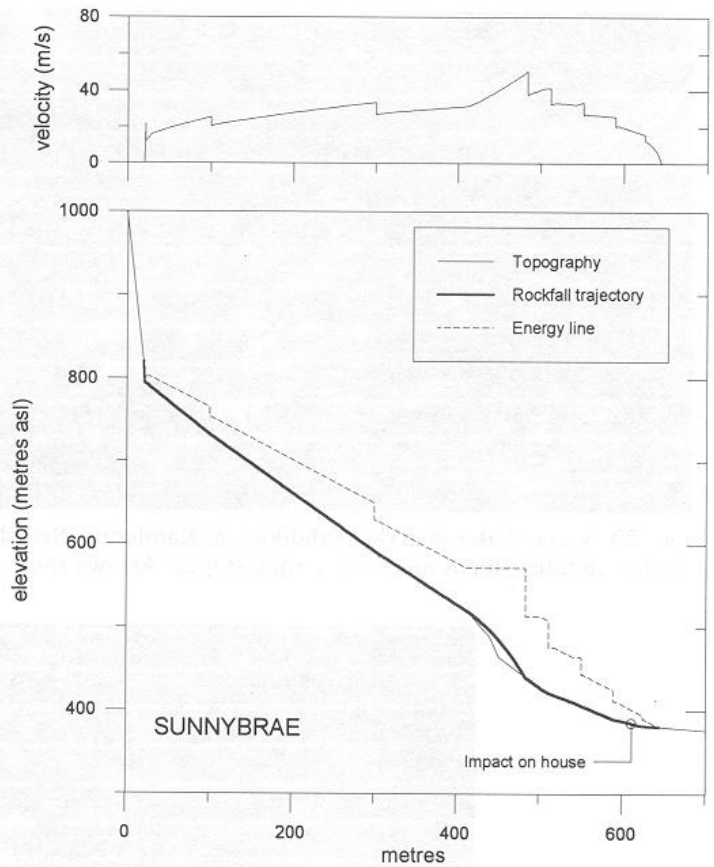
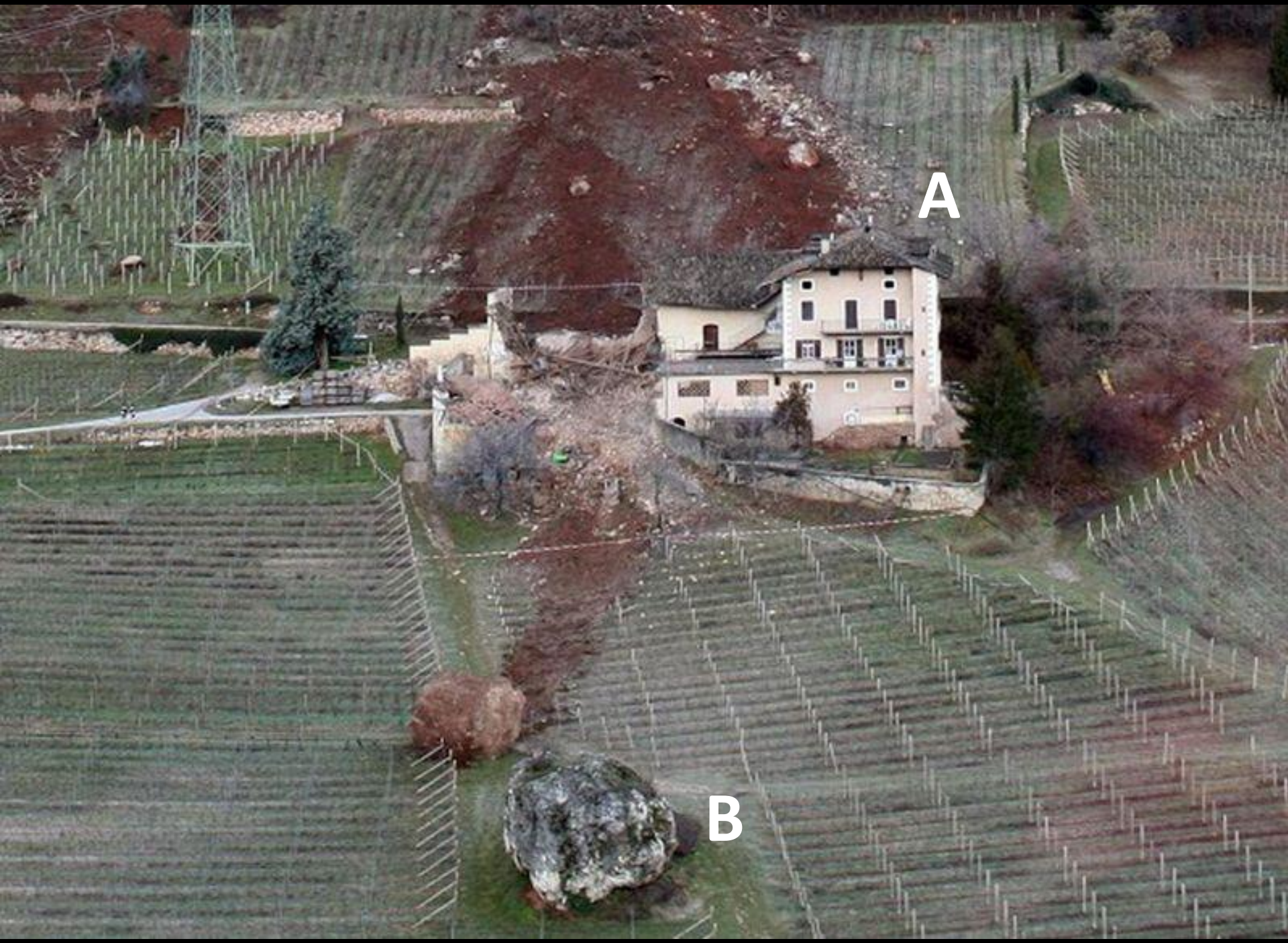


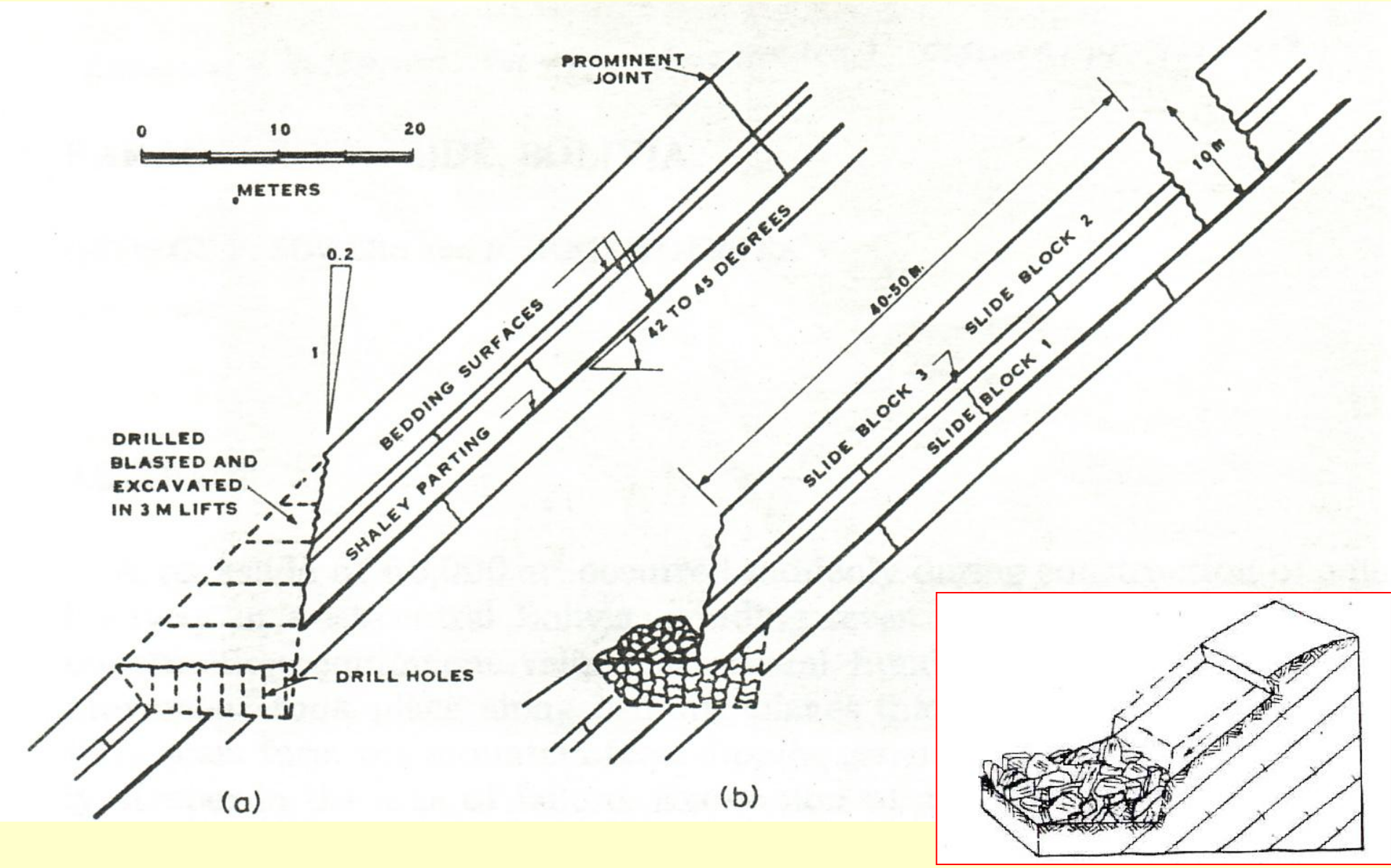
FIG. 19. Simulation of the Sunnybrae rockfall path using the ROCKFALL computer program, with k_n (normal restitution coefficient) = 0.70, k_t (tangential restitution coefficient) = 0.80, and rolling friction coefficient = 0.52. Note position of actual stopping point of boulder.

ROCKFALL CLOSES I-70 IN GLENWOOD CANYON, COLORADO [MARCH 8, 2010]

ROCKFALL IN NORTHERN ITALY
(January 2014)


A
B

Type of Motion 2: Translational Sliding

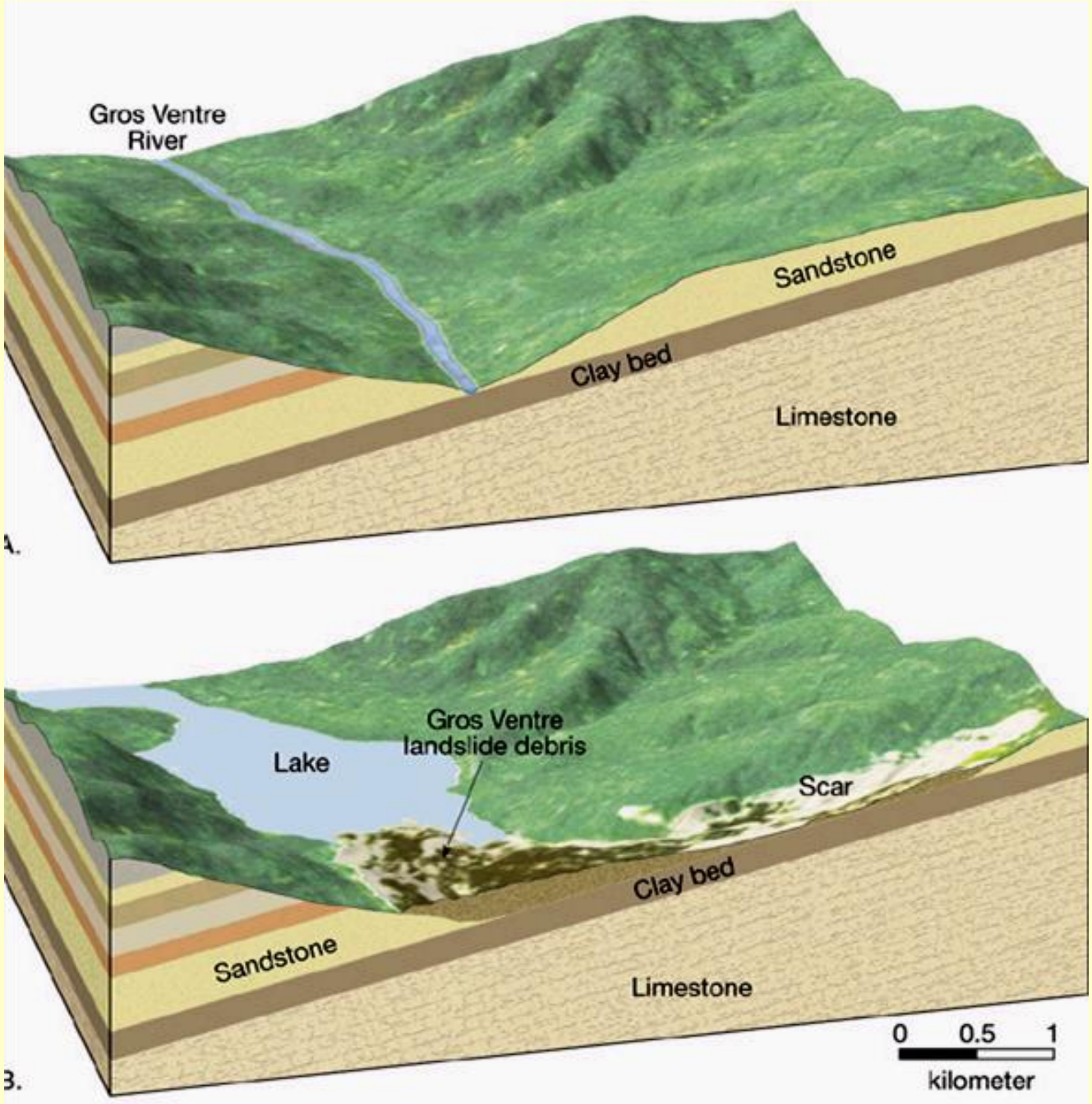


Rockslide

Rock slides occur when material moves downslope along a generally planar surface.

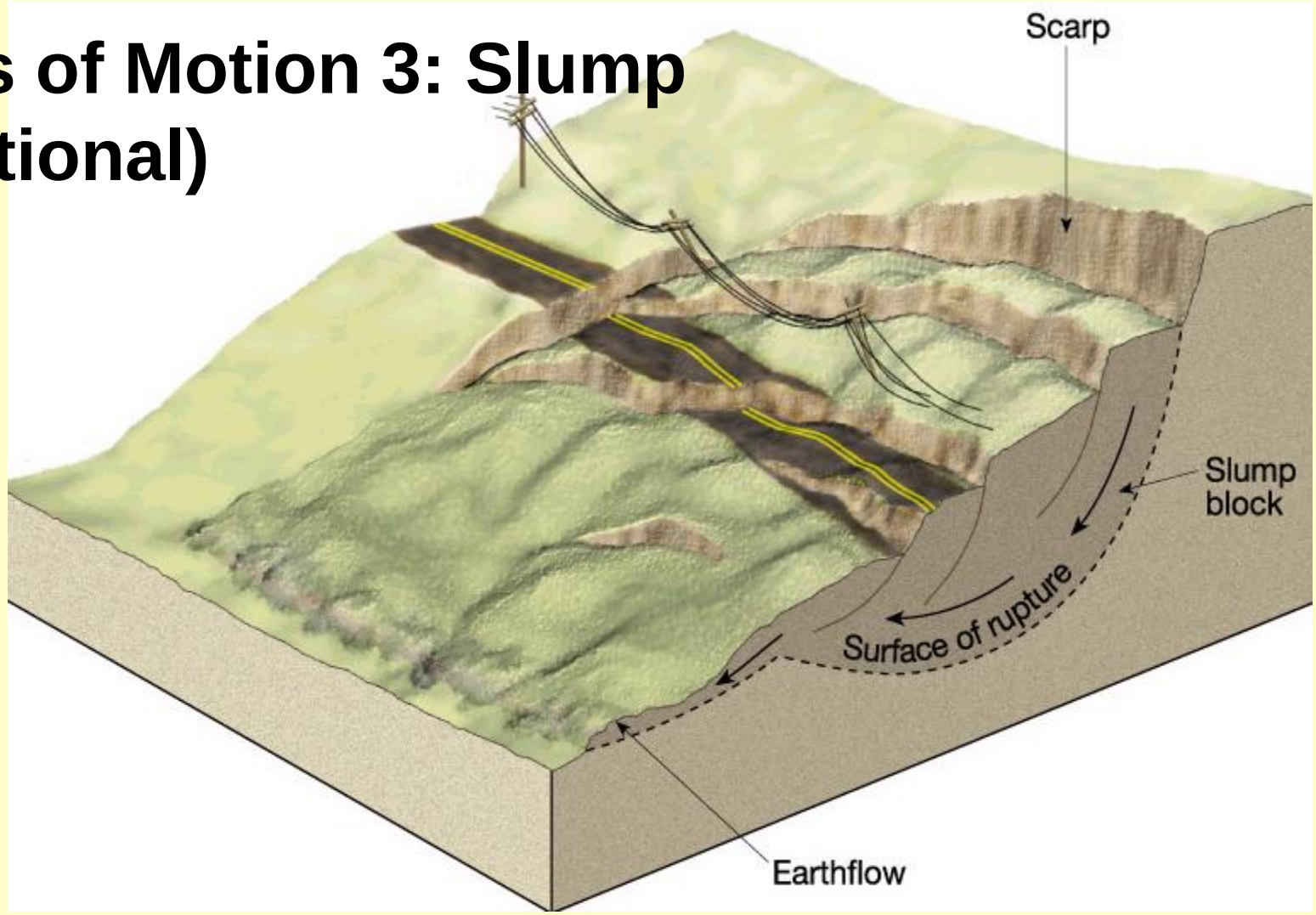
Gros Ventre Rock Slide, Wyoming, 1925

40 Mm^3 of rock failed along dipping bedding plane in claystone after heavy rain and years of river erosion of toe



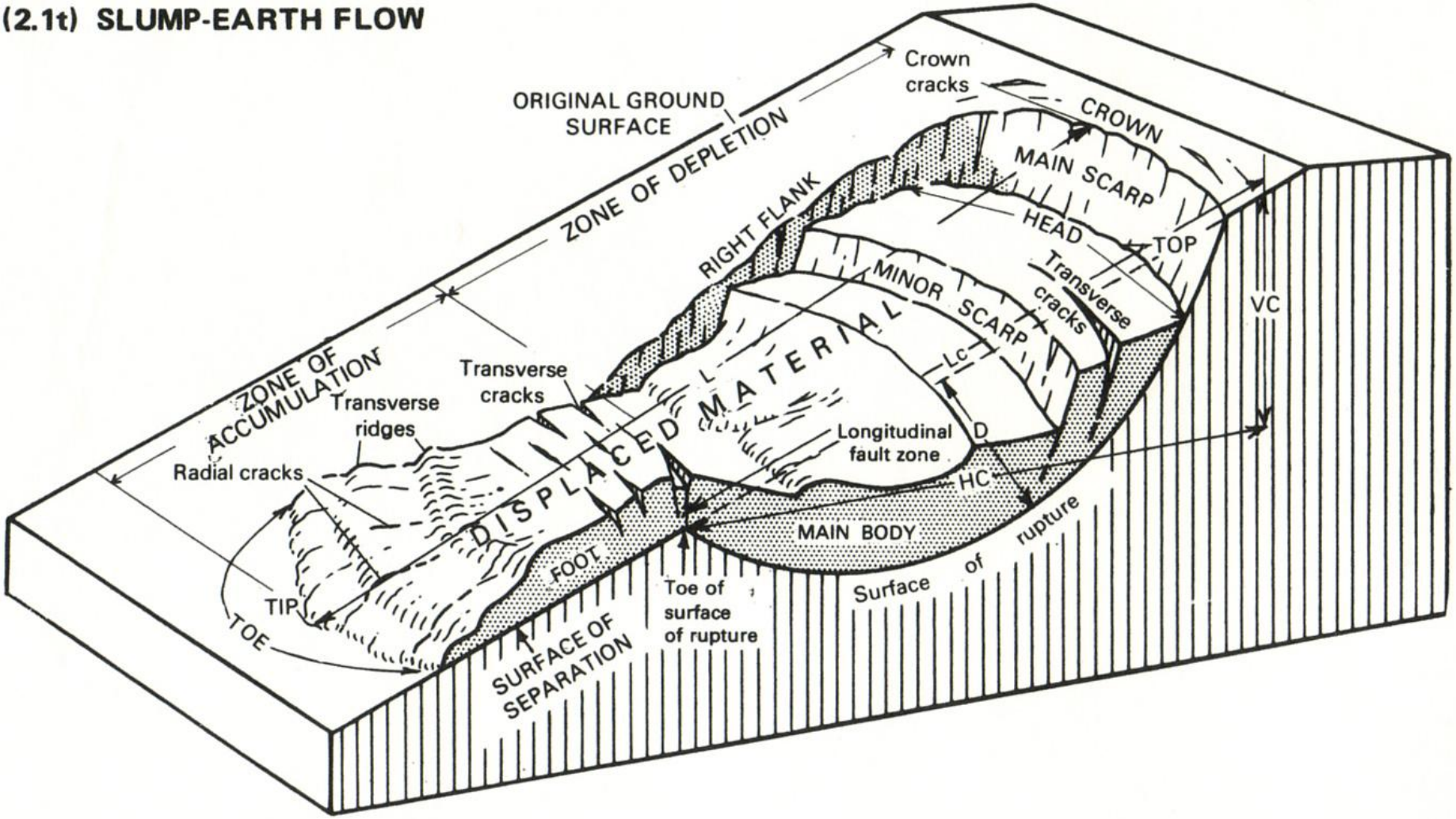
Many rockslides occur in massive limestones in the mountains of western Canada; sliding takes place on bedding planes that separate the strata.

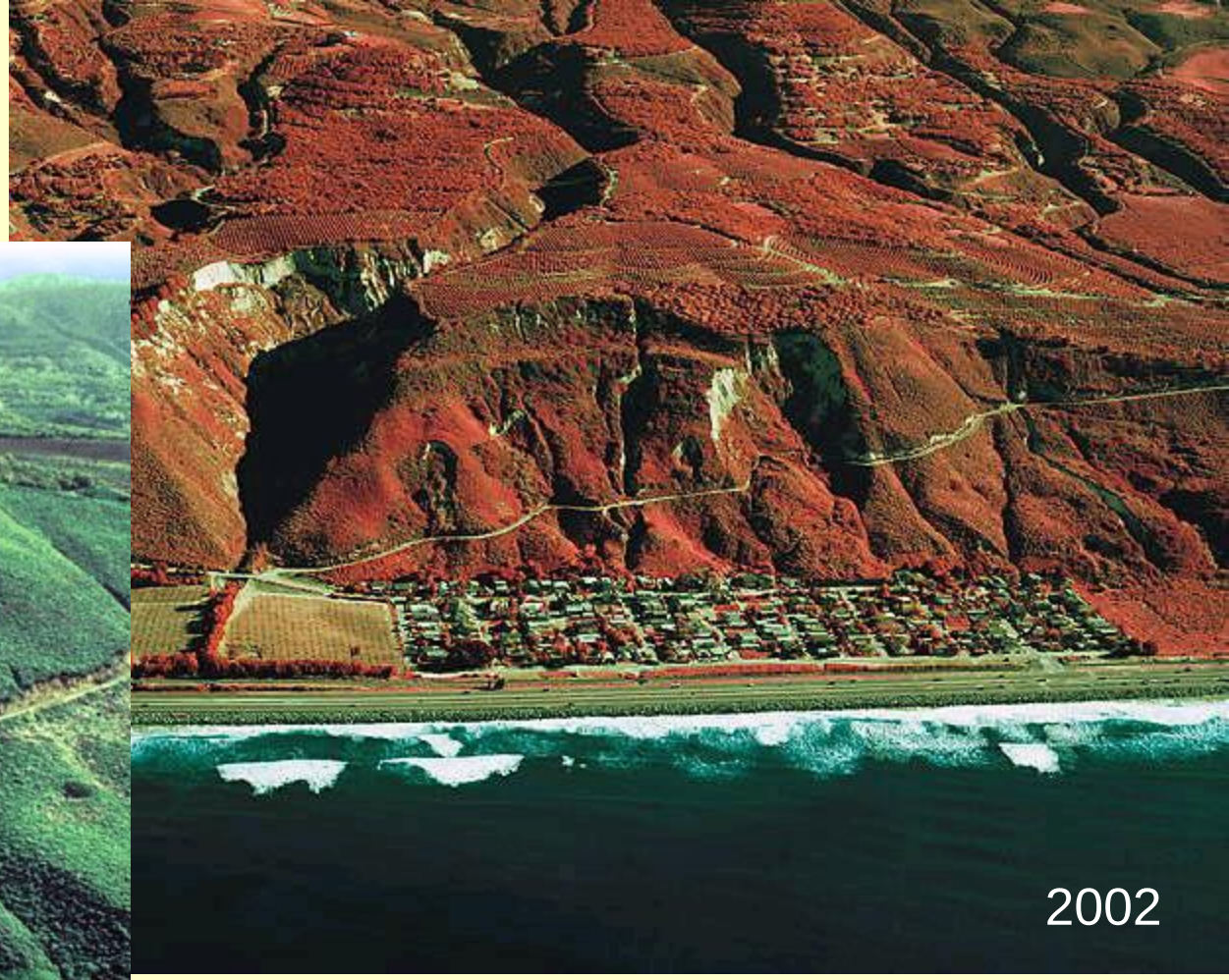
Types of Motion 3: Slump (Rotational)



Material moves as a block downward along a curved surface of a rupture, causing the slump block to rotate backward. Most slumps involve unconsolidated or weakly consolidated material and are typically caused by erosion along the slope's base.

(2.1t) SLUMP-EARTH FLOW





1995 LA CONCHITA LANDSLIDE, CALIFORNIA; A SLUMP-EARTHFLOW

2005 LA CONCHITA LANDSLIDE – DEBRIS FLOW REMOBILISATION OF 1995 DEBRIS (10 FATALITIES

USGS Photo by Mark Reid

Landslide in Laguna: There Goes the Neighborhood

Cubist speed sculpture by nature in Laguna Beach

2005 Laguna Beach landslide, California (occurred adjacent to 1978 movement); 2005 landslide destroyed 19 homes- 1978 landslide destroyed 60 homes (10 m/hr)

WHIDBEY ISLAND LANDSLIDE, WASHINGTON STATE, MARCH 27, 2013

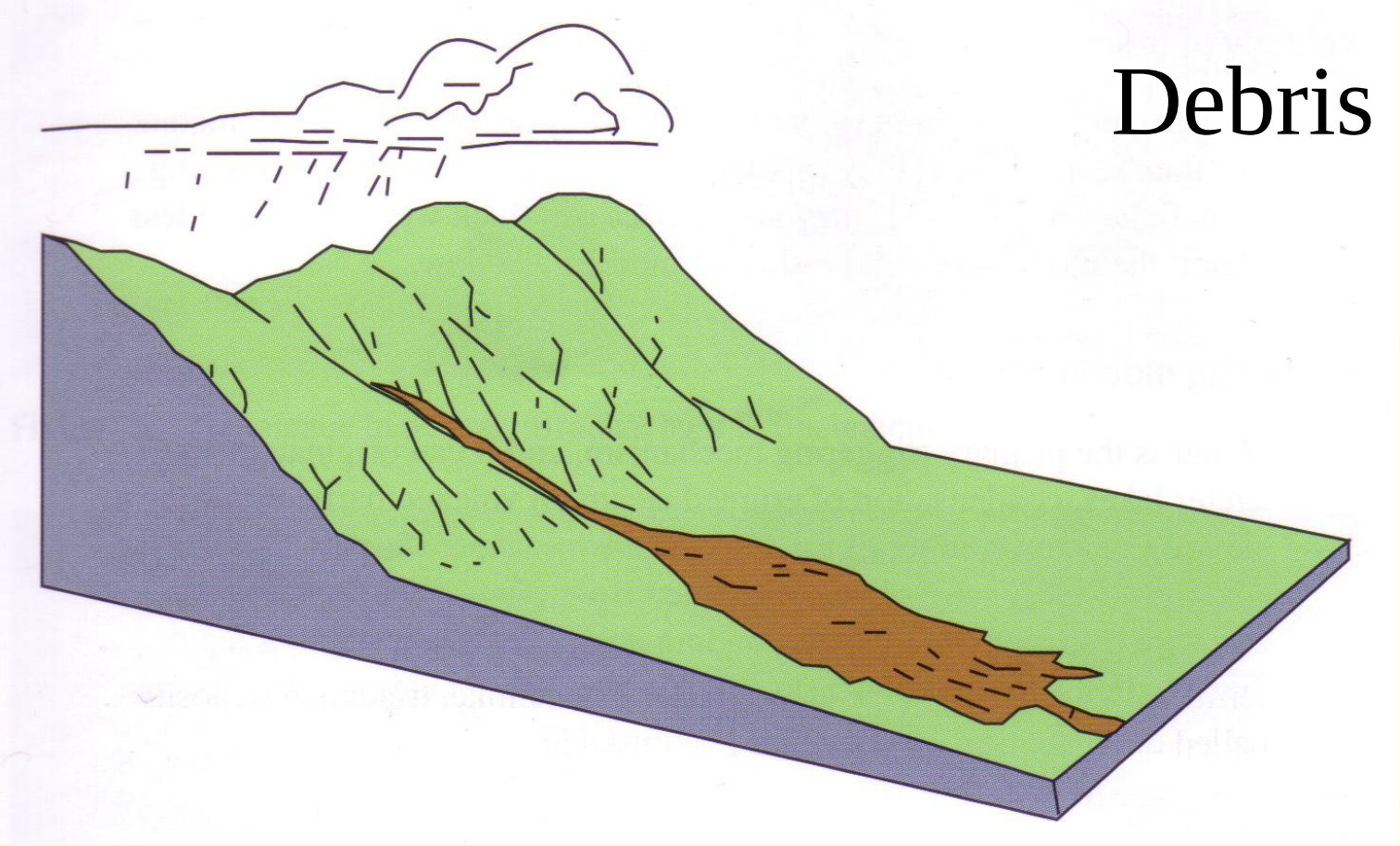
The Ledgewood–Bonair Landslide (LB Landslide) on Whidbey Island, Island County, Washington occurred around 3:45 am on March 27, 2013, and is a small portion of a much larger landslide complex (Fig. 1). The larger landslide, which is approximately 1.5 miles long, is prehistoric and may date back as much as 11,000 years. The LB Landslide is likely a reactivation of a small portion of the prehistoric complex. The dimensions of the landslide are approximately 1100 feet long (measured parallel to the shoreline) and about 300 feet into Puget Sound. Initial estimations place the volume of material mobilized as great as 200,000 cubic yards (~40,000 dump truck loads).

DNR geologist Michael Polenz identified the affected slope as a prehistoric landslide in 2005, and that finding was later published as part of a geologic map of the Camano quadrangle (Polenz and others, 2009, (http://www.dnr.wa.gov/Publications/ger_gm68_geol_map_camano_24k.pdf). Polenz's field notes from 2005 identify a large landslide complex from the top of the slope, about 200 ft above sea level, to the shore and include references to the work of Jerry Thorsen, an earlier DNR geologist, who noted episodic slide activity that affected at

Type of Motion 4: Flows

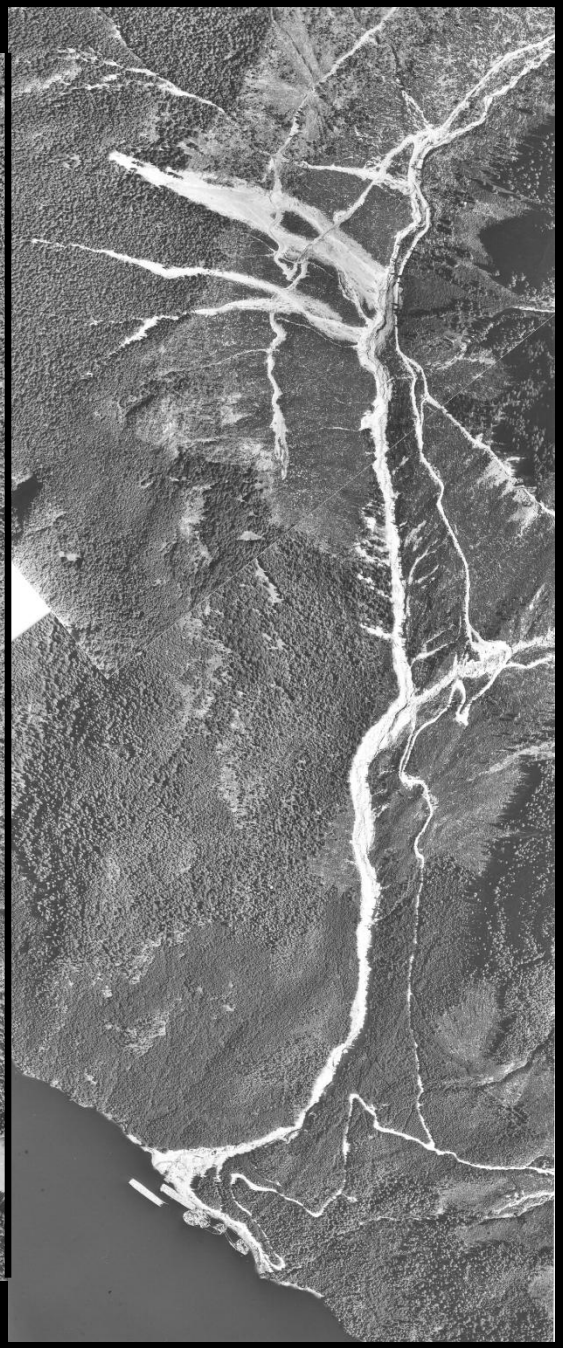
- Mass movements in which material flows as a viscous fluid
- Most flows are saturated with water and typically move as lobes or tongues
- Rate of movement of flow can be extremely slow to extremely fast
- Flows often result from the transformation of initial sliding failure (or falls)

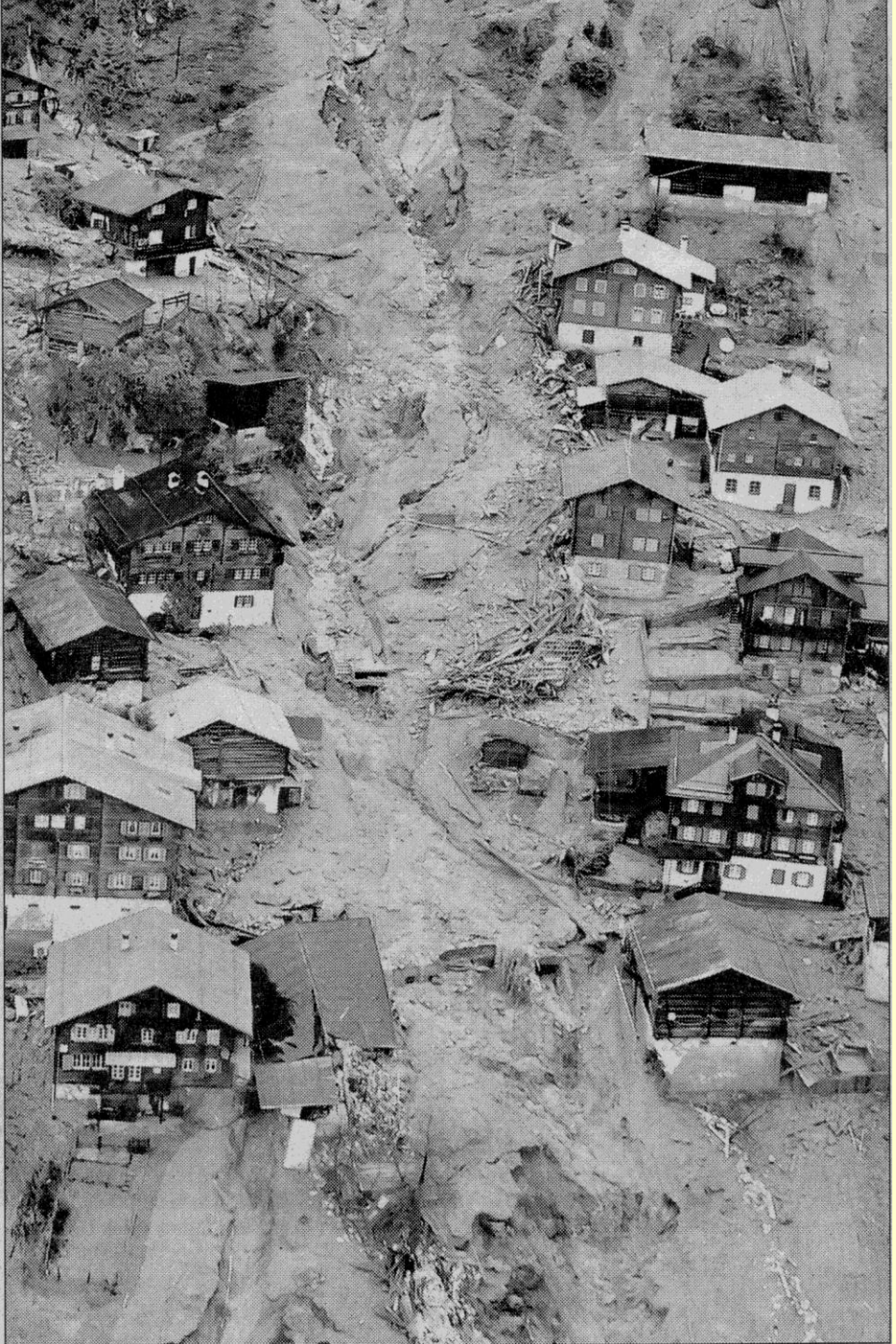
Debris Flow

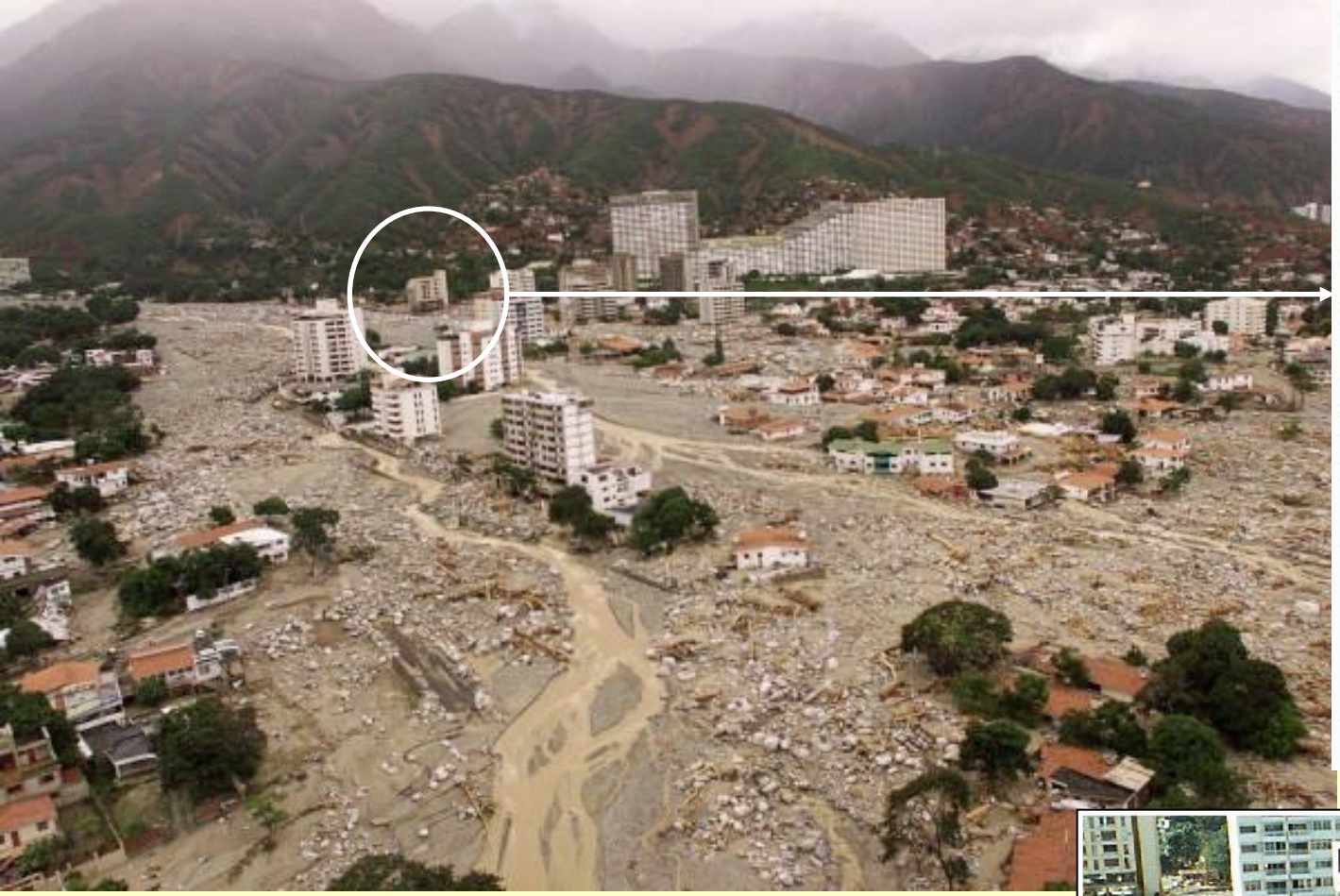


- Debris flows or Mudflows may move at speeds of up to 80 km/hr
- Mudflows are common in arid and semiarid environments, where they are triggered by heavy rainstorms that quickly saturate the soil.
- Because mudflows are so fluid, they generally follow existing channels and fan out when the slope angle decreases.
- Lahar: Volcanic Debris flows

DEBRIS FLOWS IN BRITISH COLUMBIA







Flash flood debris passed through the 3rd story of this apartment building in Los Corales sector of Caraballeda. The flood occurred at night and sleeping residents were dumped into the torrent as the left side of the building collapsed.

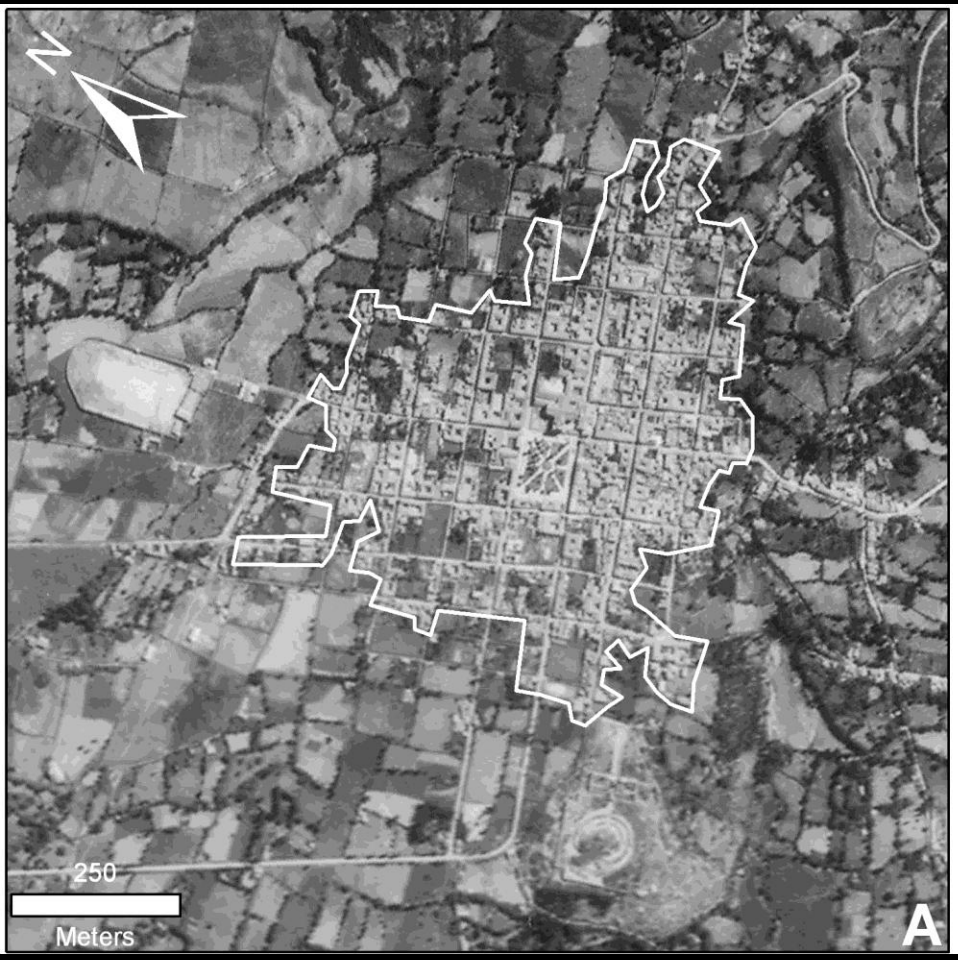
DEBRIS FLOW DAMAGE TO BUILDINGS ON CARABALLEDA FAN, VENEZUELA (DECEMBER 1999); TOTAL DEPOSITION ON THE FAN WAS 2.64 M m^3 (YIELD ~ 122,618 m^3/km^2 FROM QUEBRADA SAN JULIAN)

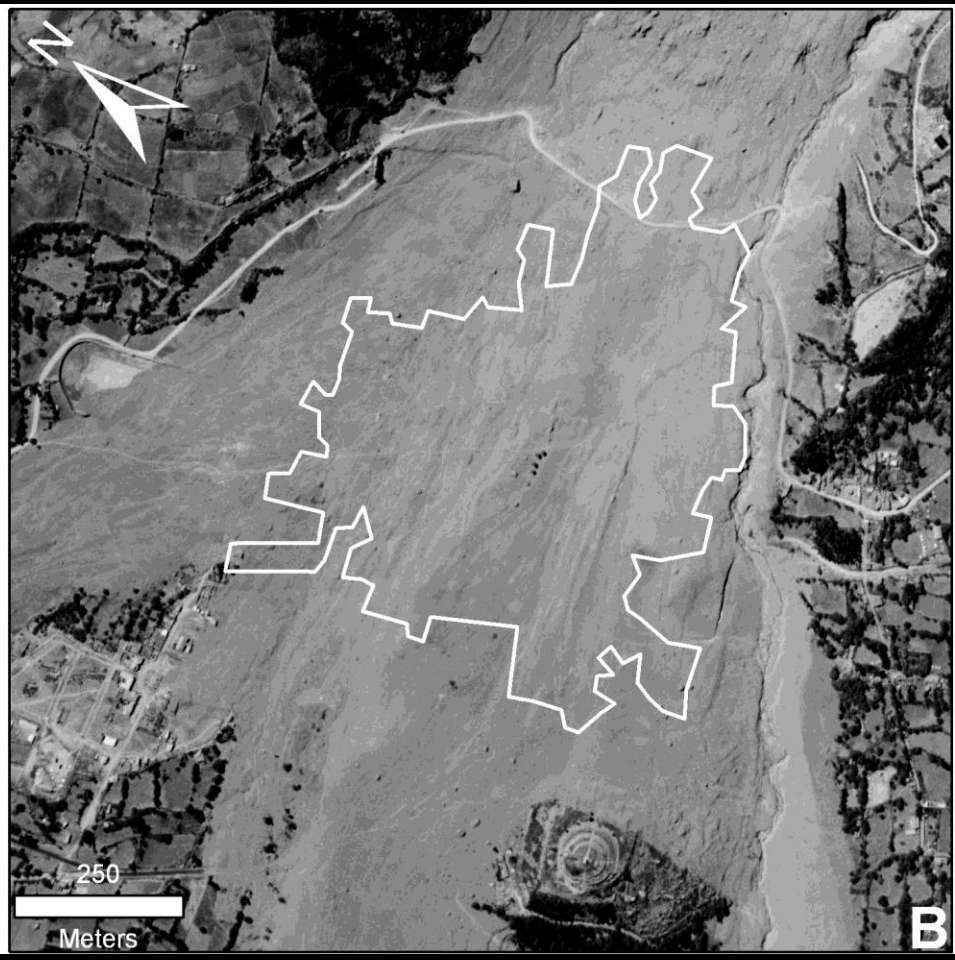
Aerial view of Los Corales sector of Caraballeda showing damage to apartment building.

Debris avalanche in Hong Kong

Landslide triggered by heavy rains in Bududa District , Uganda – March 3, 2010 (>300 deaths)

EARTHQUAKE=TRIGGERED DEBRIS AVALANCHES, SICHUAN, 2008


N
250
Meters
A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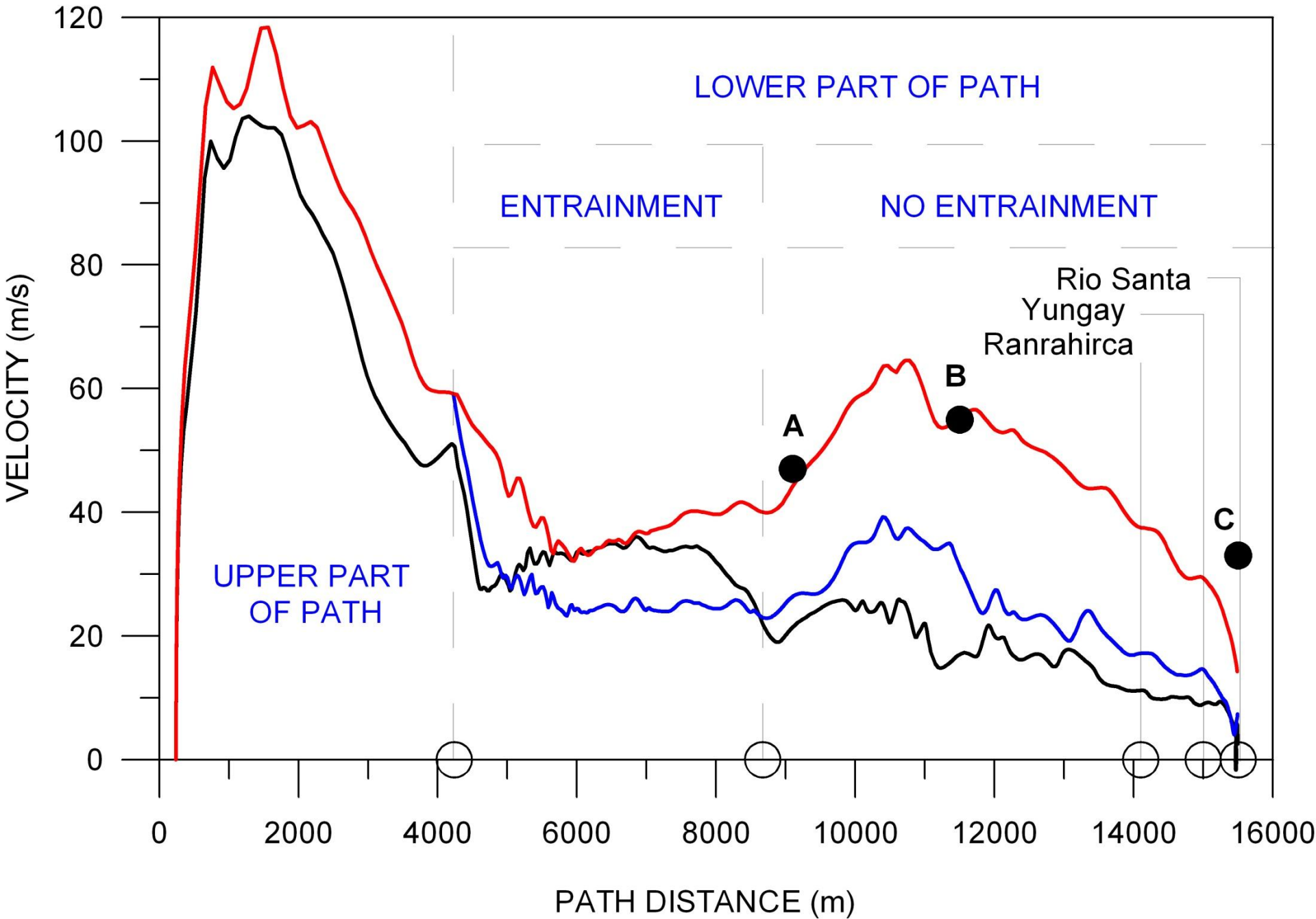
SIMULATION OF 1962 AND 1970 HUASCARAN EVENTS



2002 KOLKA GLACIER DEBRIS FLOW– SOUTHERN RUSSIA

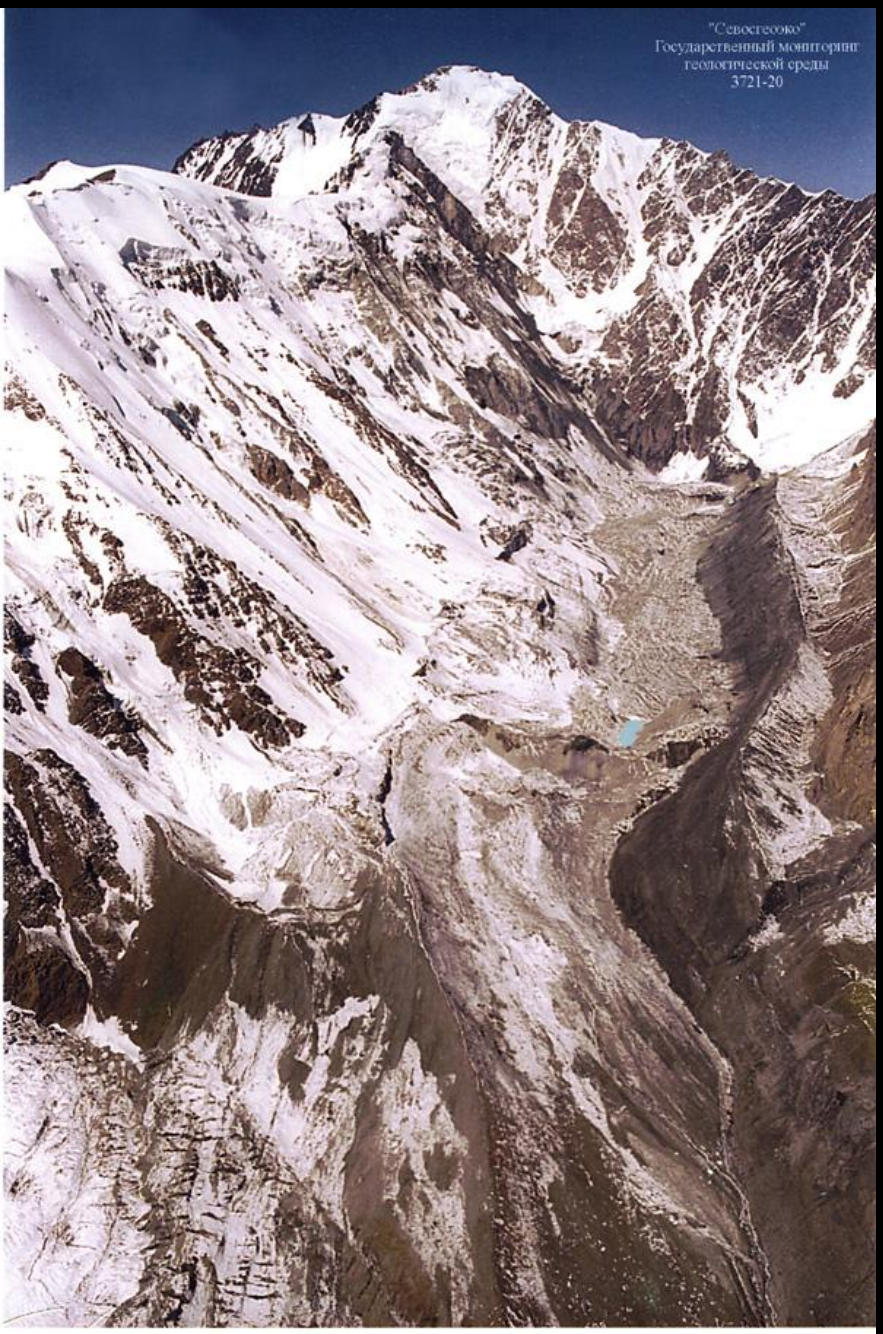


Рис. Г. Джимарай-хох, стенка обвала и верхняя часть ледника Колка. 26.06.03 г.

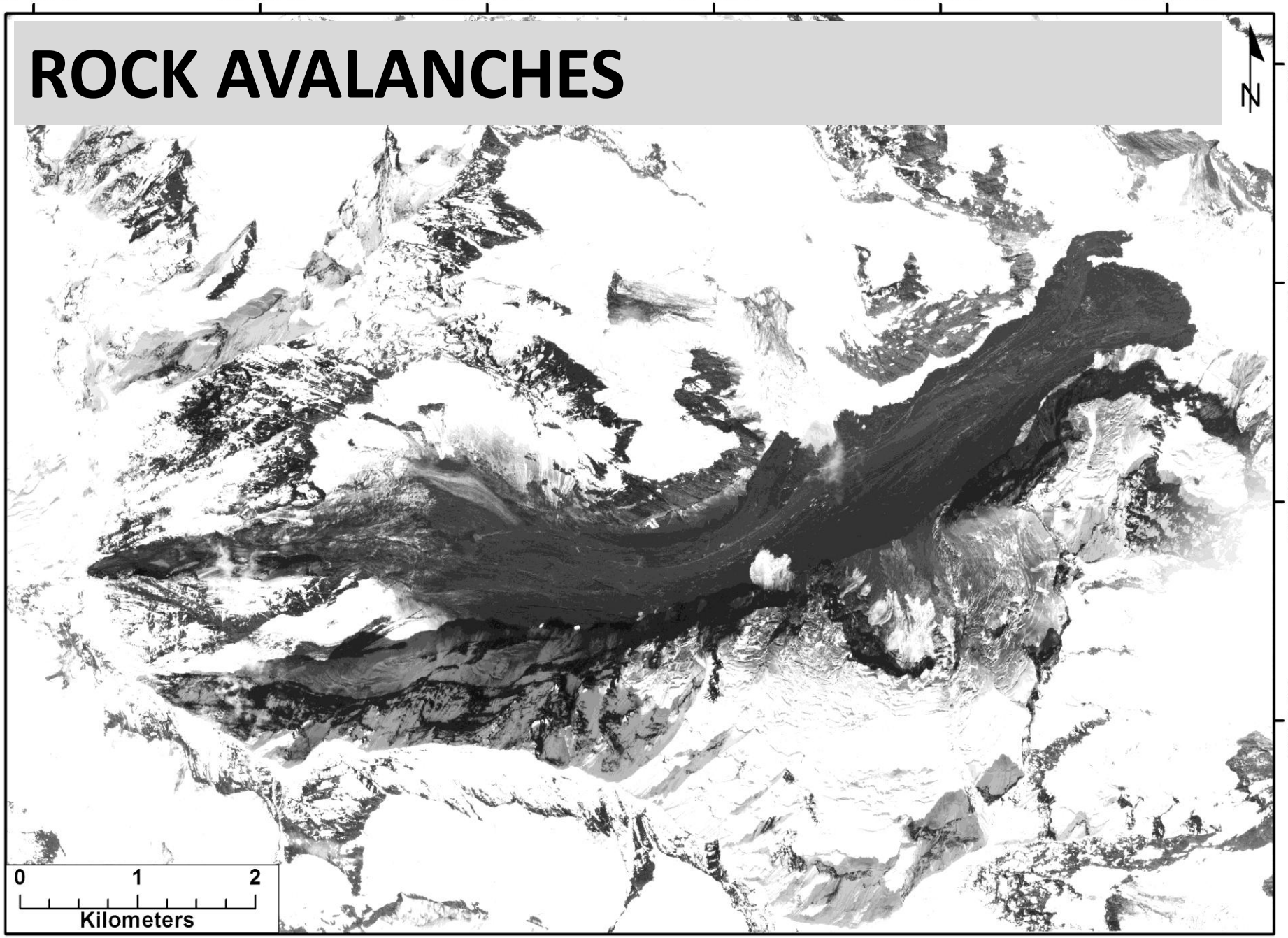
- Total Volume ca. 150 M m^3
- Total travel distance in excess of 17 km
- Mean Velocity about 50 m/s

WIDTH ~ 450 m

DEPTH ~ 275 m

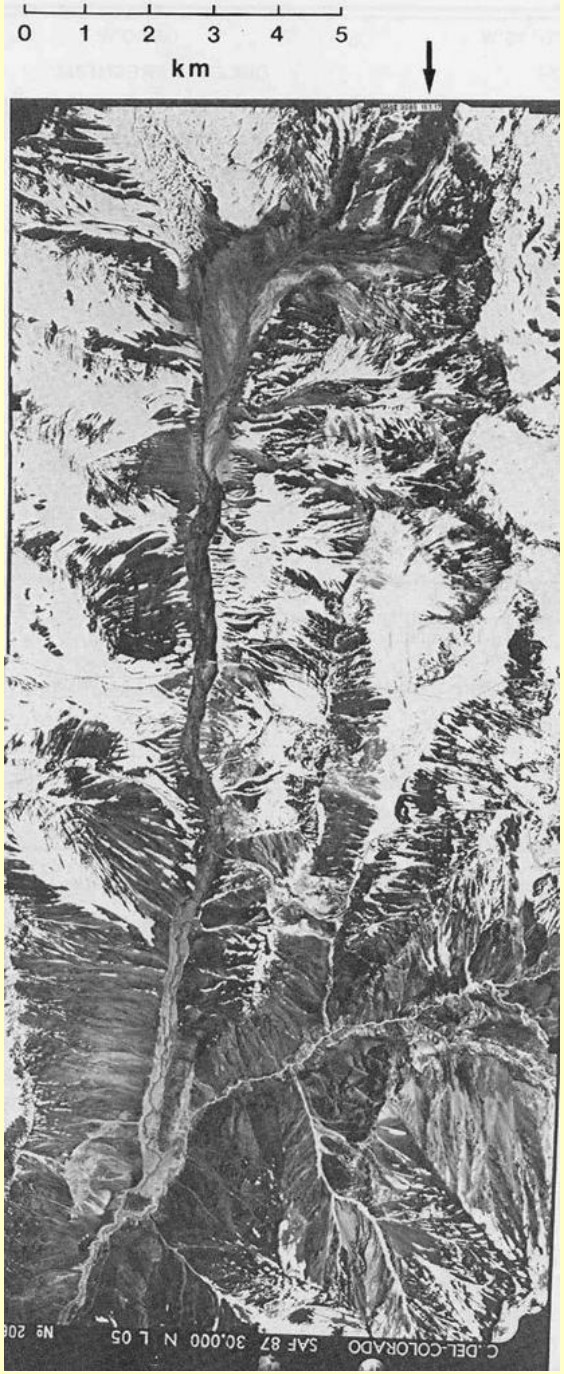
SUPERELEVATION ~ 75 m

ROCK AVALANCHES

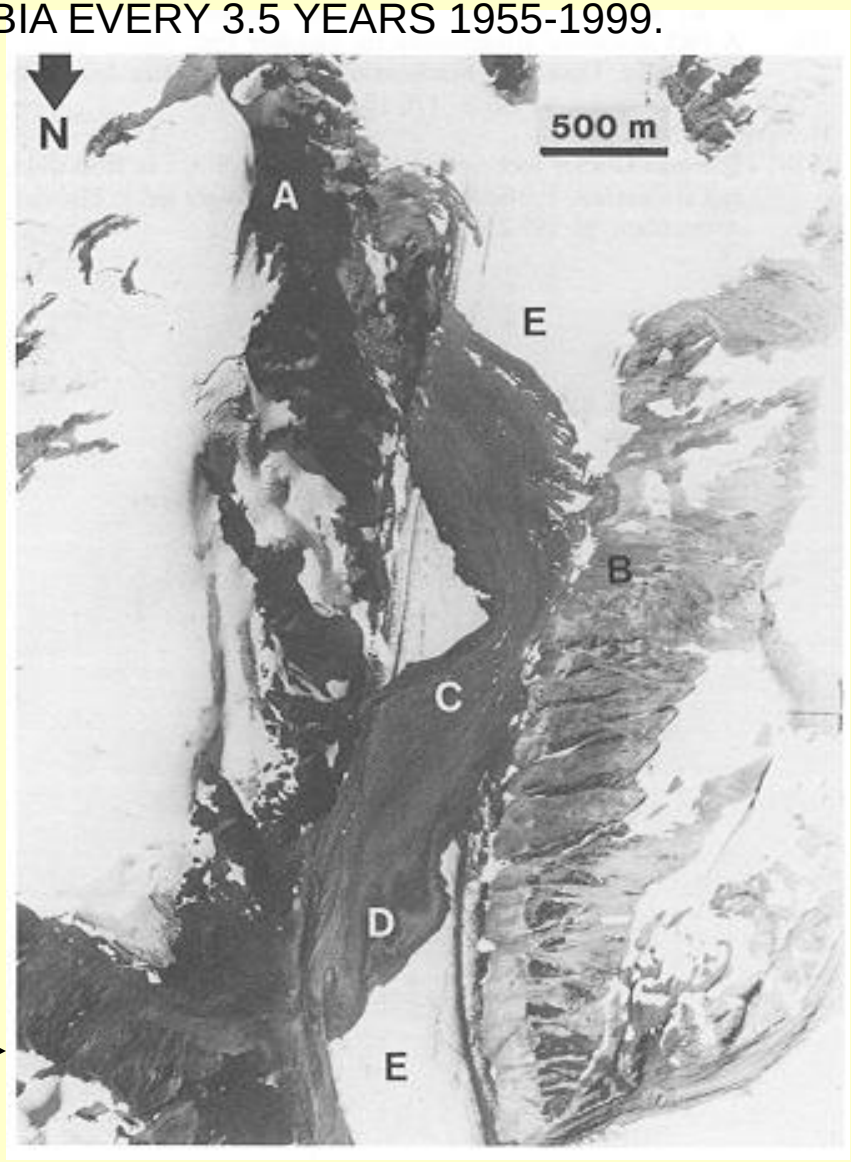


1987 Parraguirre rock avalanche-debris flow, Chilean Andes

1959 Pandemonium Creek rock avalanche, Coast Mountains, B.C.



ROCK AVALANCHES, WITH VOLUMES IN EXCESS OF 1 M m^3, HAVE OCCURRED IN THE COAST MOUNTAINS OF BRITISH COLUMBIA EVERY 3.5 YEARS 1955-1999.



1956 Tim Williams Glacier rock avalanche (3 M m^3)

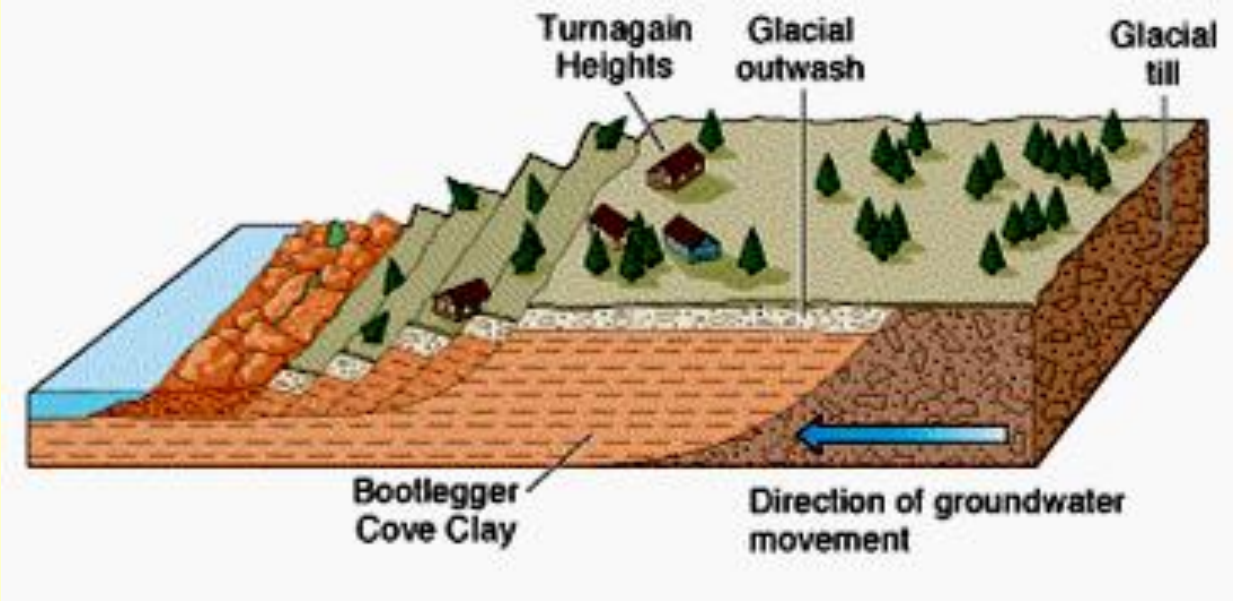
1997 Mount Munday rock avalanche (3.2 M m^3)

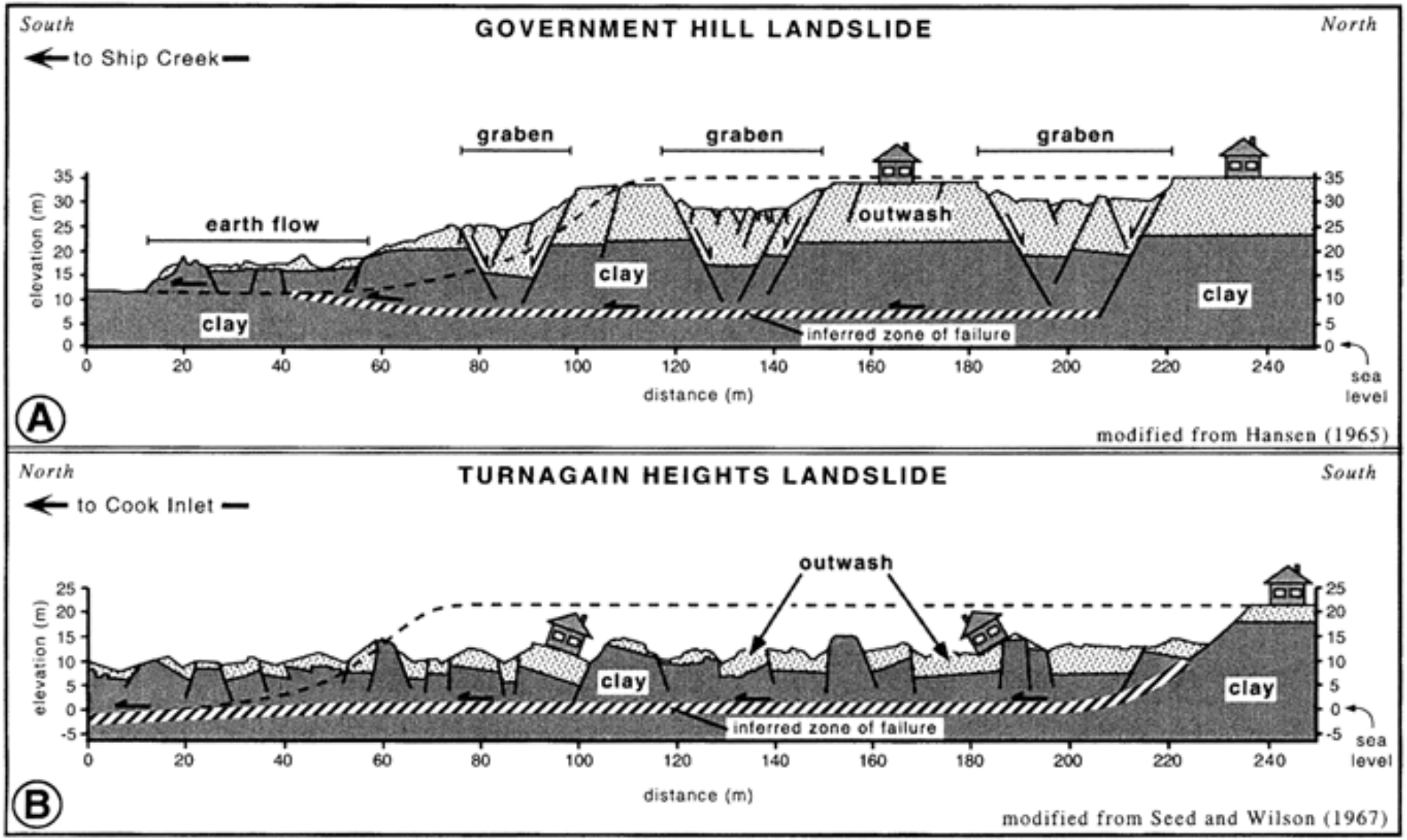
January 2010 Hunza River rock avalanche , Pakistan

VERY RAPID EARTHFLOWS IN QUICK CLAY

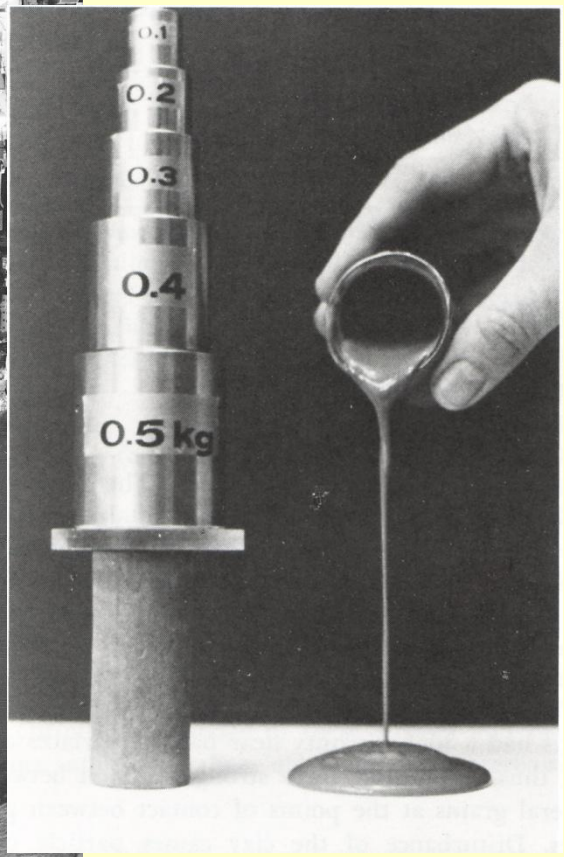
Removal of salt from marine clays reduces bonds between clay particles creating an unstable “house of cards” structure

Groundshaking by the 1964 Alaska earthquake turned parts of the Bootlegger Cove Clay into a quick clay, causing numerous slides. Numerous landslide fissures developed and extensive damage was inflicted on buildings in the area.





CROSS-SECTIONS OF LANDSLIDES AT ANCHORAGE TRIGGERED BY 1964 ALASKA EARTHQUAKE

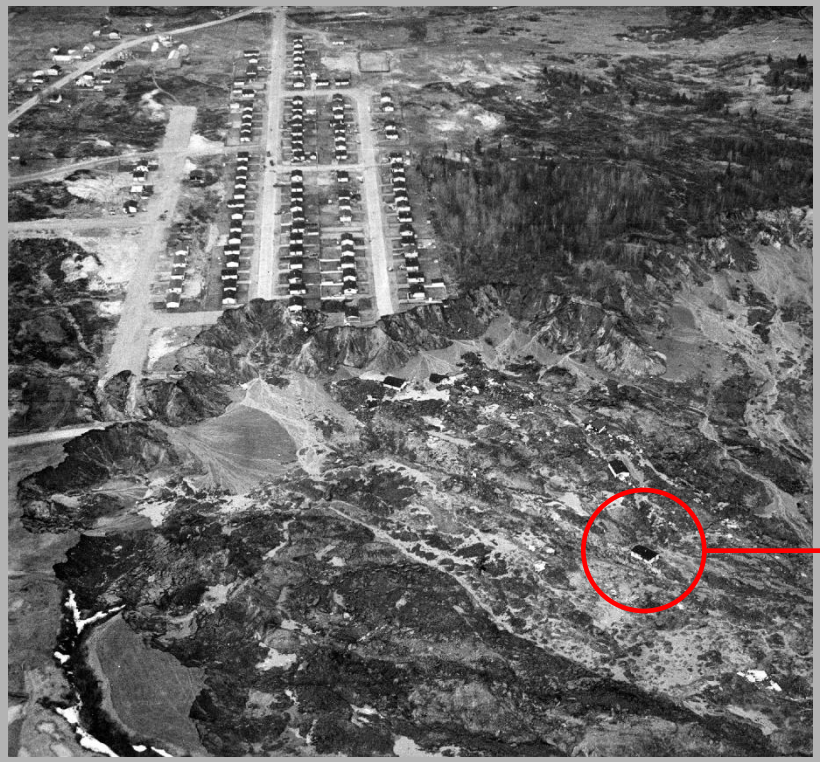


1955 landslide in quick clay, Nicolet, Quebec

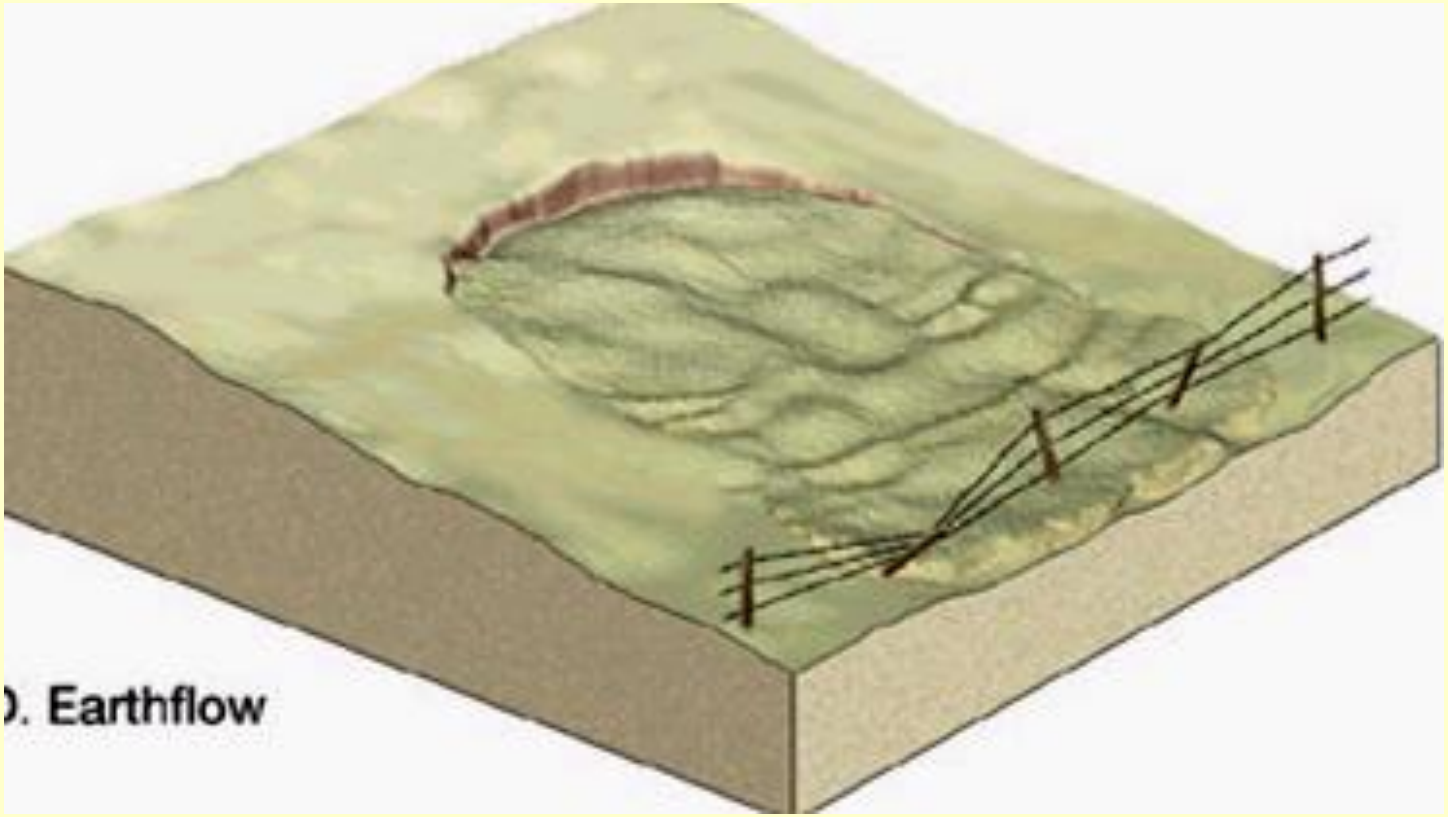
1993 LEMIEUX LANDSLIDE, SOUTH NATION RIVER

1894 St. Alban landslide

1971 St-Jean-Vianney



SLOW EARTHFLOW



Often form on hillsides in humid areas during heavy precipitation or snow melt.

Materials are rich in clay and silt.

Generally move slower than more fluid debris or mud flows

Slumgullion earthflow, Colorado, USA ; slow mass movement

1983 THISTLE LANDSLIDE, UTAH – A VERY EXPENSIVE SLOW EARTHFLOW

Thistle landslide after mitigation attempts

Present day situation at Thistle Landslide, Utah

Motochi earthflow

Japan, 1994

Triggered by rainfall

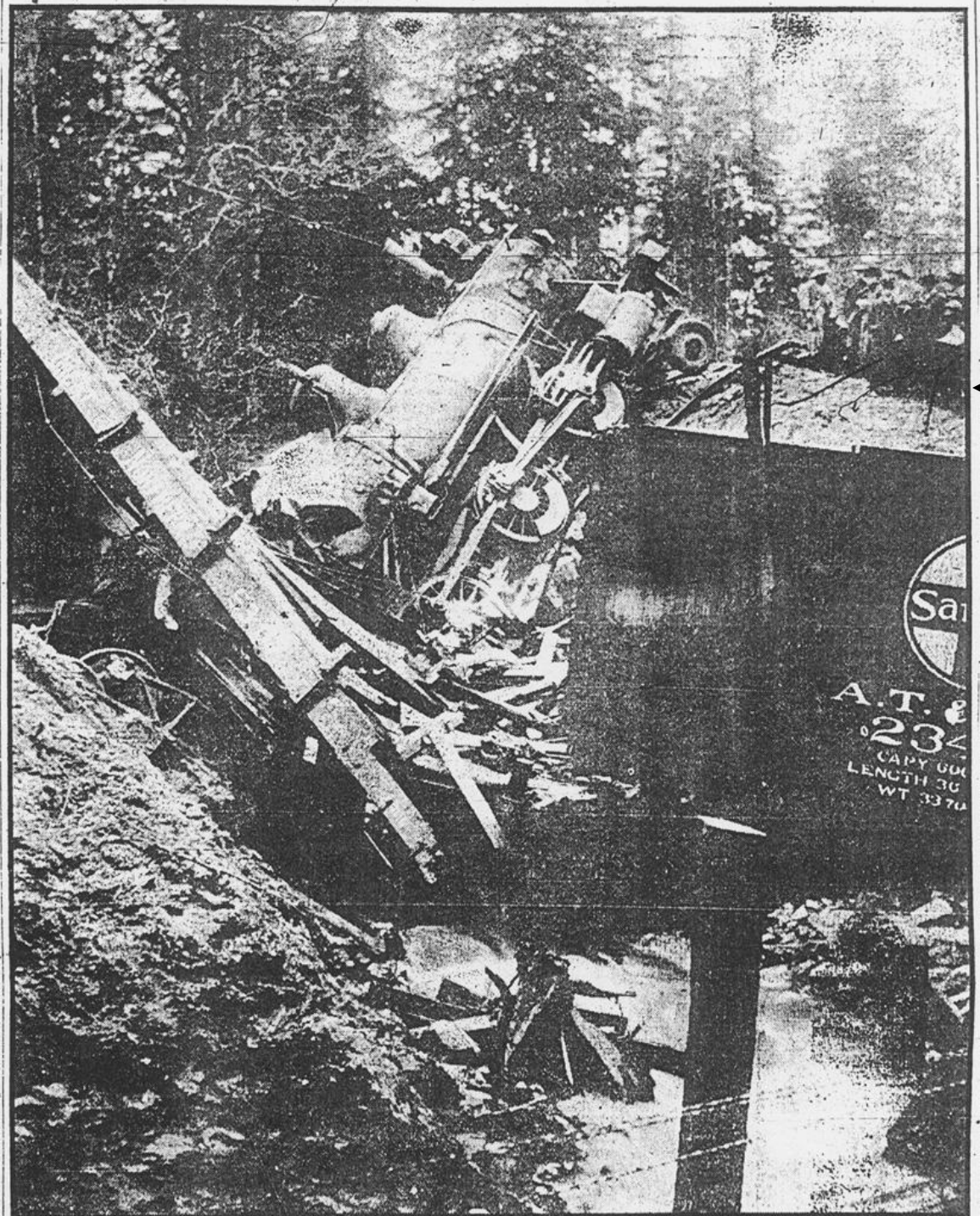
Mitigation

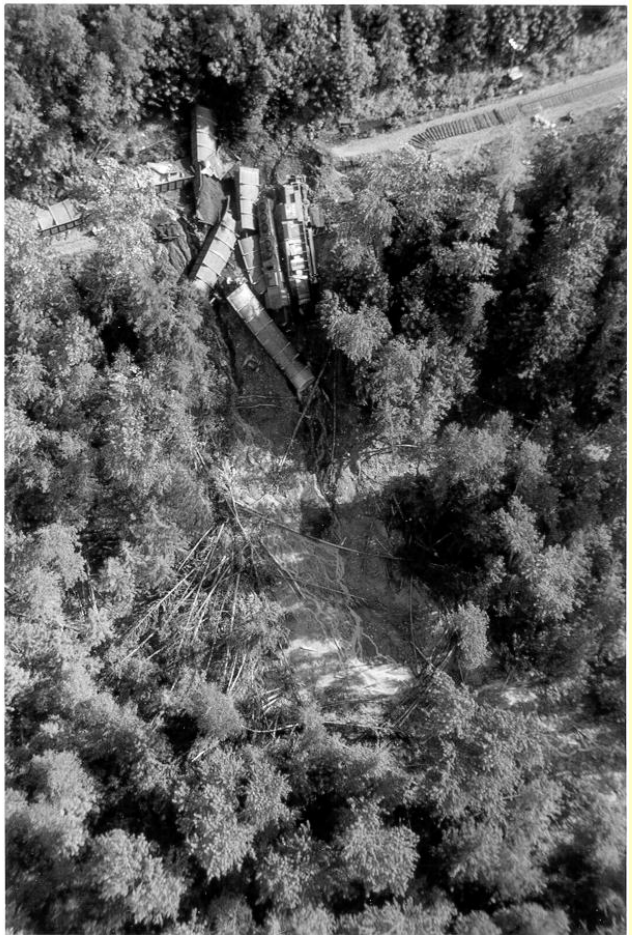
- Groundwater drainage works
- Surface drainage works
- Surface soil removal

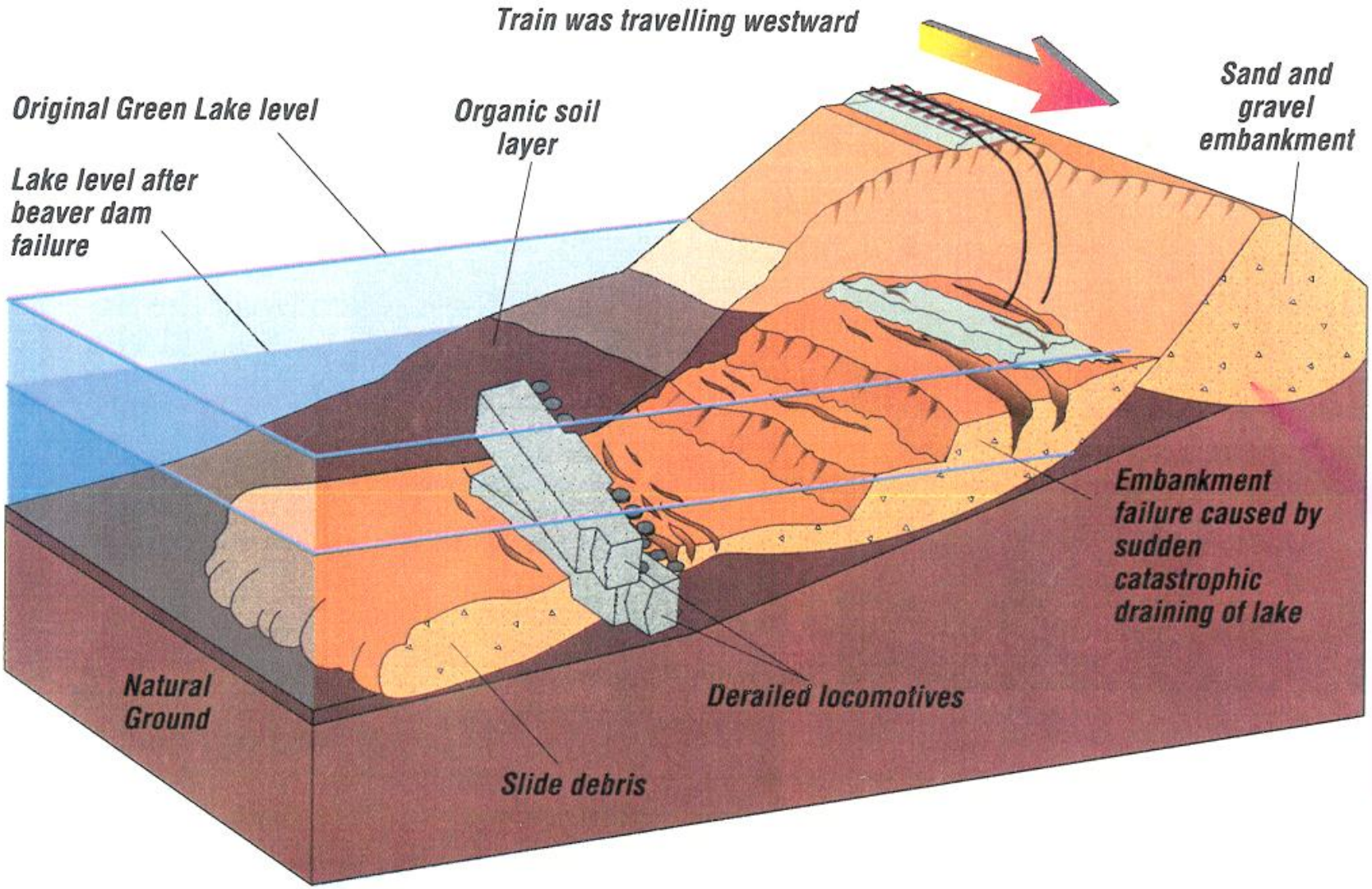
1966 ABERFAN COAL TIP DISASTER, WALES, UK

LANDSLIDES IN BUILT SLOPES

1909 embankment failure, Kilby Creek, Burnaby, B.C. – 22 deaths





Nakina—continued on page 11

Artist's rendering of Nakina derailment