LANDSLIDES AND MASS WASTING (20)

I Main Topics

A Landslides and mass wasting

B Major events of the 20th century

C Costs of mass wasting

D Natural factors affecting mass wasting

E Case history: Nevado Huascaran, Peru, May 31, 1970

II Landslides and mass wasting

A Mass wasting: gravitationally driven processes that move solid and solid/liquid masses downslope

B Examples of mass wasting

1 Landslides

2 Debris flows

3 Avalanches

4 Rock falls

5 Toppling failures

6 Creep failures

C Glaciation excluded from mass wasting phenomena

D Pantia Remis Landslide

Tin Mine, Perak, Malaysia, 10/21/1993

https://www.youtube.com/watch?v=H6Ma0SVjMHA

III Major events of the 20th century

http://www.canadacollege.net/galloway/haz.9.html

Year	Country	Name and Type	Triggering process	Impact
1911	Tadzhik Republic	Usoy rock slide	Usoy earthquake M=7.4	54 killed
1919	Indonesia (Java)	Kalut lahra (volcanic mud flow)	Kelut volcano (eruption)	5,100 killed 104 villages destroyed
1920	Ningxia (China)	Haiyuan landslide	-	~100,000 killed
1921	Kazakh Republic	Alma-Ata debris flow	Snow melt	500 killed
1933	Sichuan (China)	Deixi landslide	Deixi earthquake M=7.5	6,800 killed; 2,500 drowned when dam failed
1939	Hyogo (Japan)	Mount Rokko slide/mud flow	Rain (typhoon)	505 dead, 130,000 homes destroyed
1949	Tadzhik Republic	Kahit rock slide	Khait earthquake M=7.5	12,000 to 20,000 killed; 33 villages destroyed
1953	Wakayama (Japan)	Arita River slide/debris/mud flow	Rain (typhoon)	460 dead, 4,722 homes destroyed
1953	Kyoto (Japan)	Minamiyamashiro slides/debris/ mud flow	Rain (typhoon)	336 dead, 5,122 homes destroyed
1958	Shizuoka (Japan)	Kanogawa slide/debris/mud flow	Rain (typhoon)	1,094 dead; 19,754 homes destroyed
1962	Ancash (Peru)	Nevado Huascaran debris avalanche	-	4,000 to 5,000 killed most of Ranrahirca village destroyed

III Major events of the 20th century

http://www.canadacollege.net/galloway/haz.9.html

Year	Country	Name and Type	Triggering process	Impact
1963	Fruili-Venezia-Griulia (Italy)	Vaiont rock slide	Filling of Vaiont Reservoir	~2,000 killed; city of Longarone damaged ~ $970 million (1994 U.S.dollars)
1964	Alaska (United States)	Alaska slides	1964 earthquake M=9.4	Estimated $860 million in (1994 U.S. dollars)
1965	Yunnan (China)	Rock slide	-	444 dead; 4 villages
1966	Rio de Janeiro (Brazil)	Rio de Janeiro slides/avalanches/ debris/mud flows	Heavy rain	~1,000 dead
1967	Serra das Araras (Brazil)	Serra das Araras slides/ avalanches/debris/mud flows	Heavy rain	~1,700 dead

III Major events of the 20th century

http://www.canadacollege.net/galloway/haz.9.html

Year	Country	Name and Type	Triggering process	Impact
1970	Ancash (Peru)	Nevado Huascaran debris avalanche	Earthquake M=7.7	18,000 dead; town of Yungay destroyed and Ranrahirca partially destroyed
1974	Huancavelia (Peru)	Mayunmarca rock/slide/debris/ avalanche	Rainfall	~450 killed; Mayunmarca village destroyed failure of 150-m-high landslide dam caused major flooding downstream
1980	Washington (United States)	Mount St. Helens rockslide/ debris avalanche	Eruption of Mt. St. Helens	World's largest historic landslide 23-km-long debris avalanche with average velocity of 125 km/hr; surface remobilized into 95-km long debris flow
1983	Utah (United States)	Thistle debris slide	Snow melt and heavy rain	Total losses ~$600 million in 1994 U.S. dollars
1985	Tolima (Columbia)	Nevado del Ruiz debris flows	Eruption of Nevado del Ruiz	>20,000 dead; four towns destroyed; ~100-km long debris flow

III Major events of the 20th century

http://www.canadacollege.net/galloway/haz.9.html

Year	Country	Name and Type	Triggering process	Impact
1986	Papu New Guinea	Bairaman rock slide/avalanche	Bairaman earthquake M=7.1	Village of Bairaman destroyed. Debris avalanche formed 210-m-high dam that impounded 50-million cubic meter lake; dam failed, causing 100-m-deep debris flow downstream
1987	Napo (Ecuador)	Reventador landslide	Reventodor earthquake M=6.1 and M=6.9	~1,000 killed $1.3 billion (in 1994 U.S. dollars)
1994	Cauca (Columbia)	Paez landslides	Paez earthquake M=6.4	271 dead; 1,700 missing; 32,000 displaced; villages destroyed

Modified from Table 1, Schuster, R.L., 1996, in Landslide, Chacón, Irigaray and Fernádez, eds., A.A. Balkema/Rotterdam

III Costs of mass wasting

1 Mass wasting in the U.S.
- a Est. annual cost in U.S. as of 1978: $1 B (x 2 for 1991)
- b Predicted losses in California (1970-2000): $10 B
  Actual losses in 13 California slides: $3.5 B
- c Portugese Bend (1956-1959): $10 M (x 5 for 1991)
- d Utah (1983*): $250 million*
- e S.F. Bay Area January, 1982 storm: 18,000 landslides!

III Costs of mass wasting

2 Human activity as a contributing factor
  a Contra Costa County, California: 80%
  b Allegheny County, Pennsylvania: 90%
3 Improved geotechnical practices can <u>greatly</u> reduce slide costs:
  a New York State (1969-1976): 90% reduction
  b Los Angeles 1968-1969 storm: 97% reduction vs. pre-1952
  c State of CA (Beach Leighton): 95-99% reduction

IV Natural factors affecting mass wasting

A Geologic Factors
  1 Geomorphology: Topography; processes of erosion & deposition and deformation that create topography
  2 Composition: Rock types and weathering products
  3 Structure: Distribution of flaws (e.g., bedding and fractures) and rock types (controls geometry of failure surface)
  4 Seismicity
  5 Geologic History (Time): Past is key to future
B Environmental Factors
  1 Climate and Hydrology: Rainfall, surface/ground water flow
  2 Vegetation (Very sensitive to all factors above)

V Artificial factors affecting mass wasting

A Deposition
B Cutting slopes
C Alteration of environmental factors
  1 Groundwater levels
    a Leaking pipes
    b Dams
    c Pumping ground water
  2 Diversion of surface water
    a Road construction and paving
    b Culverts (drainage ditches)
  3 Destruction of vegetation
    a Fires
    b Logging

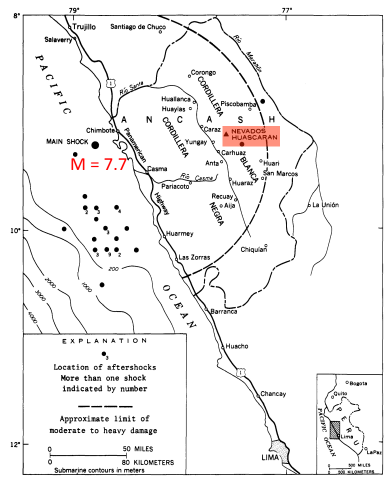
VI Case history: Nevado Huascaran, Peru, May 31, 1970

- On May 31, 1970 the most catastrophic known avalanche in history descended from Nevado Huascaran, the highest peak in the Peruvian Andes. The avalanche caused ~18,00 casualties*, including 15,000 of 17,000 resident of the city of Yungay. The avalanche was triggered at 3:23 PM by a great earthquake (M=7.7) off the coast of Peru; the epicenter was 130 km west of Nevado Huascaran. The avalanche occurred at end of wet season, when snow cover was near a maximum and the snow had begun to melt. The avalanche originated from a partially overhanging cliff (average slope of 70-80°) at 5400-6500 m elevation, where the fractured granitic rock of the peak was covered by a 30-m-thick glacier. The avalanche had a volume of ~ 50-100 million cubic meters and traveled 16 km to Rio Santa with a vertical drop of 4 km. The avalanche shot over a 230m-high ridge on its descent, launching boulders as large as 60 metric tons as far as 4 km from the ridge. The average speed of the 1970 avalanche was 280 km/sec– peak speeds probably reached ~1000km/hr. A previous avalanche from the same peak in 1962, with a volume of 13 million cubic meters, caused 4000 fatalities. That event prompted a prediction that an avalanche even larger than the 1962 could fall from the peak and threaten Yungay. The hazard posed was thus recognized, partially characterized, and partially evaluated. Mapping after the 1970 event revealed deposits from an substantially larger pre-Columbian (pre 1492) avalanche that might have attained average speeds of 315-355 km/hr.

- *Evans et al. (2009) set the fatality figure at 7,000

Map of central western Peru

- Black dot shows epicenter of M = 7.7 earthquake of May 31, 1970
- Nevado Huascaran is site of avalanche
- Dashed line marks approximate extent of earthquake damage



From USGS Circular 639

Aerial view of west face of Nevado Huascaran

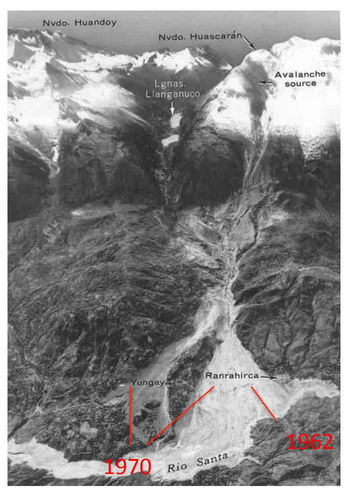
http://landslides.usgs.gov/learn/photos/international/peru_earthquake_mt._huascaran_1970

Aerial view of west face of Nevado Huascaran showing avalanche source area

http://landslides.usgs.gov/learn/photos/international/peru_earthquake_mt._huascaran_1970

Aerial view to east of avalanche source and path, with towns of Yungay and Ranrahirca

- Two avalanches, 1962 and 1970
- Both had similar sources
- Why did the 1970 avalanche hit the town of Yungay, when the 1962 avalanche did not?



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View to the east of the west face of Nevado Huasacaran (1948)

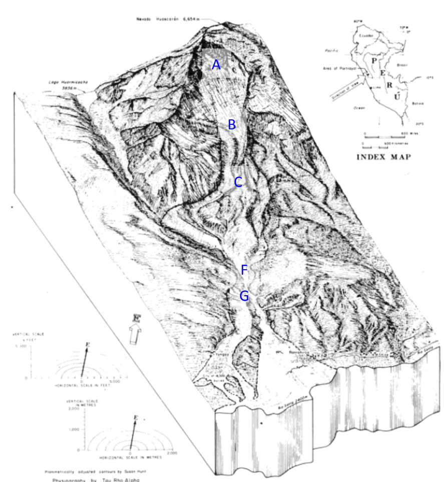
- A Highly jointed granodiorite
- B Summit glacier
- C Glacier 511
- D Terminal moraine

From Evans et al., 2009

Physiographic diagram of Nevado Huascaran, view to east

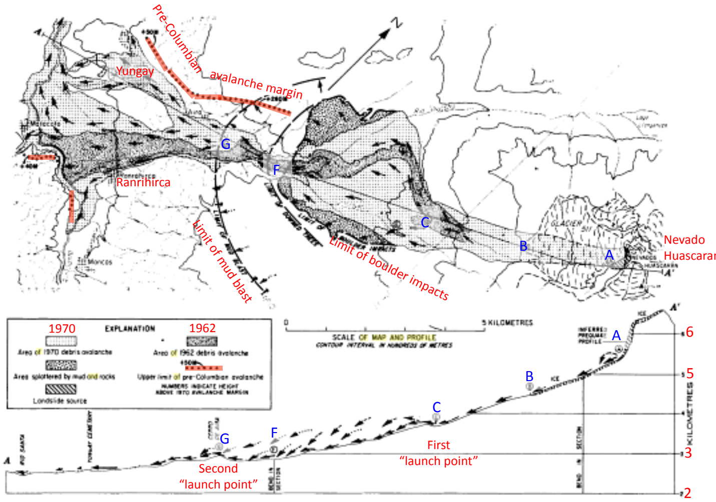
Locations

- A Source of 1970 avalanche
- B Toe of Glacier 511
- C Bend in channel between moraines
- F Point nearly in line with pts. A, B, C



From USGS Open File Report 79-373

Generalized map and profile of 1970 Huascaran avalanche



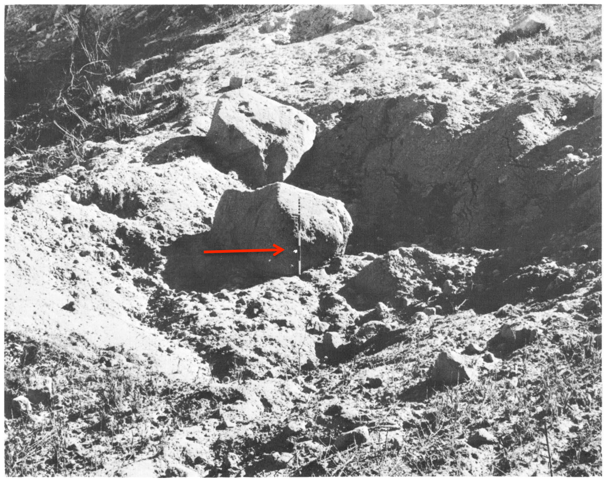
From Plafker and Ericksen, 1977

Largest known impact crater

33m long, 15m wide, 7-8m deep

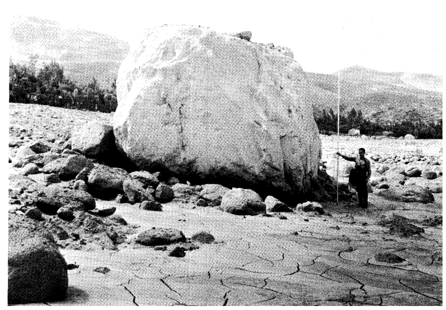
From Plafker and Ericksen, 1977

Boulder and impact crater



From USGS Circular 639

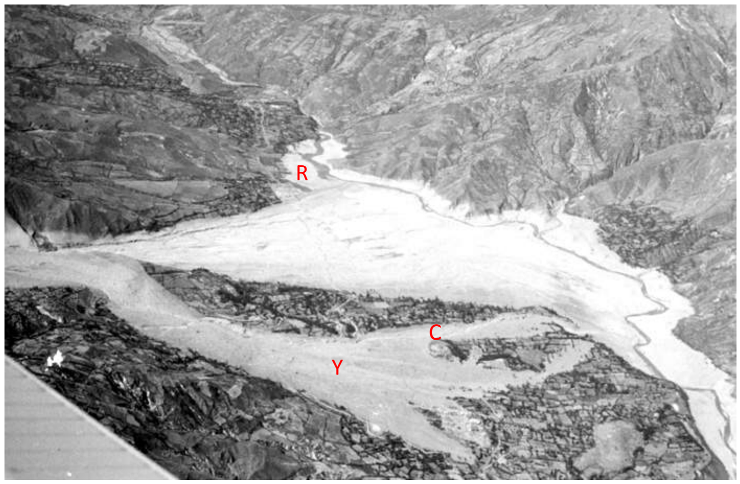
Boulders at Ranhahirca after the mud has washed away



From Plafker and Ericksen, 1977

From USGS Circular 639

Oblique view of Ranhahirca (R), Yungay (Y), and Cemetary Hill (C)

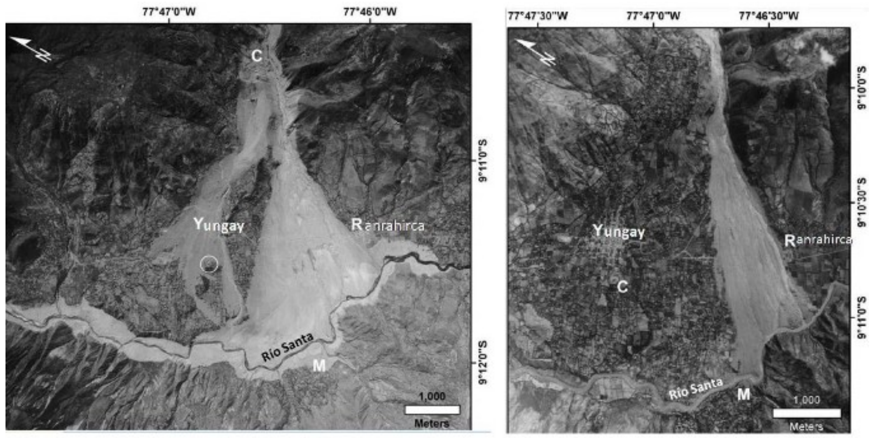


https://www.sciencebase.gov/catalog/item/51dda162e4b0f72b4471de8d

Lake formed upstream of landslide dam on Rio Santa

From USGS Circular 639

Images of 1962 and 1970 avalanches



(a) Evento 1970 (b) Evento 1962

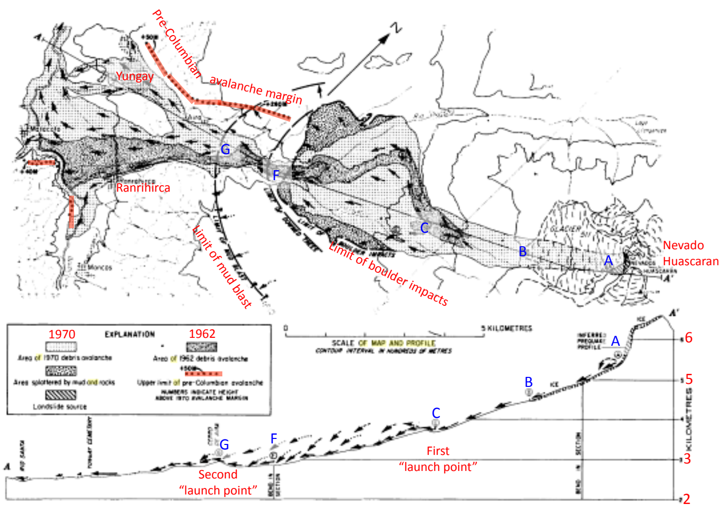
http://www.cecalc.ula.ve/blogs/notisismo/wp-content/uploads/2010/06/figura-3.jpg

View southwest along the track of the 1962 avalanche

- Debris rose up valley bends at A and B
- Debris almost overtopped Cerro de Aira at G
- Yungay = Y
- Ranrahirca = R
- Photo from Charles Sawyer

http://landslides.usgs.gov/learn/photos/international/peru_earthquake_mt._huascaran_1970

Some of the larger 1970 avalanche followed a straighter path than the 1962 avalanche

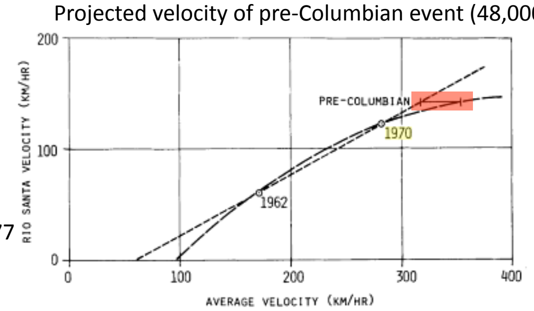


From Plafker and Ericksen, 1977

Data for avalanches at Nevado Huascaran

	1962	1970	48,000 yr
Area covered (km2)	6	22.5	>30
Volume (million m3)	>13	50-100	100-200?
Average velocity (km/hr)	170	280	315-355
Runup height at Rio Santa (m)	30	83	123
Velocity at Rio Santa (km/hr)	>60	>120	>140
Casualties	4000	>18,000	?

Projected velocity of pre-Columbian event (48,000 yr)



Results here from Plafker and Ericksen, 1977

Potential Energy

Estimate of minimum velocity at Rio Santa based on runup height

ΔP.E. = $mg\Delta h$

K.E. = $(1/2)mv^2$

$(1/2)mv^2 = mg\Delta h$

$v = (2g\Delta h)^{1/2}$

<u>1962</u>

For Δh = 30m, v_{min} = 87 km/hr

<u>1970</u>

For Δh = 83m, v_{min} = 145 km/hr

<u>Pre-Columbian</u>

For Δh = 123m, v_{min} = 177 km/hr

Potential energy release from 1970 avalanche

$m = \rho V$

m_{min} = (2.7e3 kg/m^3)(50e6 m^3)

m_{max} = (2.7e3 kg/m^3)(100e6 m^3)

g = 9.8 kg/m^{3}e6

Δh = 6000 m – 2500 m = 3500 m

Using 100 million cubic meters

ΔP.E. = $mg\Delta h$ = 9.3 e15 joules

Equivalent to ~150 Hiroshima bombs over a path length of 14.5 km

10 bombs/km or 1 bomb/100 m.

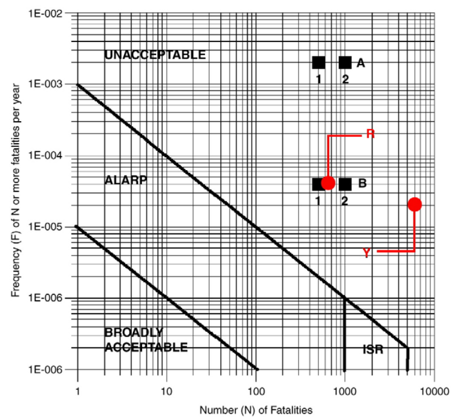
Could the 1970 event have been predicted?

- In 1962 two American scientists, David Bernays and Charles Sawyer, had reported seeing a massive vertical slab of rock being undermined by a glacier, which threatened to fall and cause the obliteration of Yungay.
- According to Sawyer, when this was reported in the *Espreso* newspaper (27 September 1962), the government ordered them to retract or face prison, and they fled the country.

From Plafker and Ericksen, 1977

Evaluation and Assessment (from Evans et al., 2009)

- Risk scenarios for Yungay–Ranrahirca area using societal risk criteria. ALARP, = As Low as Reasonably Practicable. ISR = Intense Scrutiny Region. Based on Fig. 4 of Fell et al. (2005).
- Black squares: scenarios for the Ranrahirca fan. Maximum (A1 and A2) and minimum (B1 and B2) existing hazard scenarios for 500 and 1000 deaths respectively.
- Red dots: retroactive risk for a single event in 48,000 years at Yungay (Y), i.e., the 1970 event, and two events in 48,000 years at Ranrahirca (R), i.e., the 1962 and 1970 events
- See http://faculty.washington.edu/kramer/522/SOA1_Fell_et_al_Vancouver.pdf
- See also http://australiangeomechanics.org/admin/wp-content/uploads/2010/11/LRM2007-c.pdf



Report from a survivor

- Among these survivors was the engineer Mateo Casaverde who was accompanied by French geophysicist G. Patzelt and his wife. He recalls: ¨*We were driving from Yungay to Caraz while, passing the cemetery of Yungay the earthquake started. You could see clearly the vertical part of the seismic waves rolling along the asphalt of the highway. We abandoned the car when the earthquake was just finishing. We heard a deep noise, different from the earthquake, but not so much so. It was coming from Huascarán and we saw between the mountain and Yungay a giant cloud of dust. The quake had caused an avalanche. Part of Huascarán was falling. The only place where we were that offered any protection was the cemetery. It was built on an artificial hill, the remains of the pre-Inca pyramid. We ran about 100 metres from the highway before entering the cemetery, which had also suffered from the effects of the earthquake. I turned to look at Yungay. At that moment you could see a giant wave, about 60 metres high, about to hit the left hand side of the city. This wave was certainly not dust. We ran up the stairs. We reached the 3rd level of the structure, which was more damaged, and found a man, a woman and three children trying to get up higher. We turned to the right, and ran along the third level. It was then that the wave hit. The avalanche reached the cemetery hitting the frontal part, practically at the same height as the third level. It passed us just below out feet, maybe about 5 metres away. The sky went dark. We looked around. Yungay and its many thousands of inhabitants had disappeared.¨*

http://www.thehuaraztelegraph.com/2012/06/yungays-disaster-of-1970/

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