MANAGEMENT OF NATURAL HAZARDS
IN MOUNTAIN BASINS

Debris flows

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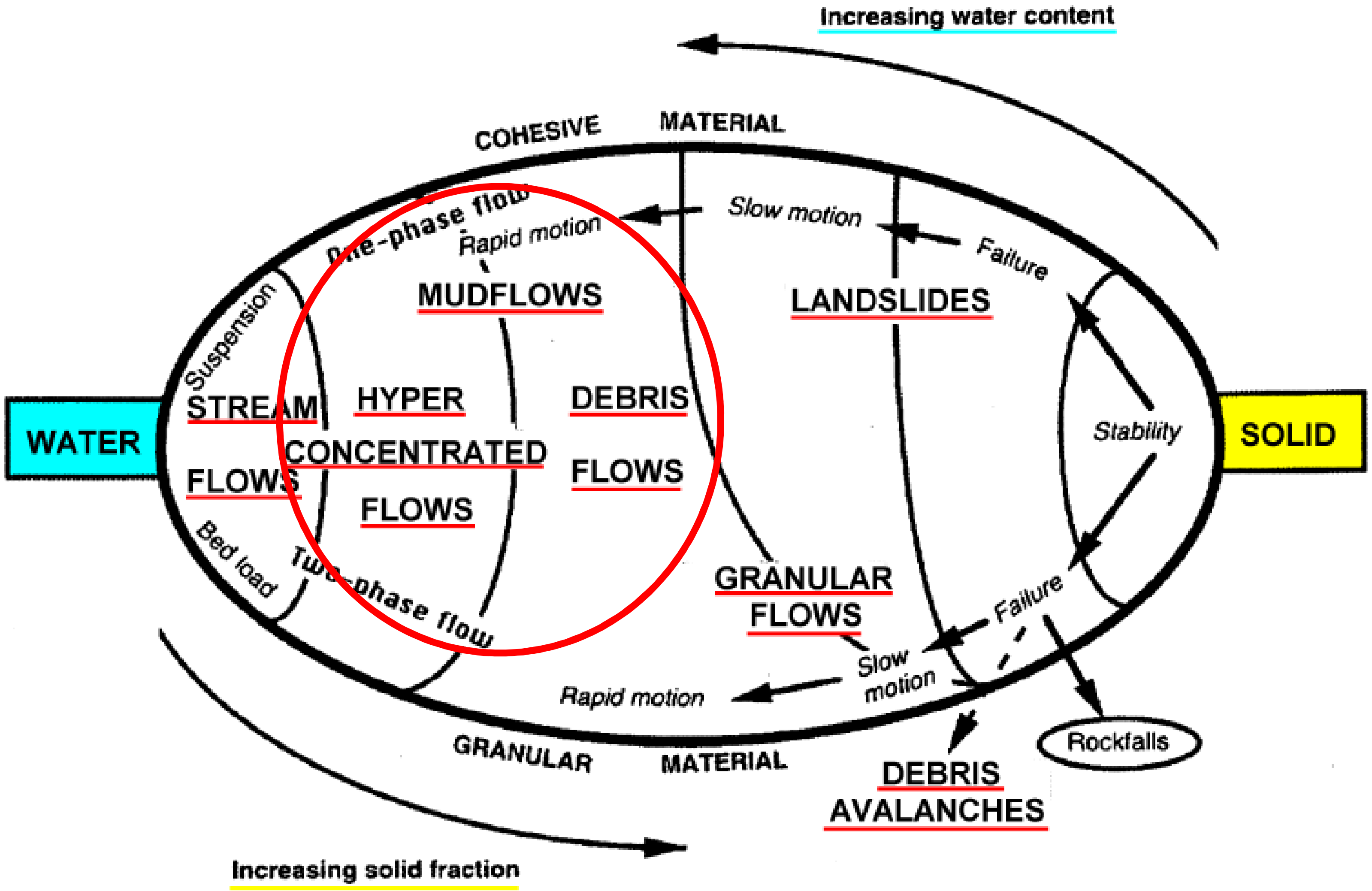
Academic year 2014/2015

Credits to:
Dr. Lorenzo Marchi – CNR IRPI Padova
P.R. Bierman, D.R. Montgomery (2014) Key concept in Geomorphology.

Flows within mass movements



Coussot and Meunier (1996)

Definition of debris flows

- Rapid downstream mass movement of sediments flowing (i.e. with some internal mixing of the original mass) along a channel (ephemeral or perennial)

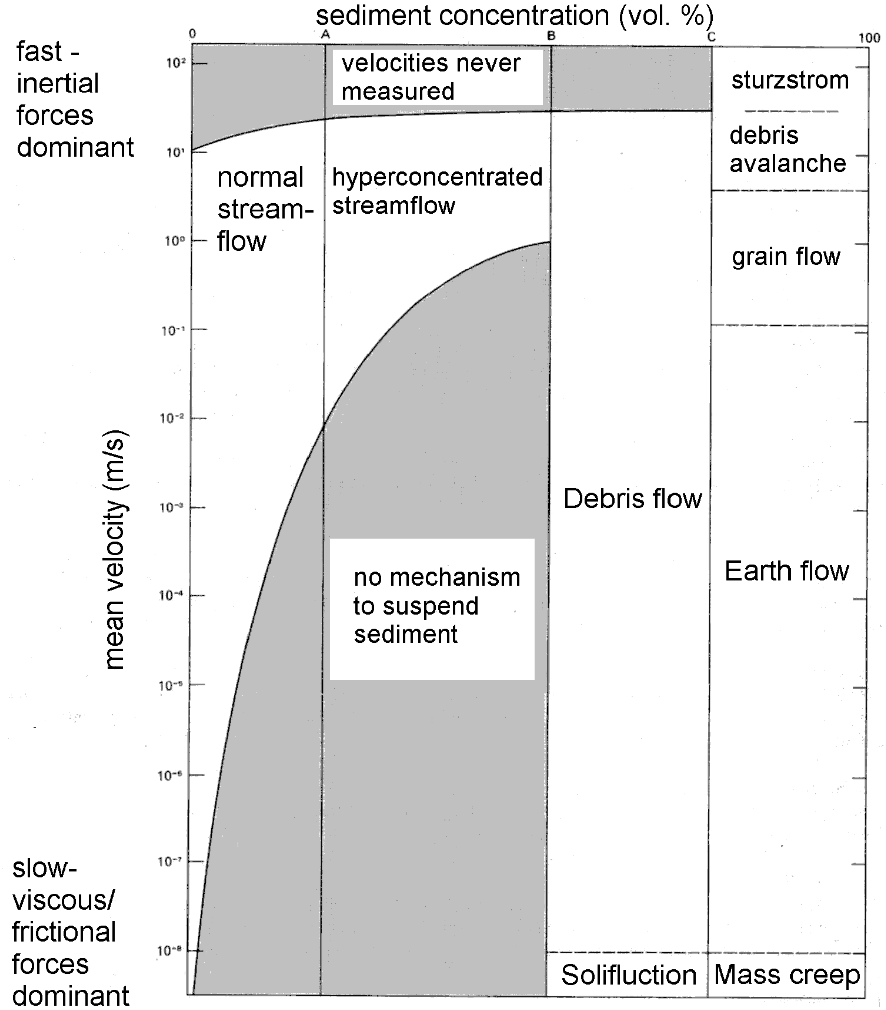
- Sediment concentration 30%-70% in volume (higher than fluvial flows, lower than landslides)

- Complex rheology (stress – strain)

- High density (up to 2,000 kg m^{-3})

- High velocity (2-5 m s^{-1}, up to 20 !)

- A very powerful processes for its high momentum (density times velocity)



FLUID TYPE	NEWTONIAN	NON-NEWTONIAN		
INTERSTITIAL FLUID	WATER	WATER+FINES		WATER+AIR +FINES
FLOW CATEGORY	STREAMFLOW		SLURRY FLOW	GRANULAR FLOW
FLOW BEHAVIOR	LIQUID	PLASTIC		

Pierson and Costa (1984)

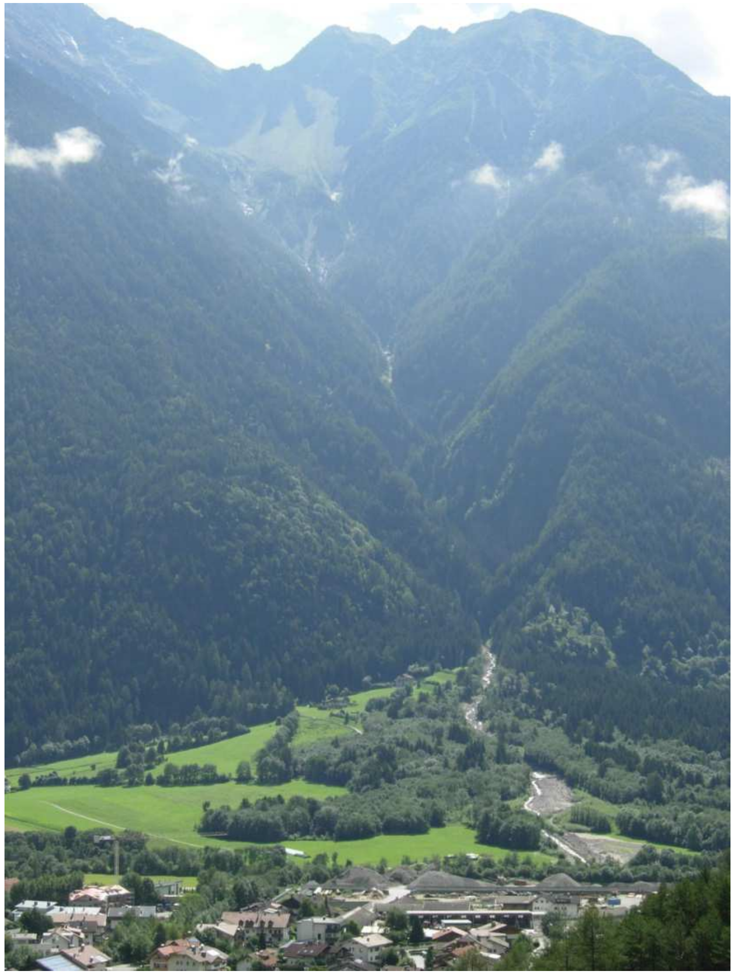
Definition of debris flows

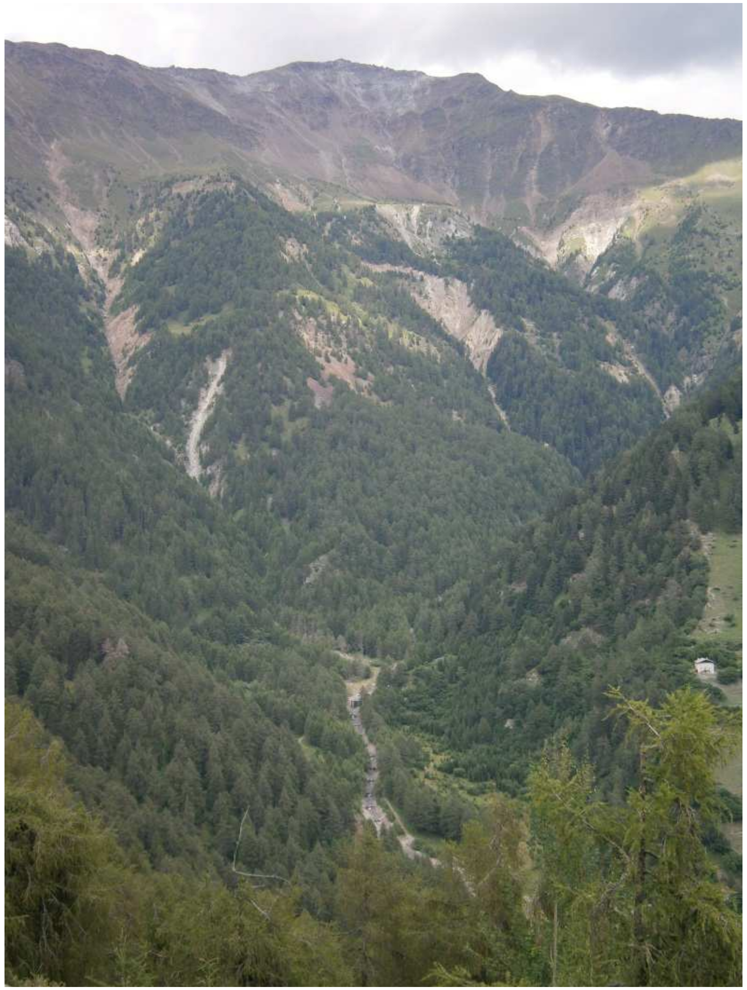
- *Channelized* d.f.

- *Unchannelized* d.f.

Debris flow channels

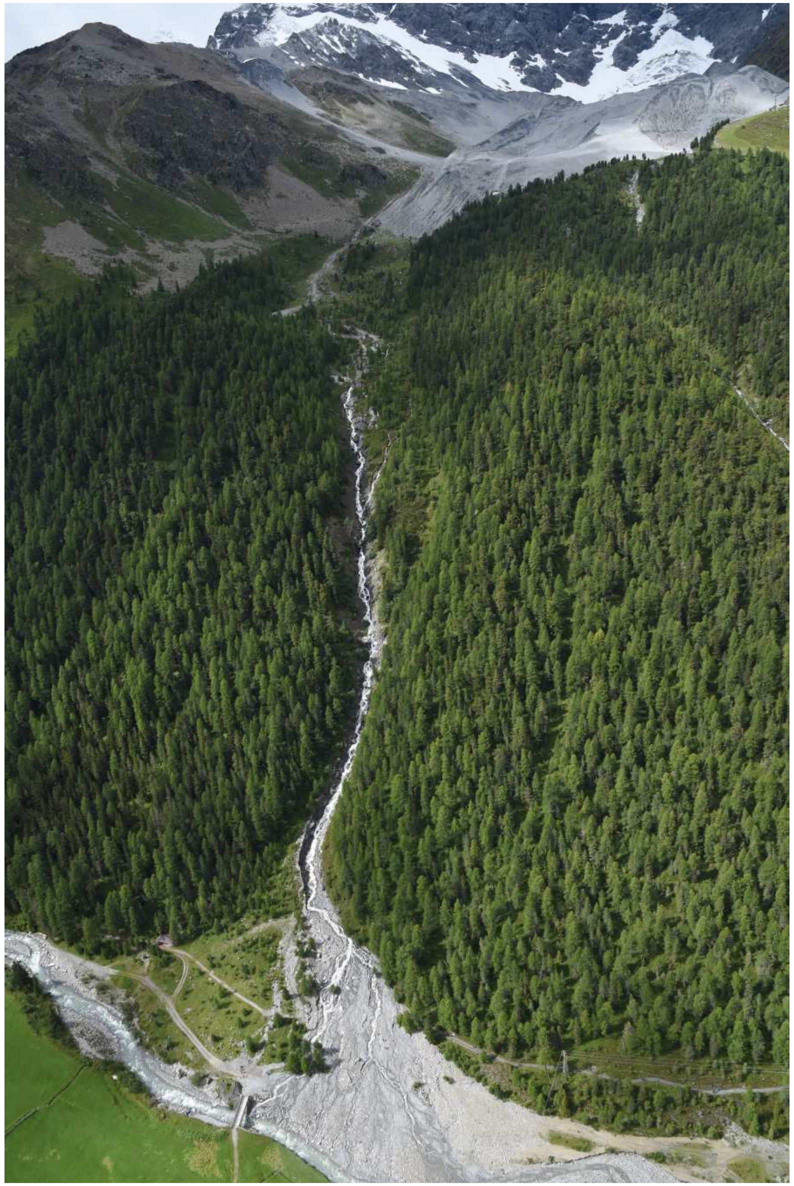
- Necessary conditions:
  - ✓ Steep channel slopes
  - ✓ Availability of loose sediment (on hillslopes or channel)





Debris flow channels

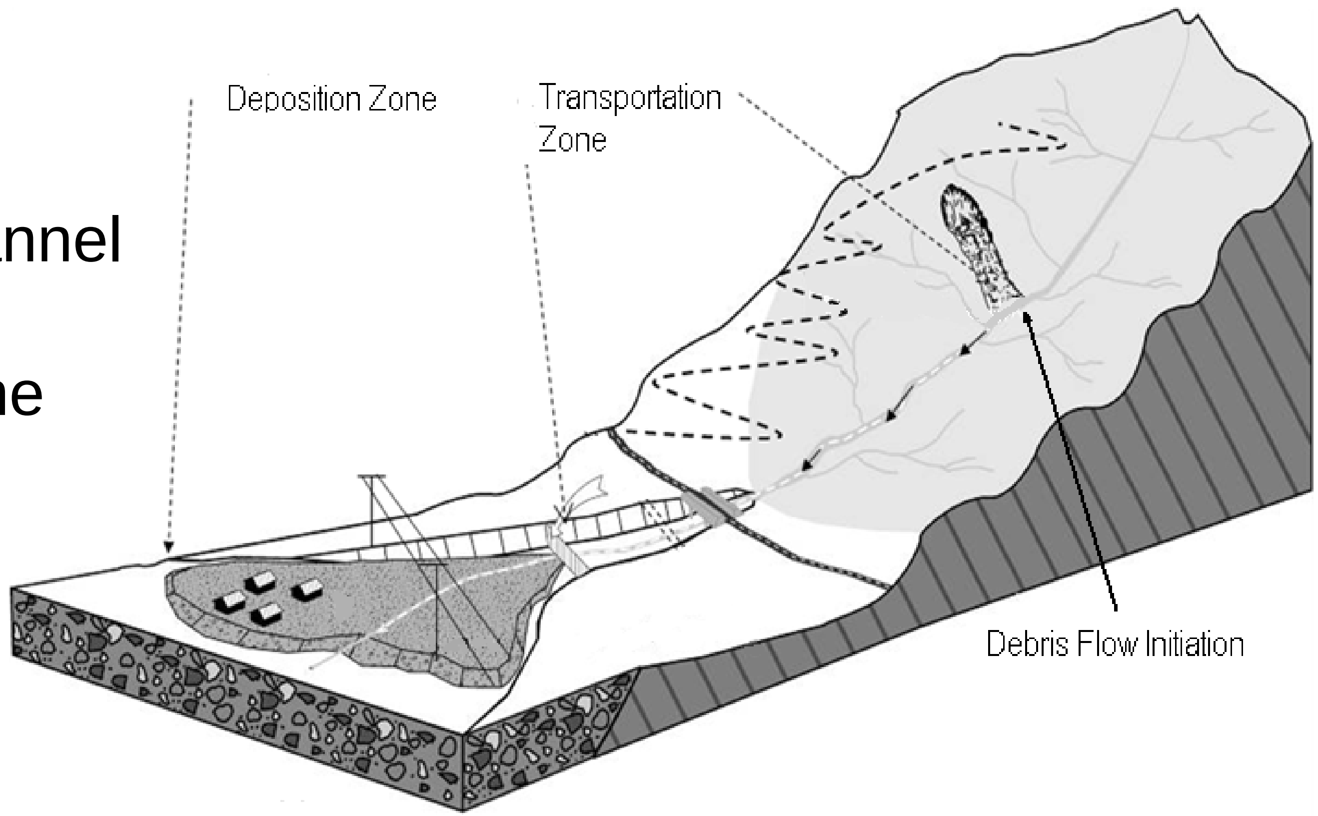
Photo courtesy of the Province of Bolzano



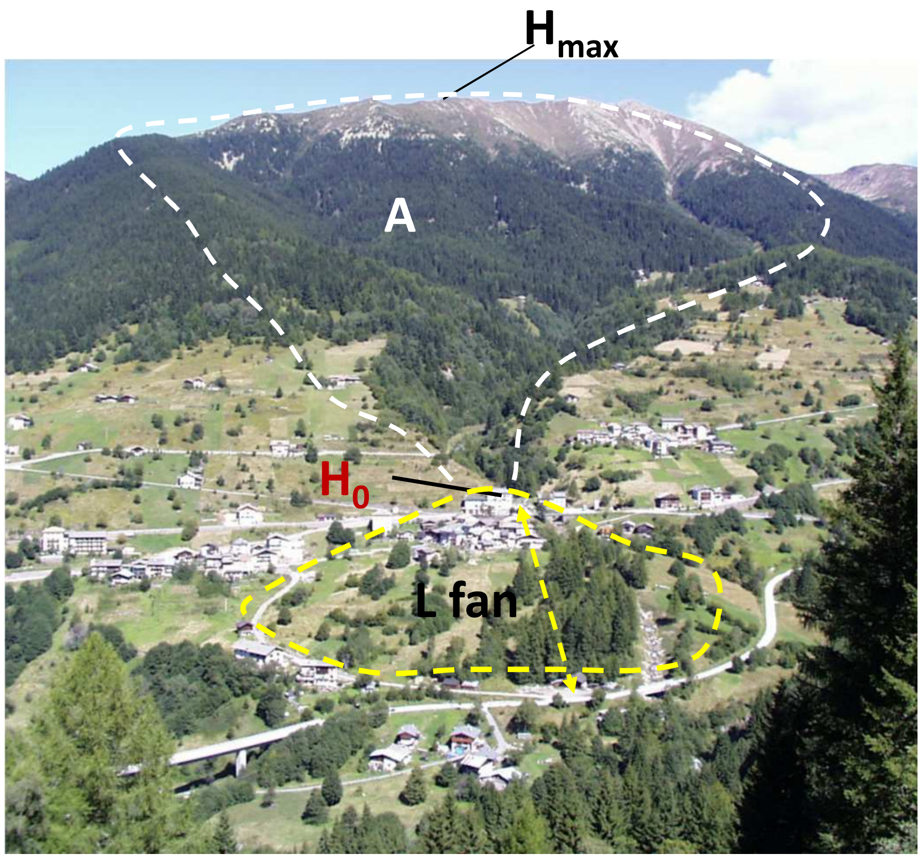
Debris flow basins

Small basins: drainage area mostly 10 km^2 (up to 30 km^2)

- Initiation areas
- Propagation channel
- Depositional zone



Identification of debris flow-prone channels



✓ Melton number:

$$Me = \frac{H_{max} - H_0}{\sqrt{A}}$$

(A in m²)

✓ Fan inclination (in °):

$$S_{fan} = \arctan\left(\frac{\Delta H_{fan}}{L_{fan}}\right)$$

H_{max} = max elevation of the basin (in m)

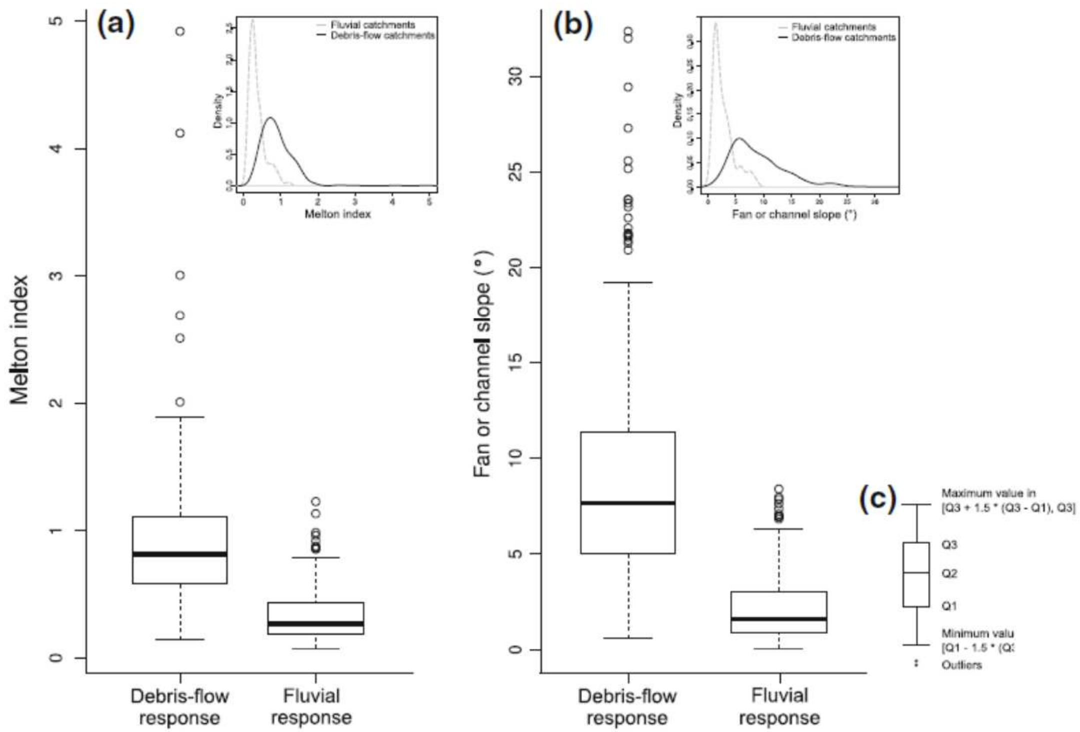
H_0 = max elevation of the fan (fan apex) (in m)

A = drainage area (in m^2)

ΔH = difference in elevation from fan apex to fan toe (in m)

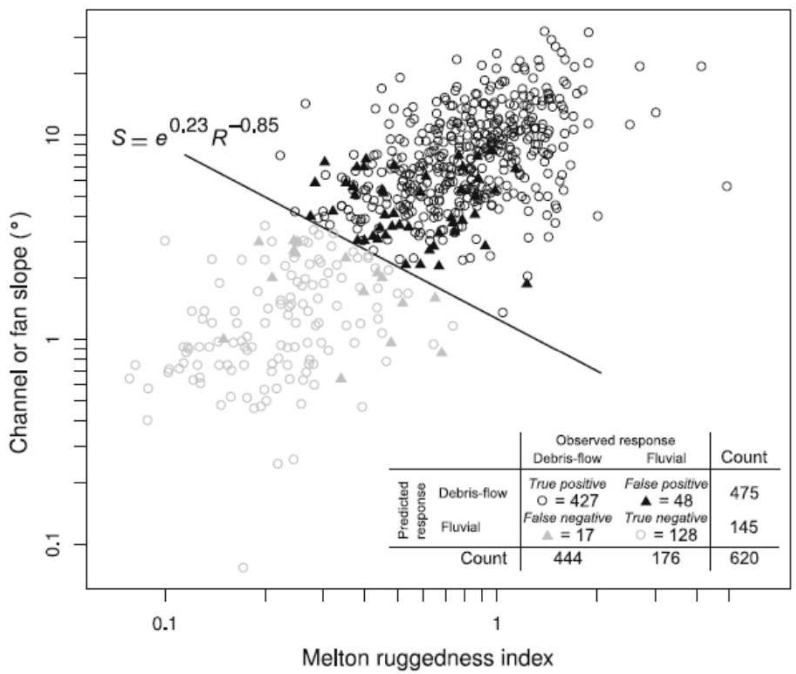
L_{fan} = channel lenght along the fan (in m)

Debris flow-prone basins



With respect to fluvial basins, debris flow basins have:

- ✓ Higher Melton index
- ✓ Steeper fans



From Bertrand et al (2013, Natural Hazards)

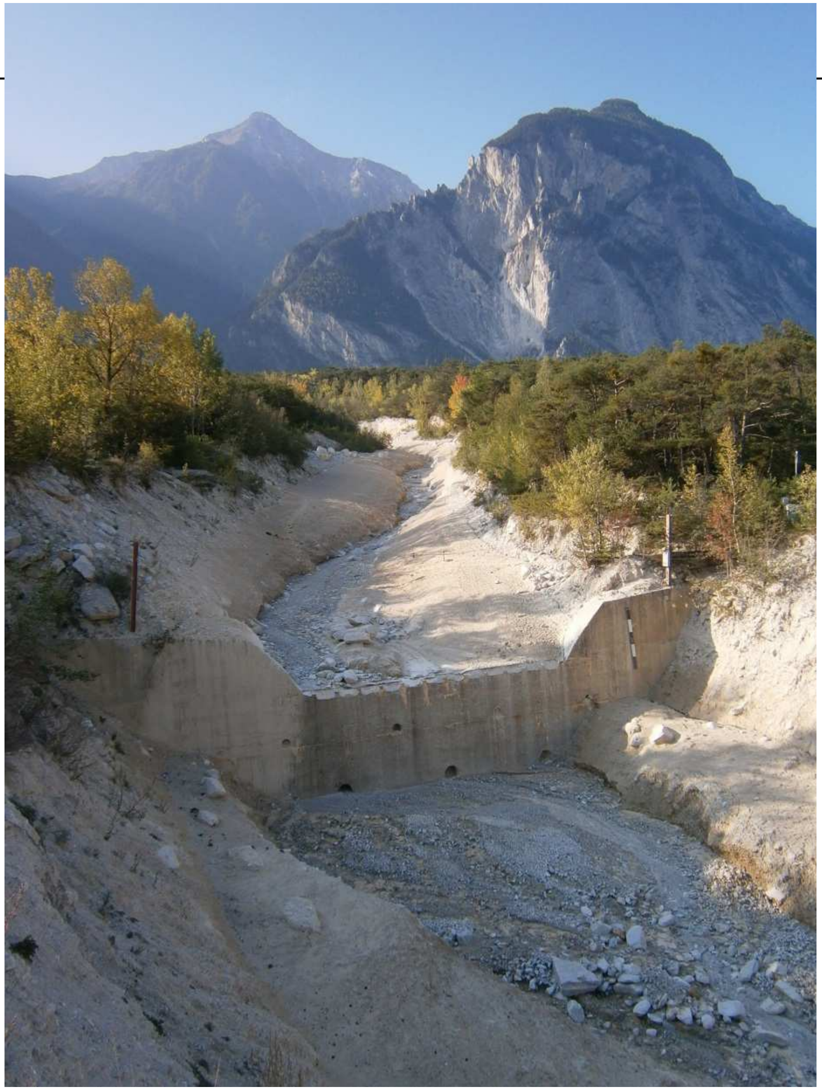
Debris flow initiation

- ✓ Talus slopes
- ✓ Slides/slumps on hillslopes
- ✓ Steep colluvial channels/hollows
- ✓ Collapse of moraines/landslide dam
- ✓ Collapse of structures (check-dams)

✓ Inclination >14-15° (less with «dam-break» triggering)

Debris flow initiation

Debris flow propagation



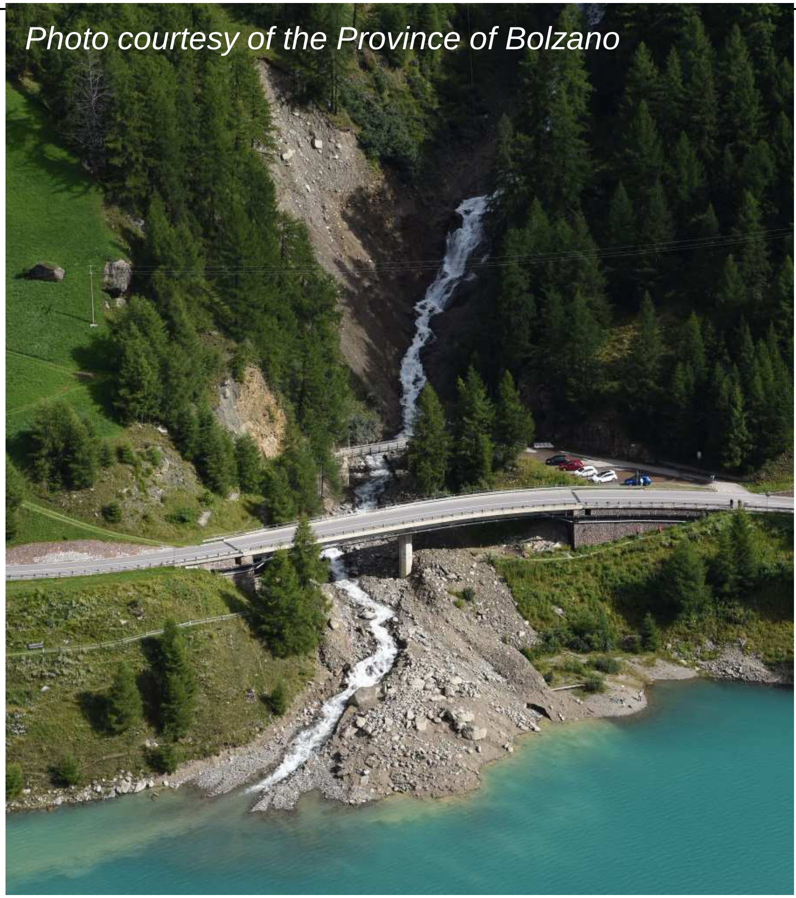
- ✓ Inclination >9-10°
(without relevant deposition)

- ✓ High scouring potential

Debris flow propagation

Video courtesy of the Province of Bolzano

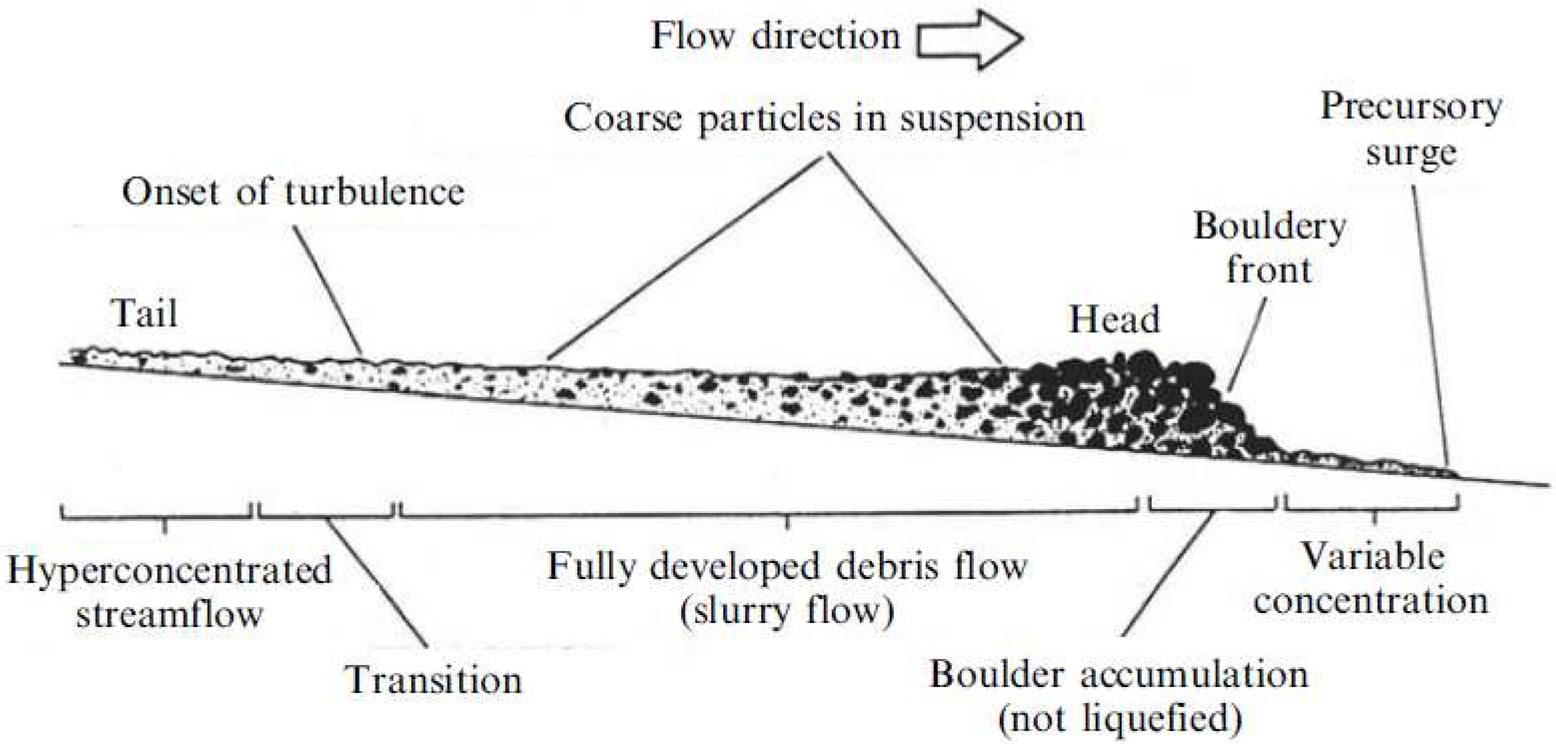
Debris flow deposition



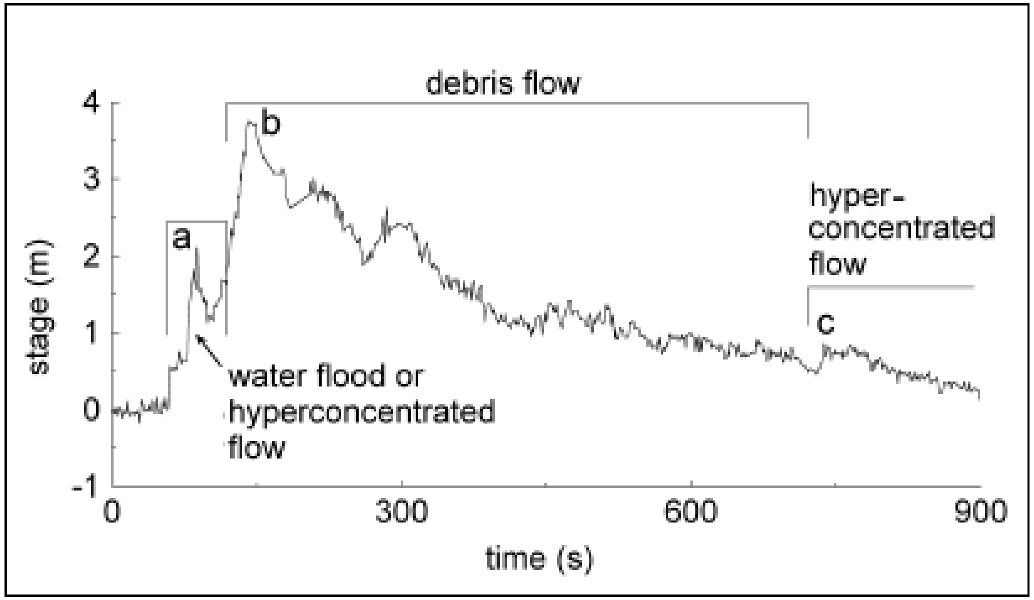
- ✓ Debris fans («cones»)
- ✓ Retention basins
- ✓ Local channel widening

- ✓ Inclination < 8 ° (<4° abrupt stop) (role of width-to-depth ratio)

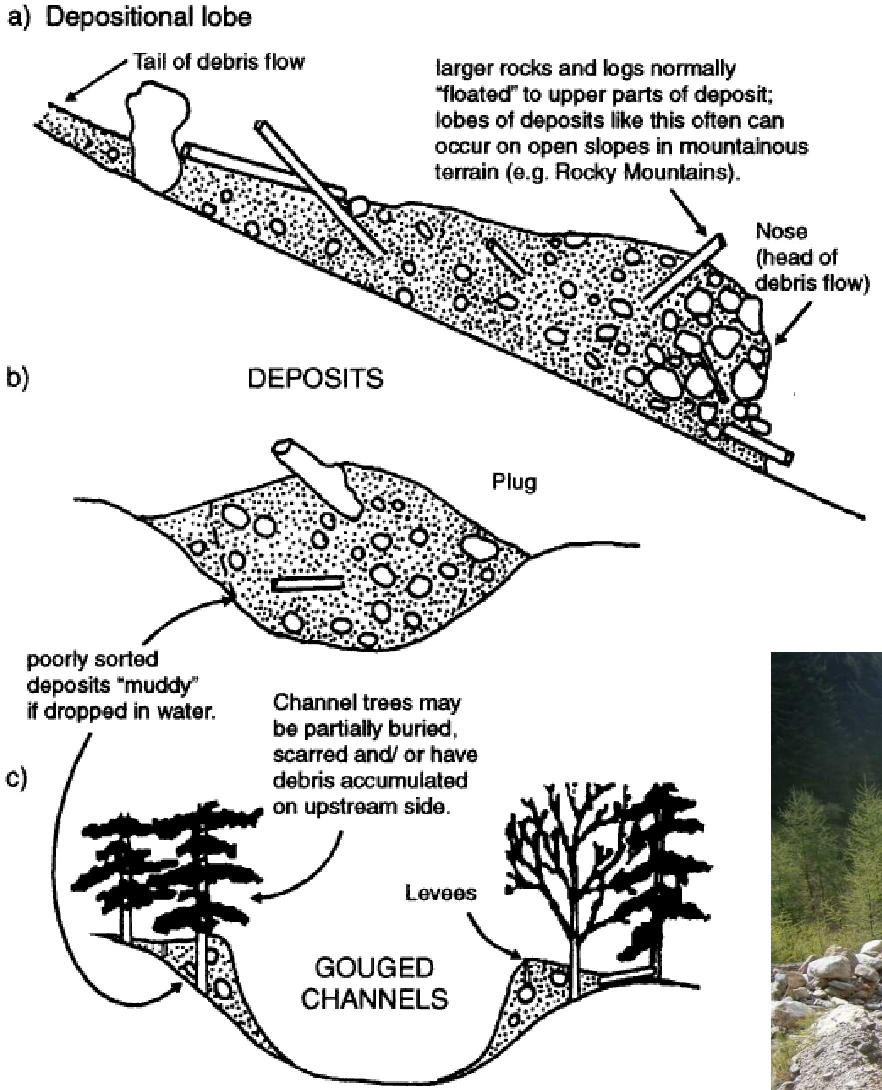
Debris flow characteristics



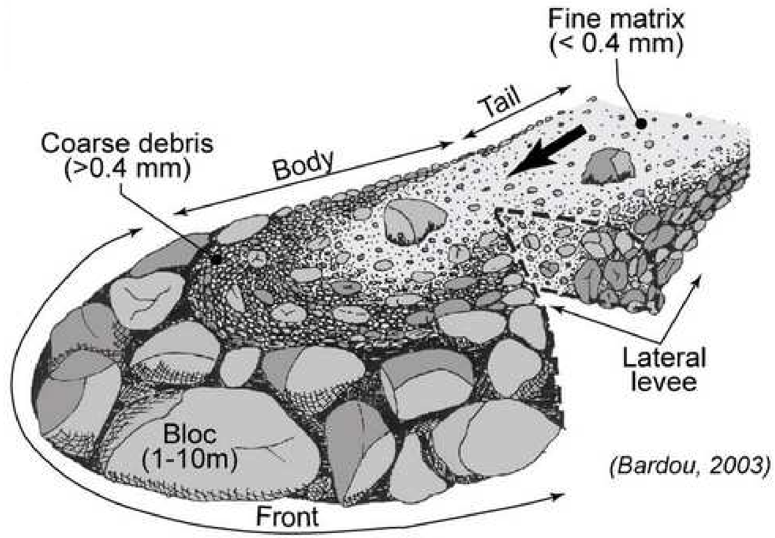
Debris flow characteristics



Debris flow characteristics



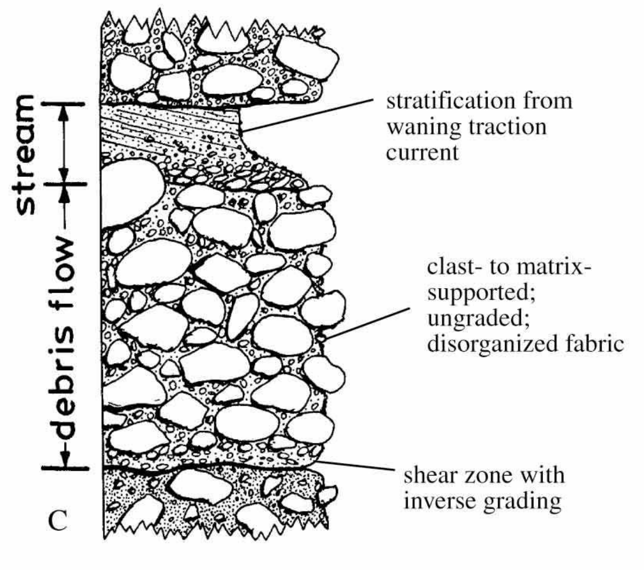
✓ Lobes

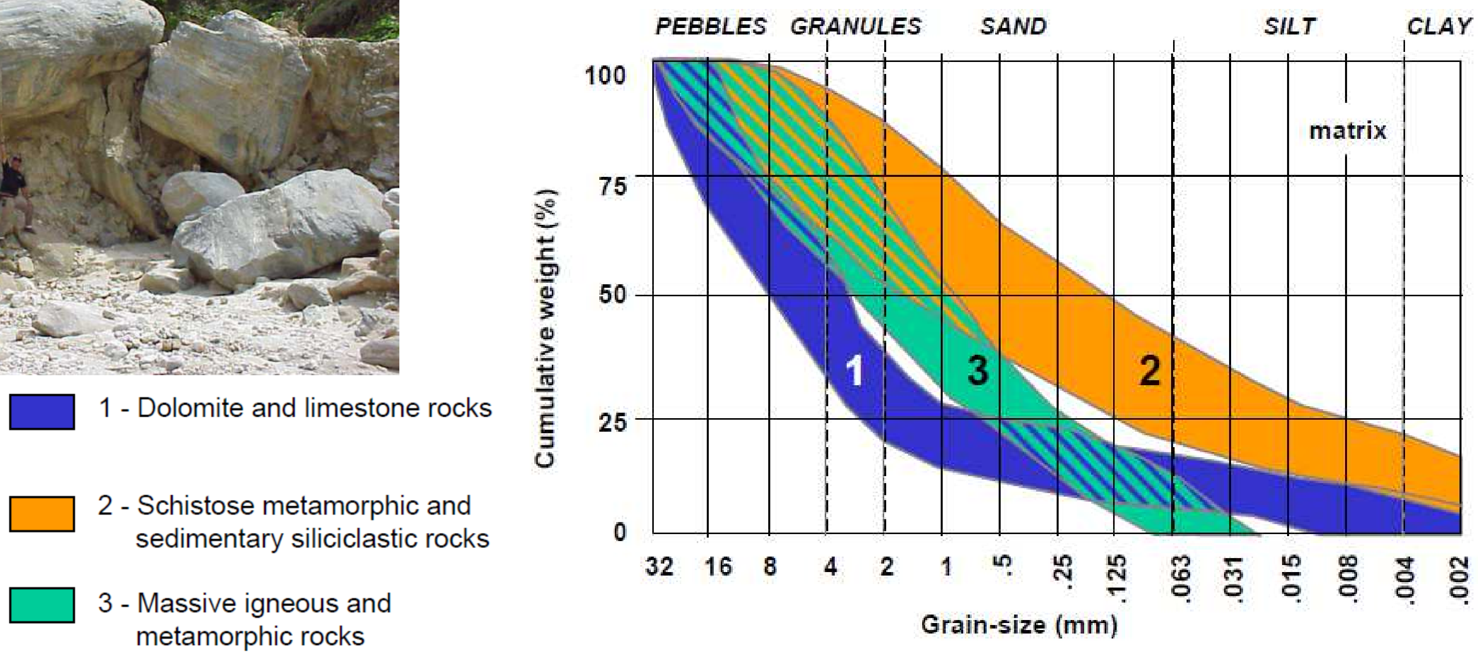


✓ Lateral levee

Debris flow characteristics

- ✓ Highly unorganized, ungraded deposits (no layering as found in fluvial deposits)
- ✓ Frequent presence of large boulders (even very large, up to 10 m in diameter) and wood
- ✓ Clast- or matrix- supported





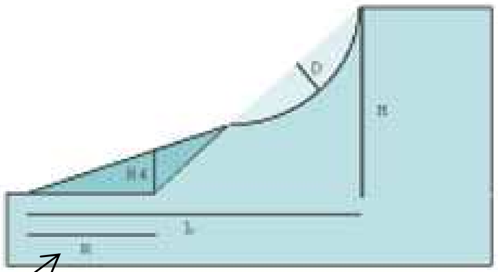
Debris flow characteristics

- ✓ Flow velocity V
- ✓ Flow depth H
- ✓ Peak discharge Q
- ✓ Volume (magnitude) V

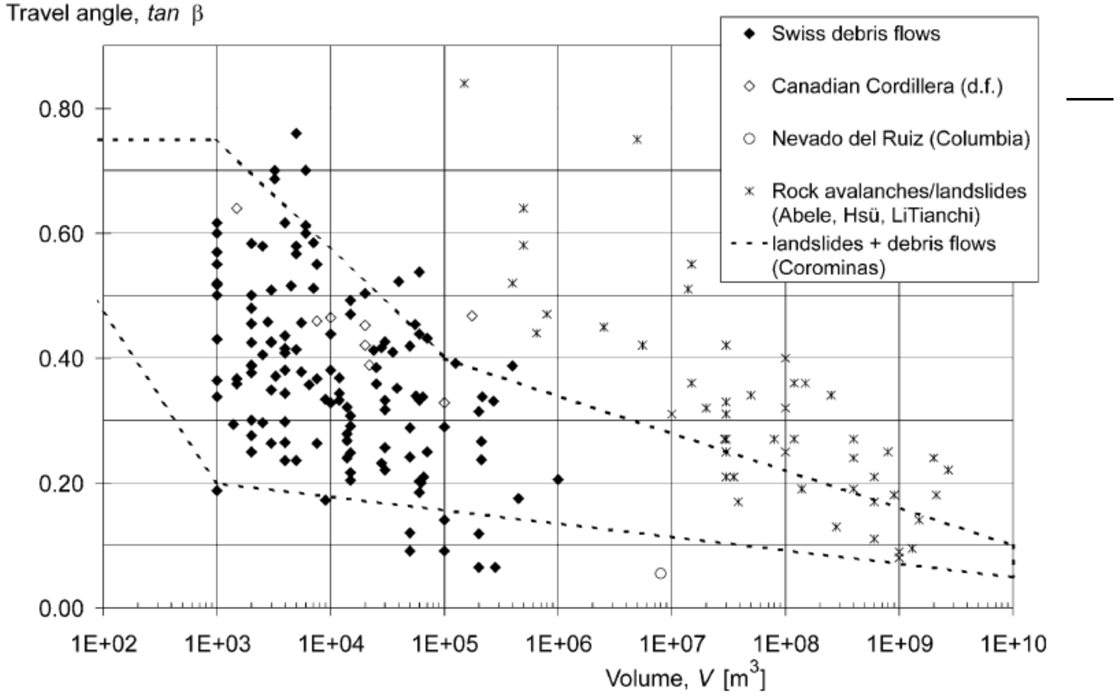
Sito	N dati	Q_p (m^3s^{-1})	V (ms^{-1})	S (-)	H (m)
T. Moscardo *	12	3 - 255	0.9 - 5.0	0.10	0.7 - 4.0
Kamikamihori Valley * (Giappone)	12	24 - 124	1.9 - 6.4	0.09	1.5 - 4.1
Mt. St. Helens (USA) (Shoestring Site) *	6	0.012 - 25	0.8 - 4.4	0.12 - 0.4	0.05 - 2.8
Mt. St. Helens (USA) (Pine C. + Muddy R.)	20	2400 - 66800	3 - 28	0.003 - 0.15	2 - 21
Alpi Svizzere	29	15 - 640	3.5 - 14	0.07 - 0.53	1 - 10
Jiangia Gully (Cina) *	33	46 - 3133	4 - 14.5	0.05 - 0.073	0.6 - 5.5
Mevado del Ruiz (Colombia)	17	710 - 48000	5 - 17	0.009 - 0.17	2 - 25

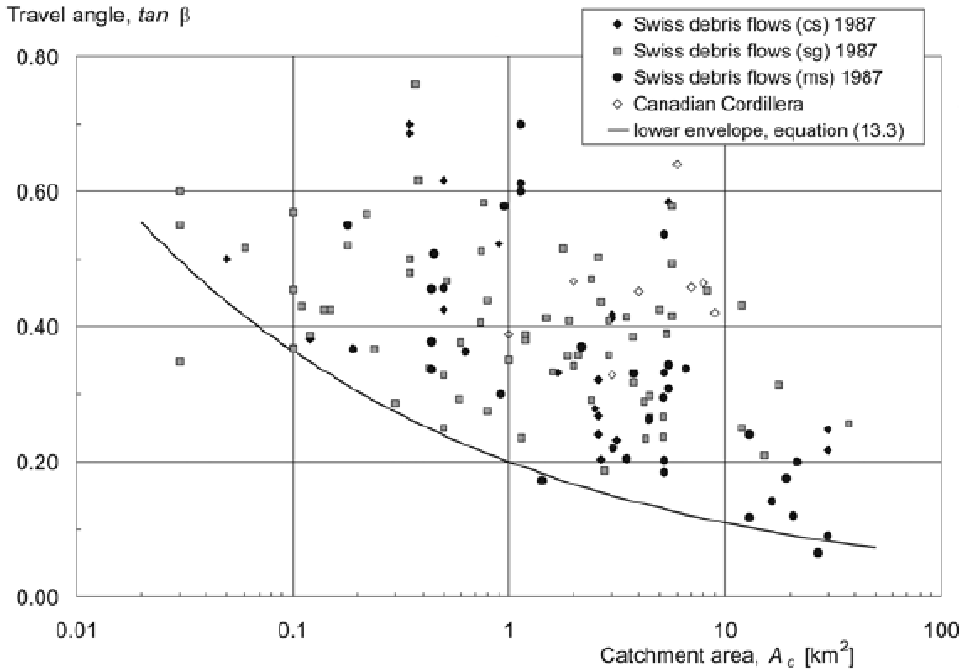
D.F. characteristics

- ✓ Travel distance L and travel angle $\tan \beta = H/L$



Runout (distance travelled in the depositional zone)





$$L = 1.9 V^{0.16} H^{0.83}$$

$$\tan \beta_{min} = 0.20\, A_c^{-0.26}$$

From Rickenmann (2005)

Large rainfall-induced debris flows

Chieppena Creek (Trentino)
November 1966
- ✓ Basin area 33 km^3
- ✓ Volume 950,000 m^3

Vargas (Venezuela)
December 1999
- ✓ Basin area 28 km^3
- ✓ Volume 1.8 Million m^3