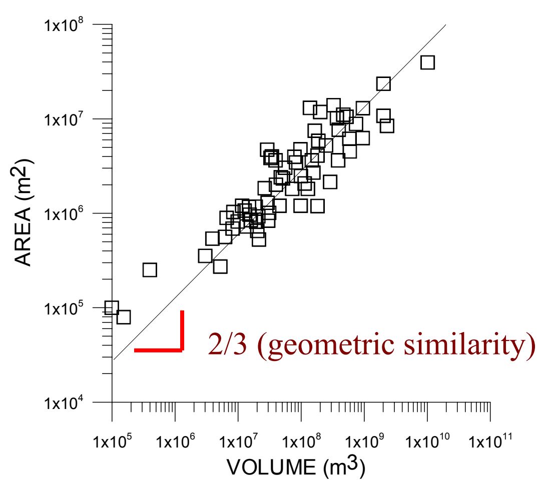
Frequency of Rock Avalanches

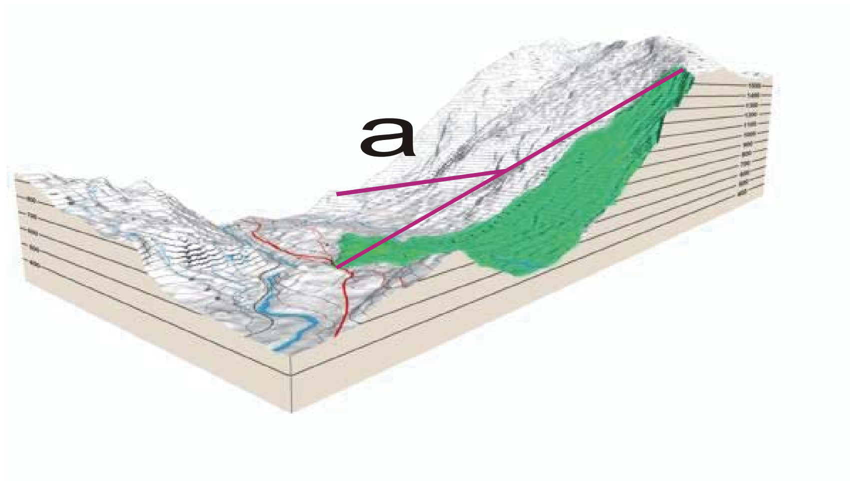
Reference	Location	Area ($10^3 km^2$)	Geology	Study Period		Number of Cases	Frequency[1] (cases/year /10,000 km²)	Return period (years per 10,000 km²
Abele (1974)	North calcareous Alps	61	sedimentary	postglacial	11,000	40	0.0006	1,670
Abele (1974)	South calvareous Alps	28	sedimentary	postglacial	11,000	32	0.0010	1,000
Whitehouse and Griffiths (1983)	Central New Zealand	10	sedimentary	postglacial	10,250	14	0.0014	714
Cruden (1985)	Alberta Rockies, Canada	60	sedimentary	postglacial	11,000	129	0.0019	526
Eisbacher (1979)	Mackenzie Mtns. N.W.T., Canada	27	sedimentary	postglacial	11,000	14	0.0005	2,000
Abele (1974)	Central Alps	82	metamorphic and crystalline	postglacial	11,000	21	0.0002	5,000
Evans (unpublished)	Coast Range, B.C., Canada	12	metamorphic and crystalline	2,000 B.P. to present	2,000	3	0.0012	833
Abele (1974)	The Alps	176	mixed	postglacial	11,000	93	0.0005	2,000
Eisbacher and Clague (1984)	The Alps	176	mixed	1,200 A.D. to 1,984	784	8	0.0006	1,670

Frequency: 1 : 700 to 1 : 5,000 per year per 10,000 km² of mountains

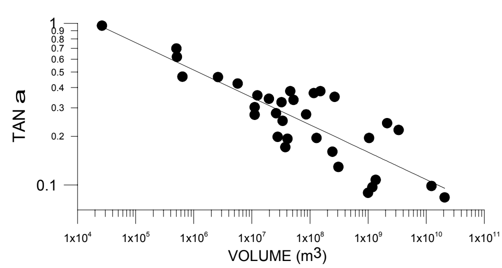
Empirical methods:
Area-volume correlation (Li, 1983)



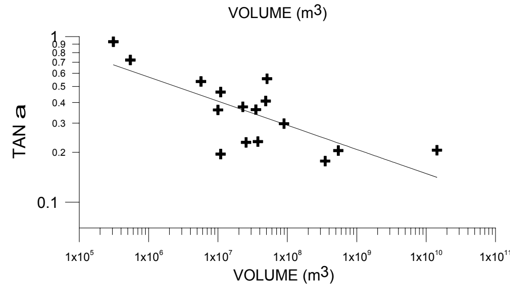
Fahrböschung (travel angle)



Mobility increases with volume



"Scheidegger plot" (1973)



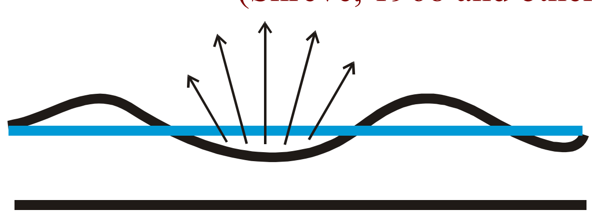
Center of gravity displacement (Hungr, 1981)

Why excessive travel distance?

- air cushion hypothesis (Shreve, 1968)
- fluidization by air/steam
- mechanical (roller bearing) fluidization
- acoustic fluidization (Melosh, 1979)
- frictional melting (Erissman, 1978)
- undrained loading - mud lubrication (Heim, 1881)

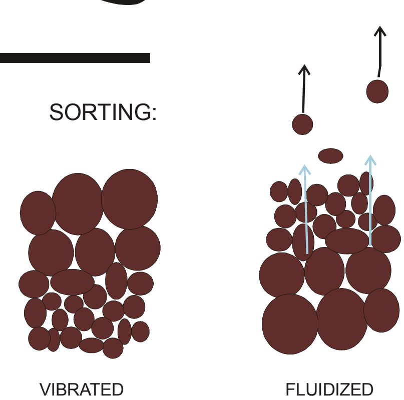
Gas Uplift Hypotheses?

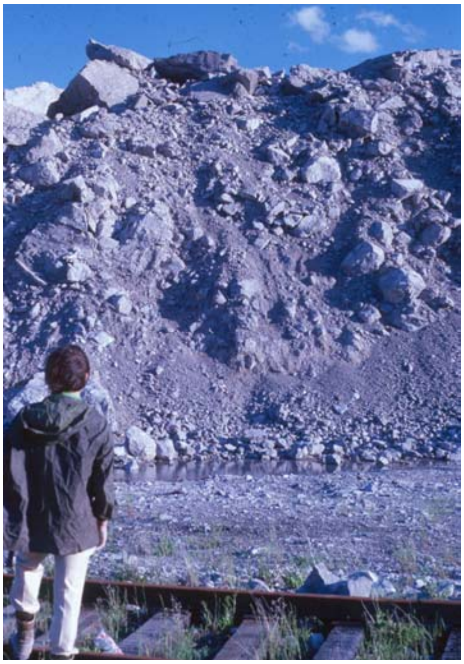
(Shreve, 1968 and others)



Rock avalanche debris is usually inversely graded.

Fall-out cones or fans are not observed

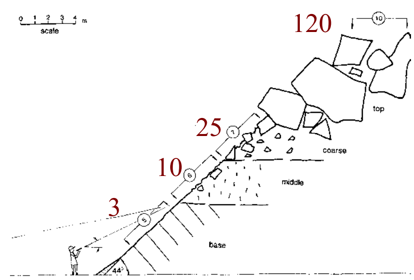




Frank slide debris

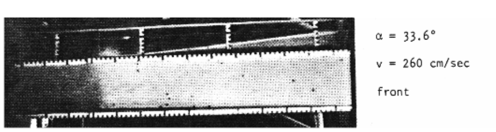
(Cruden and Hungr, 1983)

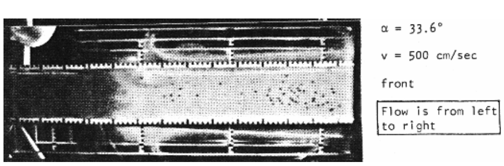
D_{50}(cm)

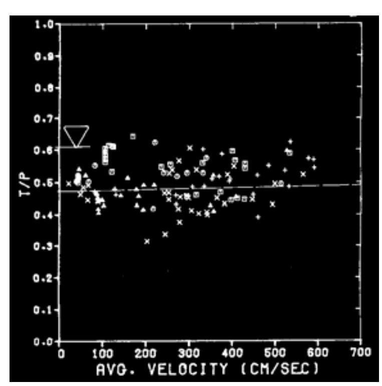


Mechanical Fluidization?

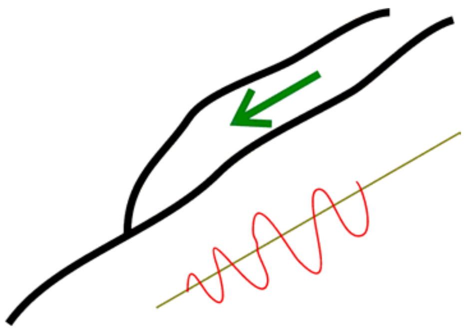
High speed flume tests (Hungr, 1981)







Acoustic fluidization ? (Melosh, 1979)

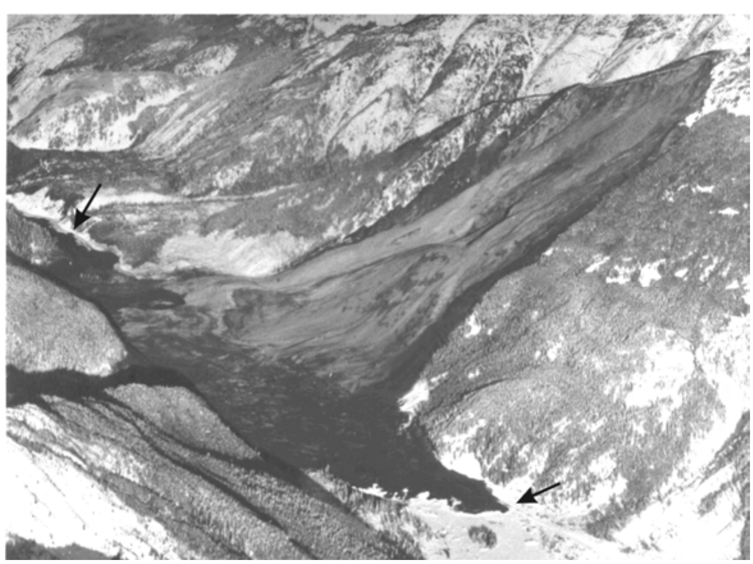


Vibration created by the boundary conditions of the flow bed (not a material characteristic)

-Is the vibration harmonic?

-Why volume dependence?

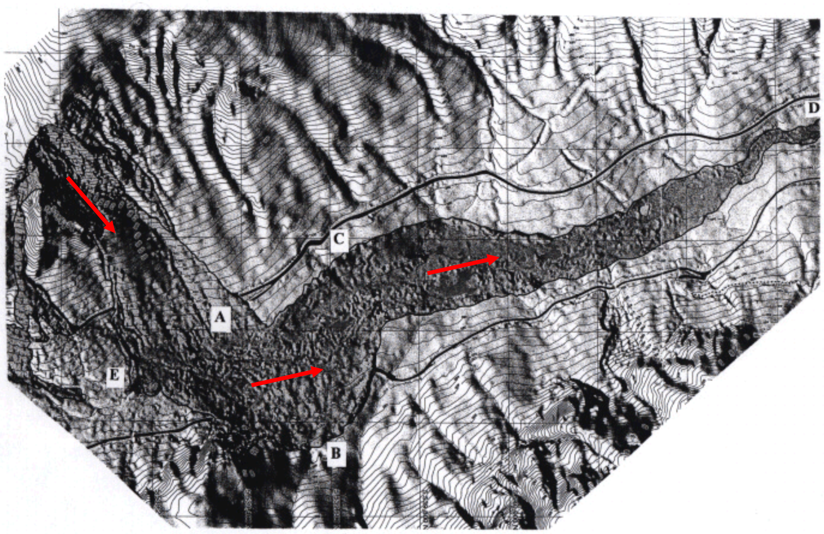
Displacement of alluvium, Hope Slide, B.C. (1964)



Displacement of alluvium, Frank Slide, Alberta (1903)

Coal waste dump flow slide

Rock slide-debris avalanche



Nomash River, Vancouver Island

Nomash River debris deposit

proximal

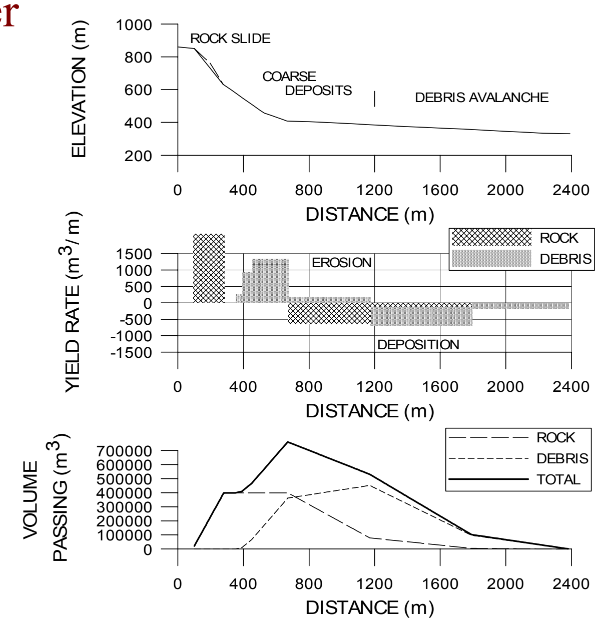
distal

Nomash River

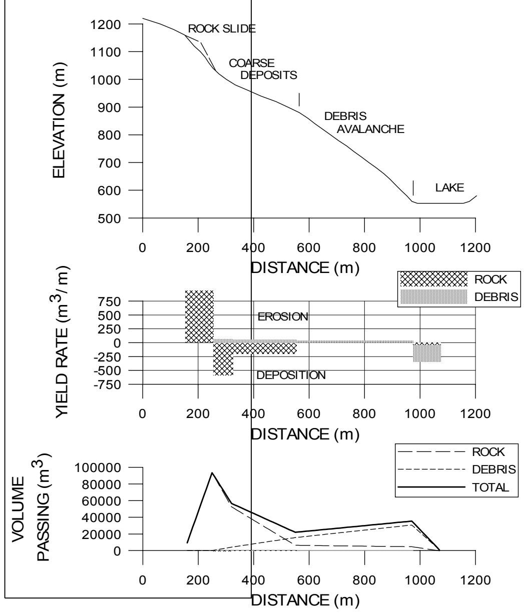
Profile

Yield rate (m^3/m)

Volume balance

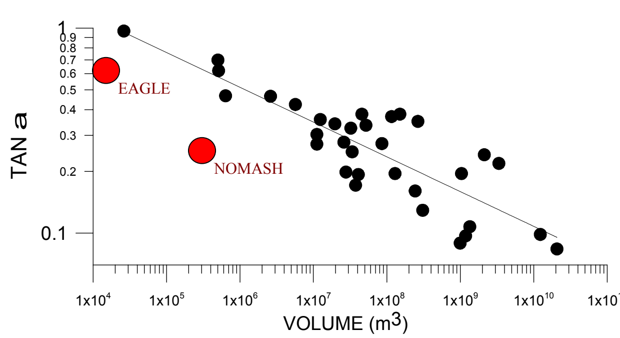


Eagle pass slide, B.C. Interior

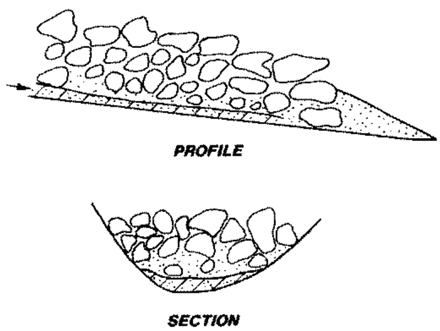


Material entrainment:

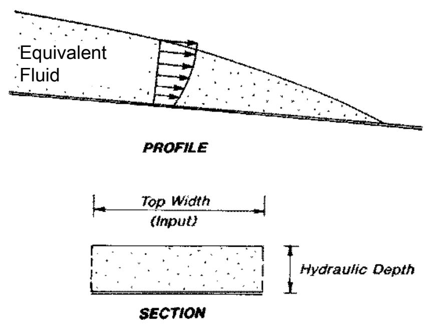
1. Increases volume
2. Lubricates base of the slide
3. Increases mobility



Modelling: concept of equivalent fluid

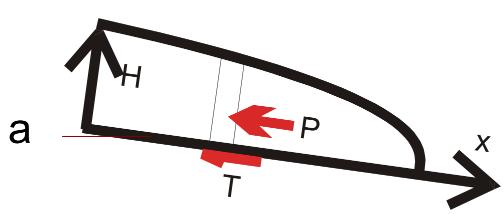


Prototype



Model

Modelling: St.Vennant Equation, Eulerian



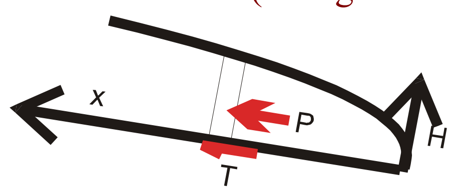
$$\beta v \frac{dv}{dx} + \frac{dv}{dt} = g \sin\alpha - \frac{T}{\rho H} - gk \cos\alpha \frac{dH}{dx}$$

Acceleration =

Gravity – friction – pressure term (P)

St.Vennant Equation, Lagrangian

(Savage and Hutter, 1988)



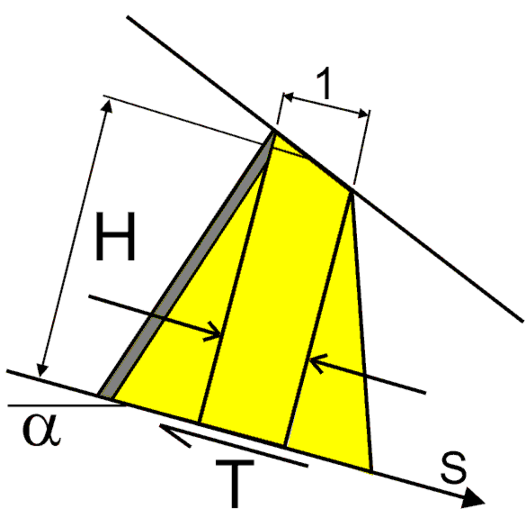
Moving Coordinate system

$$\frac{dv}{dt} = g\sin\alpha - \frac{T}{\rho H} + gk\cos\alpha\frac{dH}{dx}$$

Acceleration =

Gravity – friction – pressure term (P)

Dynamic equilibrium of a column



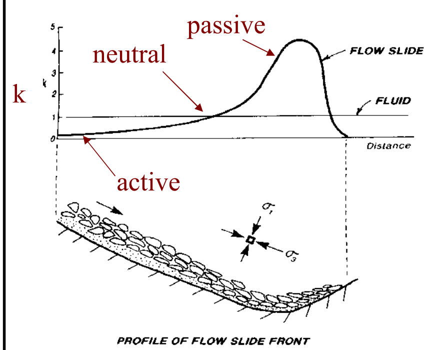
T = resisting stress

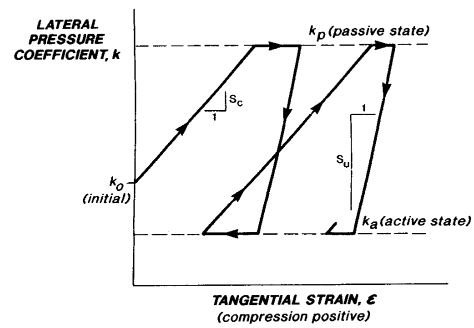
Pressure term:

$$P = \gamma k \frac{dH}{ds} H\cos\alpha$$

k – lateral pressure coefficient

Lateral pressure in a flowing debris sheet





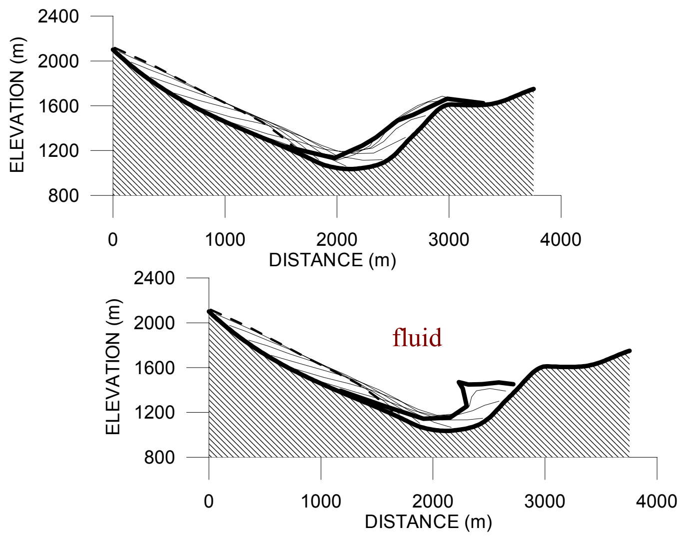
Avalanche Lake runup,

Northwest Territories

(Evans et al, 1994)

600

“Frictional fluid”



Resisting force, T

Frictional: $T = (\sigma - u) \tan \phi$

Plastic: $T = \tau$

Viscous: $T = \dfrac{3V\mu}{H}$

Bingham: Yield stress + viscous effect

Voellmy: $T = (\sigma - u) \tan \phi + \gamma \dfrac{V^2}{\xi}$

Friction and pore-pressure

"Bulk friction angle"

$$\tan\phi_b = (1 - r_u)\tan\phi$$

Pore-pressure ratio

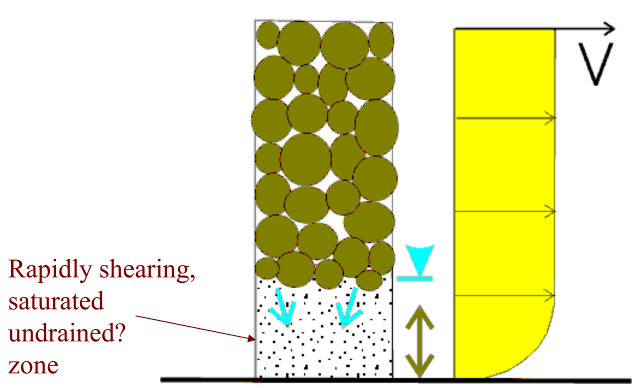
$$r_u = \frac{u}{\sigma_v}$$

Is r_u constant?

1) Stress level changes (thinning = dilation)
2) Velocity changes (increasing v = dilation)
3) Consolidation drainage ("diffusion")
4) Mixing, "autosuspension"
5) Comminution (grain crushing, Sassa, 2002)
6) Entrainment of material (colluvium, alluvium etc)
7) Entrainment of surface water

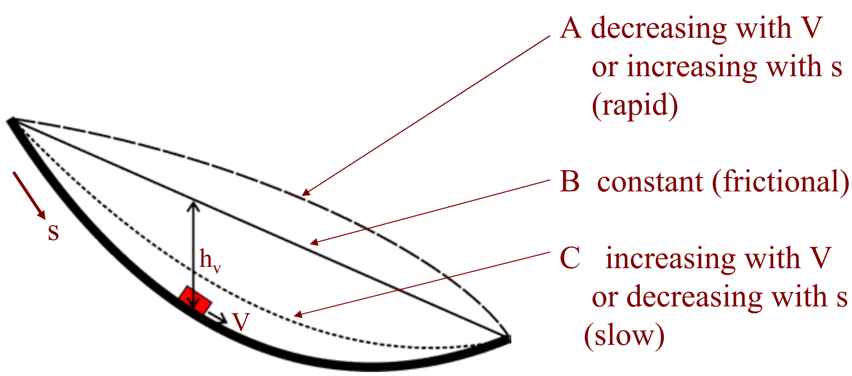
Voellmy model (Voellmy, 1955, Koerner, 1976)

$$T = (\sigma - u)\tan\phi + \gamma\frac{V^2}{\xi}$$



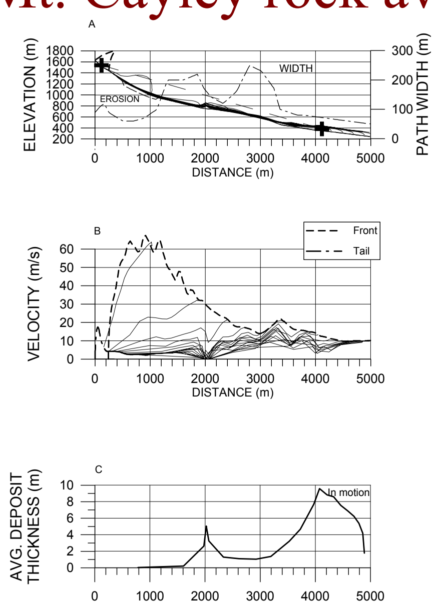
Velocity Head Concept (Koerner, 1976)

The resisting force is:



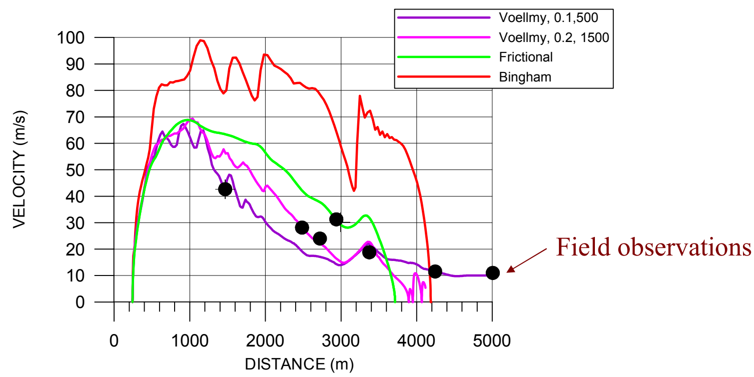
Mt. Cayley rock avalanche, 1983

(Evans et al., 2001)



Front velocity profile, Mt. Cayley

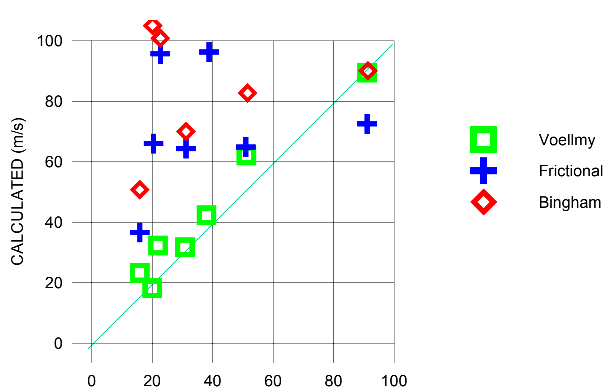
(Evans et al., 2001)



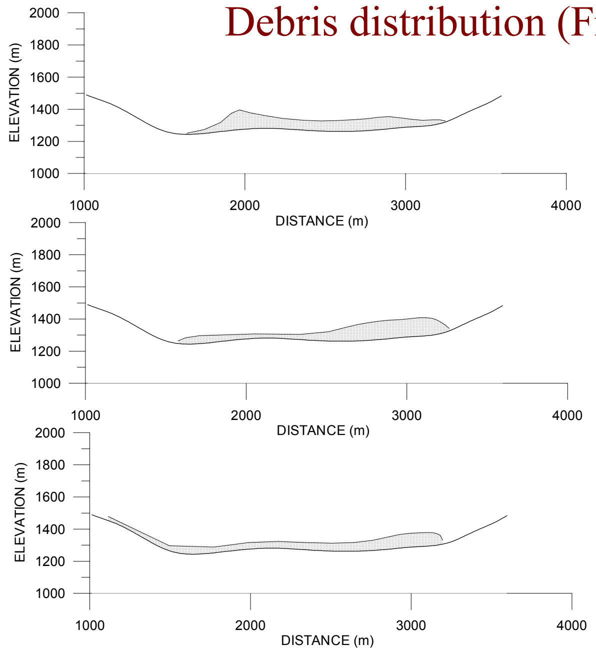
Frictional: fi=30, ru=0.45
Bingham: tau=18kPa, viscosity=1 kPa.s

Velocity comparison

(23 rock avalanches, Hungr and Evans, 1996)



Debris distribution (Frank Slide)



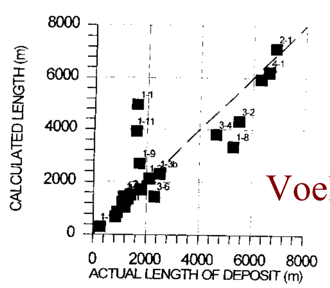
Frictional

Voellmy

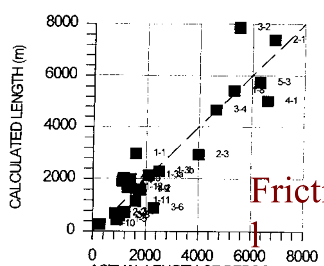
Bingham

Magnified 5x

Length of deposit comparison

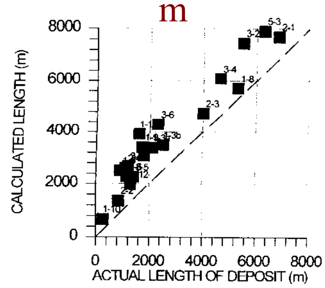


Voellmy



Frictiona
l

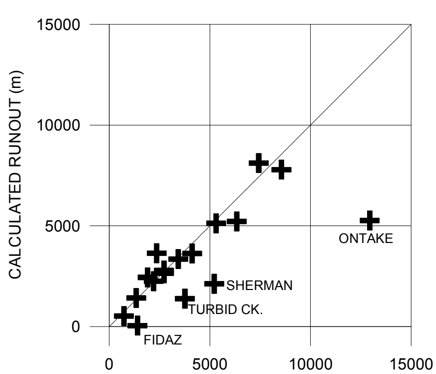
Bingha
m



Calibration:

1. Compile data on path geometry and character,
2. Debris distribution, velocities
3. Select cases similar to the slide un question
4. Run program to obtain requisite runout
5. Compare debris thickness, velocity distribution
6. Select the “best fit” rheology and parameters

Voellmy model with fixed parameters first – order prediction



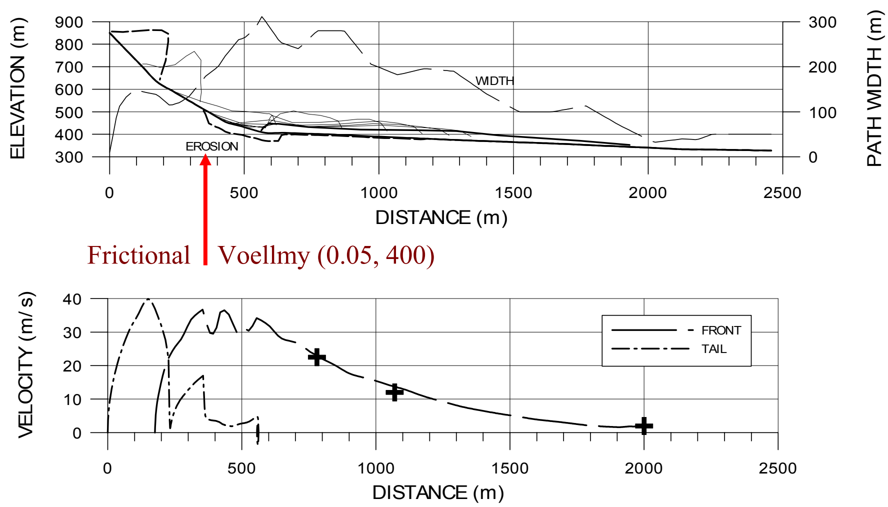
$\mu = 0.1$

$\xi = 500\ m^2/s$

Model with material entrainment

Nomash River slide, 1999

Source volume: 370 000 m^{3}Entrained debris: 400 000 m^3



Conclusions:

1. Rock avalanches are complex, but predictions are possible.
2. Our approach is to concentrate on the external aspects of behaviour. We consider the micro-mechanics intractable.
3. We should be open-minded about the rheological character of rock avalanche motion
4. Analysis must consider the character of material forming the path
5. Material entrainment should be considered