Tuesday, April 14, 2026

From susceptibility to risk. Landslide classification

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Outline of the presentation

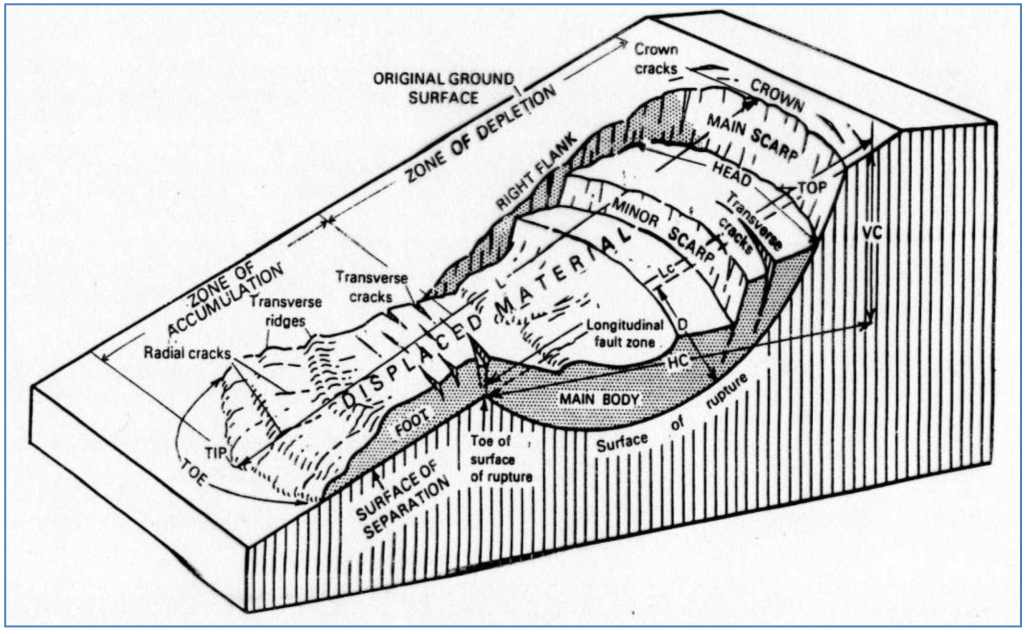
- Some definitions (need of a common terminology)
- Landslide classifications:
    - Varnes
    - Hutchinson
    - Sassa
- Landslide activity
- Flow-type slope movements
- Wildfire and landslides

Landslide Classification

Definition:
Movement controlled by gravity, surficial or deep, rapid or slow, of materials forming a slope or a whole ridge/mountain (Varnes, 1978).

Definition:
Movement of a mass of rock, soil or debris along a slope (Cruden, 1991).

Both definitions do not take into account other geological hazards, such as subsidence, sinkholes, avalanches of snow or ice.



Susceptibility

Susceptibility (S)*: probability of occurrence of a potentially damaging event in a given area.*

Hazard (H)*: probability of occurrence of a potentially damaging event in a given area and in a given time frame.*

Susceptibility and **Hazard**
in practice should respond to two simple questions

WHERE may the event occur?

WHEN may the event occur?

Definitions

Vulnerability (V)*: degree of losses of a given element or of a given group of elements at risk, resulting from the occurrence of a natural event. It is expressed by a value between 0 (no damage) and 1 (total loss).*

Risk (R)*: expected number of casualties, injured, damage to properties, destruction of economic activities, due to occurrence of a given event. It is expressed by V x H.*

Not only geologists and engineers, but need to work with economists, sociologists, land planners, etc.

Natural hazards

Messina (photo G. Iovine)

Colorado, USA (photo: S. Cannon)

Amalfi Coast

PREVENTION

Often, work in the shade, not very visible

↓

inadequate political weight, poor public agreement.

EMERGENCE

Strong visibility, high emotional impact, huge support/solidarity.

For any type of "natural disaster", the social and the economical costs of prevention actions are much less that those necessary to manage the phases of emergence and re-construction.

Prevention does not involve only politicians and decision makers (will in using funds and resources) and the research bodies, but the whole population. **It is a cultural problem.**

"Natural" hazards

But…… are they really "natural"?

Or, in some way, human actions "prepare", "help",

"determine" their occurrence?

And, above all, amplifies their effects?

LECCEPRIMA DOMENICA, 15 SETTEMBRE 24°

GALLIPOLITODAY A cura di Redazione

"Crollo a Gallipoli: sottovalutate alcune avvisaglie"

La Federconsumatori locale ricorda il precedente "sprofondamento di un tombino in via Firenze". E si chiede: "Il cedimento è stato davvero causato solo dalle piogge o ci sono altre cause?"

Redazione LeccePrima · 1 Aprile 2007

"Le cause del disastro non sembrano ancora del tutto chiare. E', infatti, risaputo che la zona di via Firenze ha un sottobosco di cave su cui sono state costruite strade e abitazioni, forse in modo non proprio oculato. Ma il crollo di questi giorni, che ha attentato all'incolumità pubblica e, in particolare a quella dei residenti ed eventuali passanti, è stato solo un effetto delle piogge di questi ultimi giorni?". E' questa la domanda che si pone Tina Palermo, responsabile della sezione gallipolina di Federconsumatori.

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IL TRATTO DI STRADA CHIUSO AL TRAFFICO

Frana un pezzo della provinciale 126 Celle San Vito resta di nuovo isolato

Cade palo della linea telefonica: interrotte comunicazioni

Il piccolo centro foggiano al momento è irraggiungibile

FOGGIA - Nuovamente isolato Celle San Vito, il piccolo centro foggiano a causa di uno smottamento sulla provinciale 126 che ha reso intransitabile la strada: unica via di collegamento con gli altri paesi della provincia di Foggia. In poche settimane è la seconda volta che Celle San Vito rimase tagliata fuori da ogni tipo di collegamento stradale: il 9 febbraio scorso, il più piccolo paese della Puglia, era rimasto isolato a causa della neve.

La strada non è percorribile

Ieri sera è franata un pezzo della provinciale 126: subito dopo l'allarme sul posto è giunta una squadra dei Vigili del fuoco che constata la pericolosità dell'arteria hanno disposto la chiusura di un tratto della

Petacciato

Silvi

Niscemi

Resilience

Initially proposed in the 1970s in the field of ecology, referred to ecosystems.

Widely used recently to indicate the capability of a system to adsorb perturbations.

As concerns natural disasters, resilience is the **capability to resist and to recover losses due to disasters**.

Three components:

- ✓ response to the perturbation event;
- ✓ capability of self-organization; and
- ✓ capability to learn and adapt.

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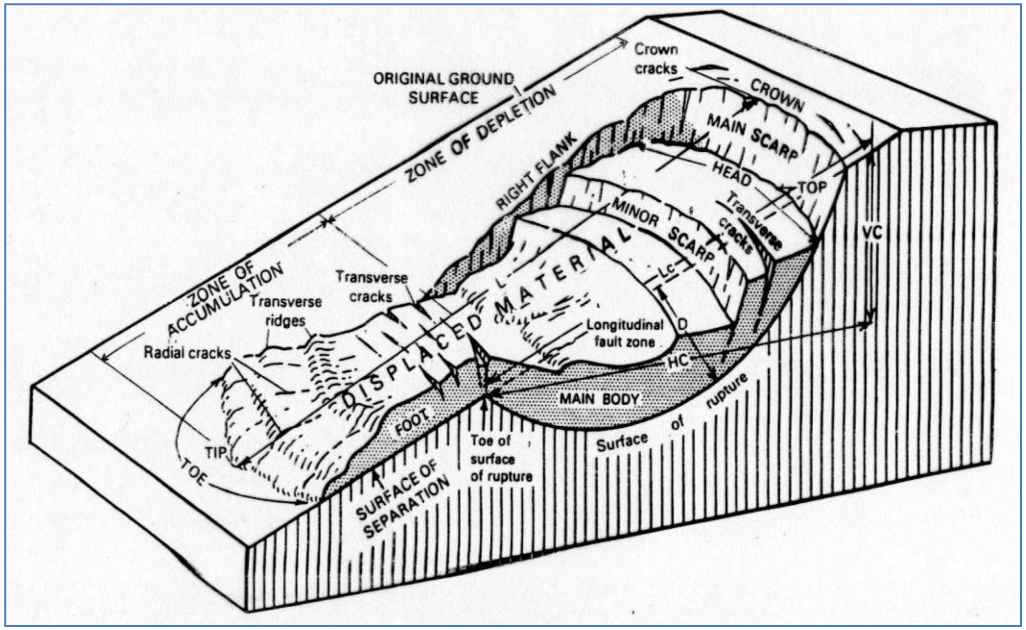


Landslide Classification

Main character-guides in landslide classification

1. **Causes of movement**
2. **Duration and recurrence of movements**
3. **Type and mechanical properties of involved materials**
4. Characters and possible pre-existence of a **failure/sliding surface**
5. **Type of movement**
6. Variety of **characters-guide**

David J. Varnes

(1919-2002)

USGS

science for a changing world

Classification of Varnes (1978)

Type of material

Rock mass: in situ rock, including the discontinuities.
Rock: natural material that, in samples ouside of its place, shows high cohesion, even after prolonged contact with water.
Soil: natural material consisting of aggregates of grains that can be separated through sollecitations or through more or less prolonged contact with water. Based upon grain size, it is possible to distinguish debris and earth.

Type of movement

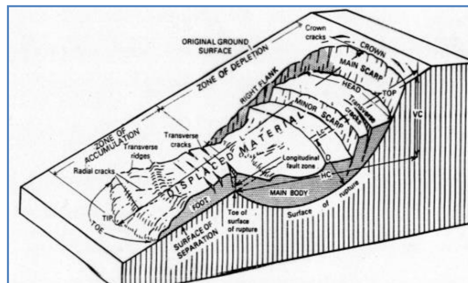
Fall

Topple

Slide

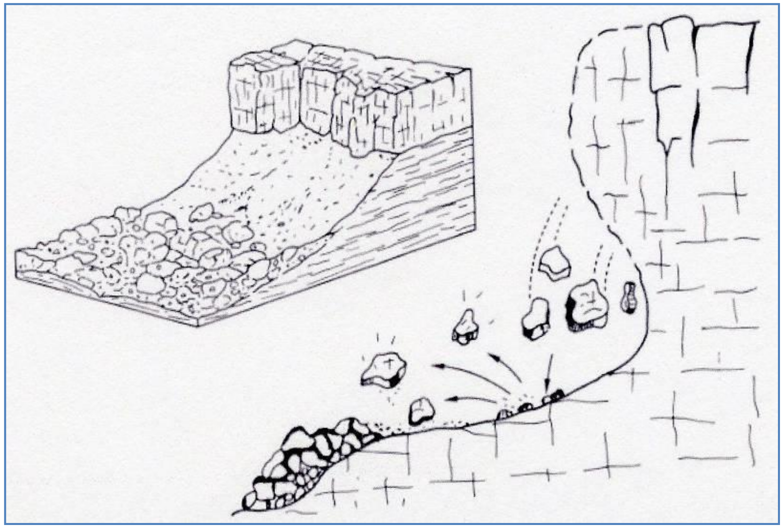
Lateral Spreading

Flow

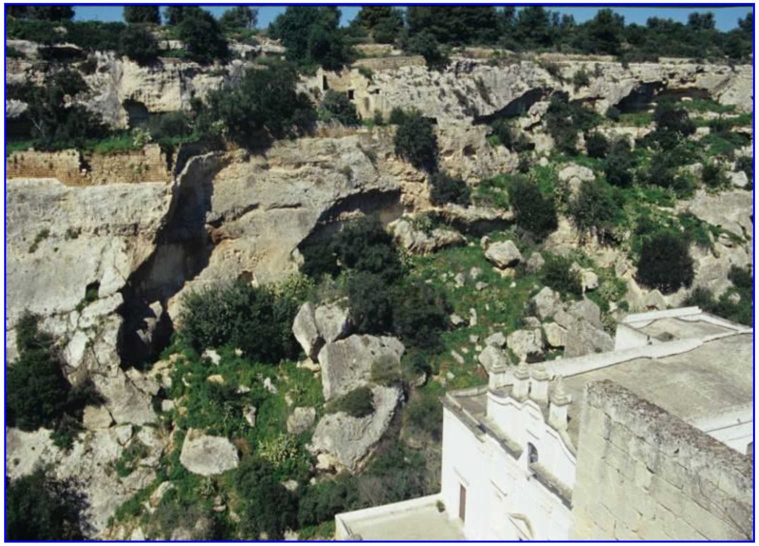


Later on, Cruden & Varnes (1996)

Fall

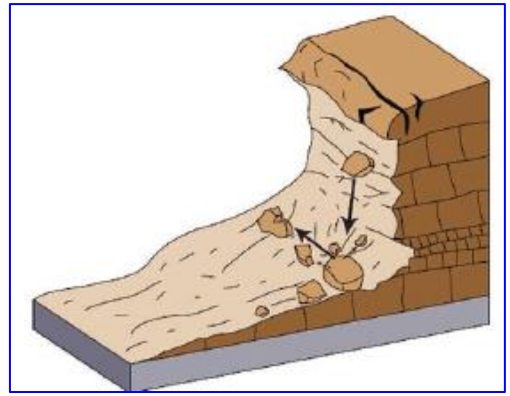


Detachment of variable volumes of rock (from small blocks to huge boulders), which **movement occurs in free air by gravity**. The impact with the slope below will determine fragmentation of the landslide material, or induce further movement, in the case of steep slopes.



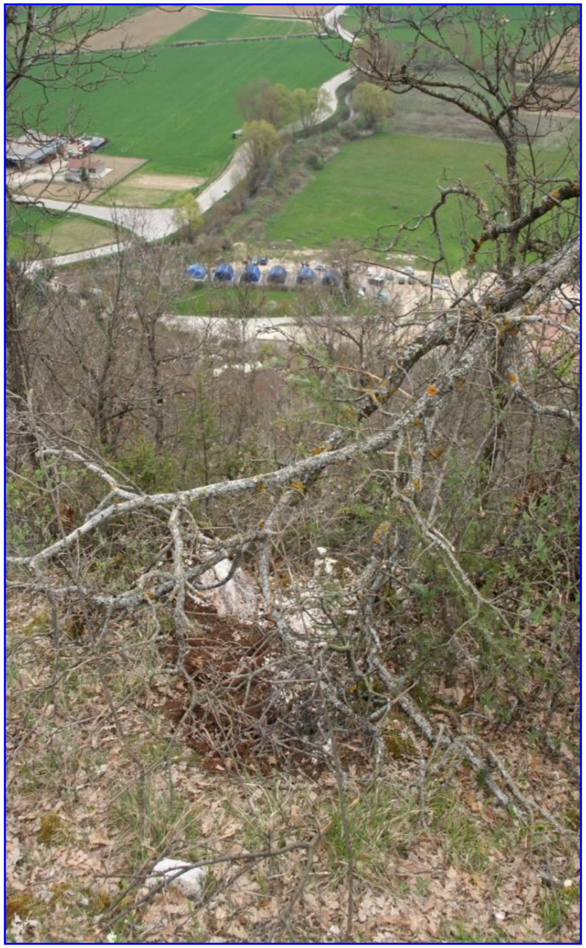
Fall

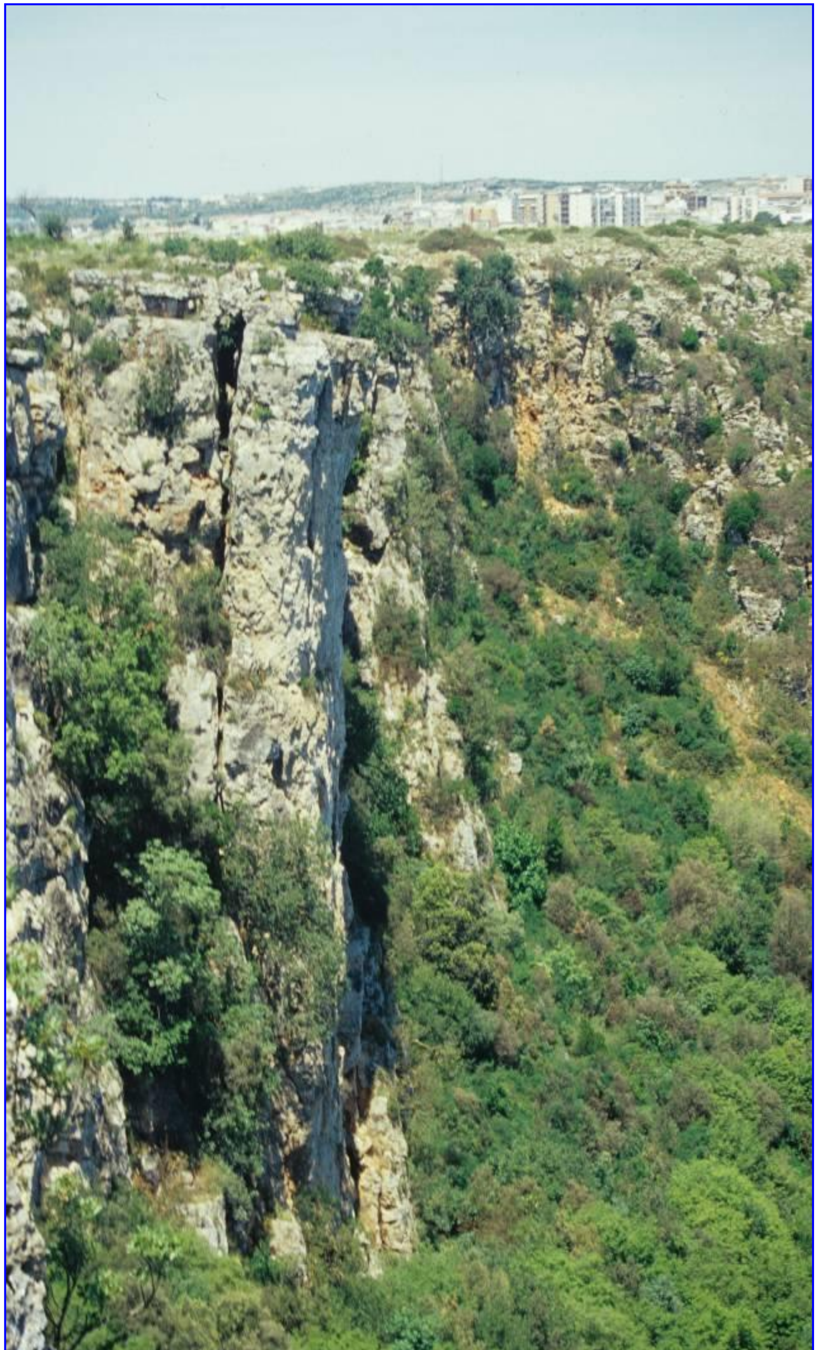
Campania, S Italy



Cappadocia, Turkey

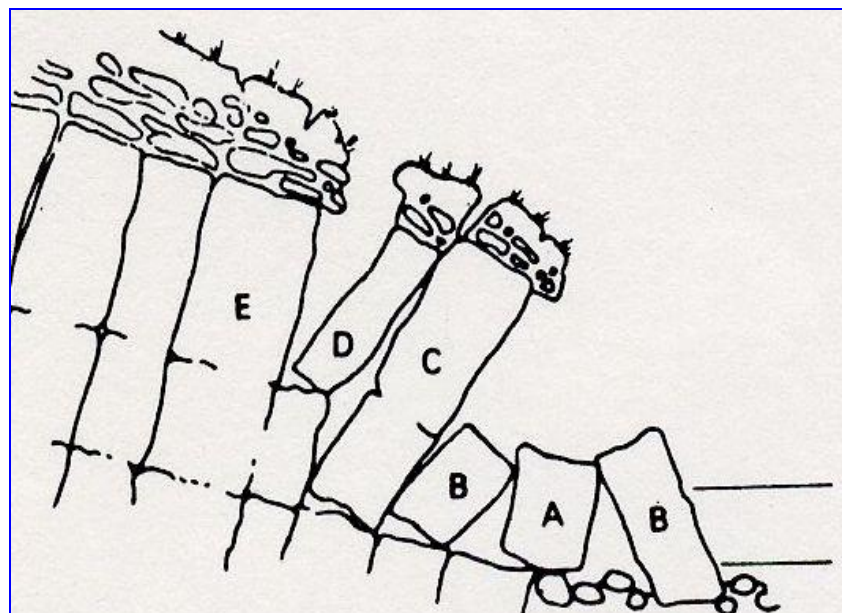
Fall





Topple

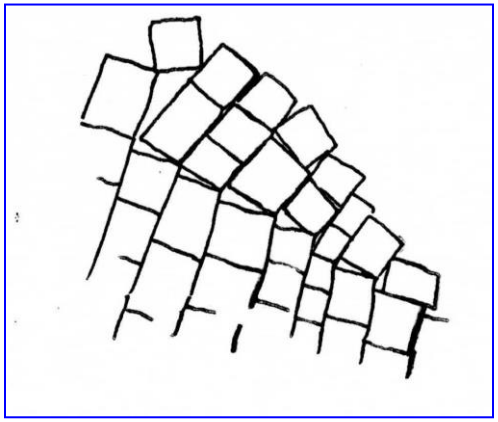
Topple failures affect rock masses characterized by presence of clear vertical or sub-vertical fractures.
The movement occurs by forward advancement of the rock pillars or towers, around a **rotation point situated below the baricentre** of the affected mass.



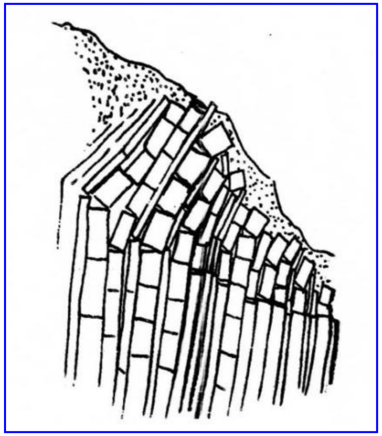
Topple

Flexural topple. Sub-vertical discontinuity system dipping toward the inner slope, delimiting semi-continuous columns or prisms of rock.

Block topple.
Columnar volumes of rock are subdivided by transversal discontinuities with wide spacing.



Flexural topple with blocks. Failure mechanism characterized by about continuous folding along the rock prisms, subdivided by several transversal discontinuities.

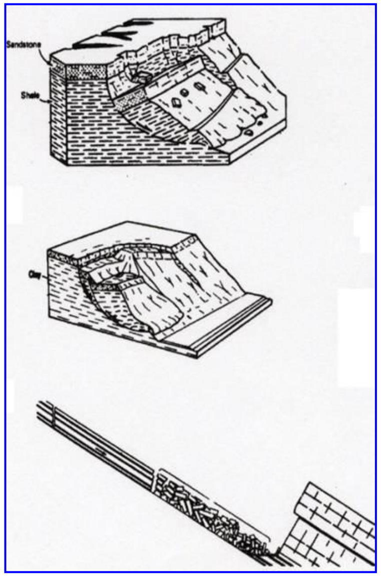


Slide

Movement occurs by **shear failure** along one or more rupture surfaces.

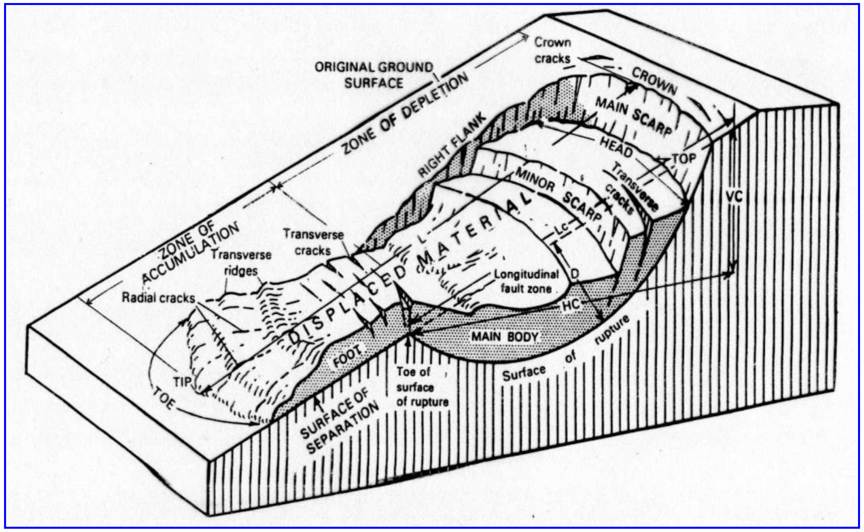
The failure surfaces are visible or may reasonably be reconstructed.

Slides are distinguished in rotational slides and translational slides, depending upon the shape of the failure surface.



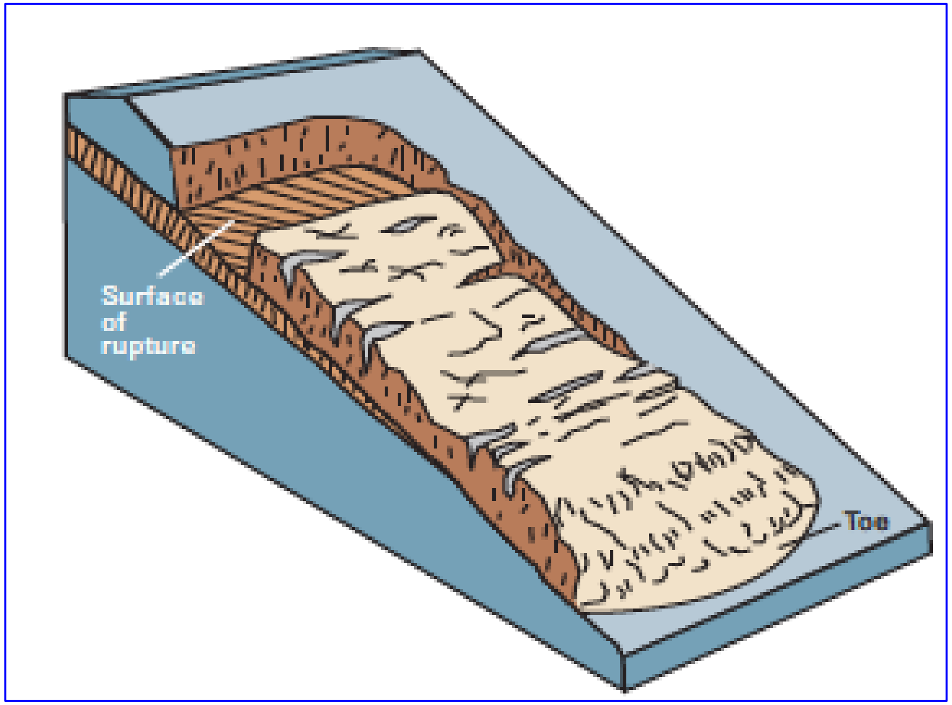
Slump

Rotational slides



Rotational slide (slump)

Slide



Translational slides

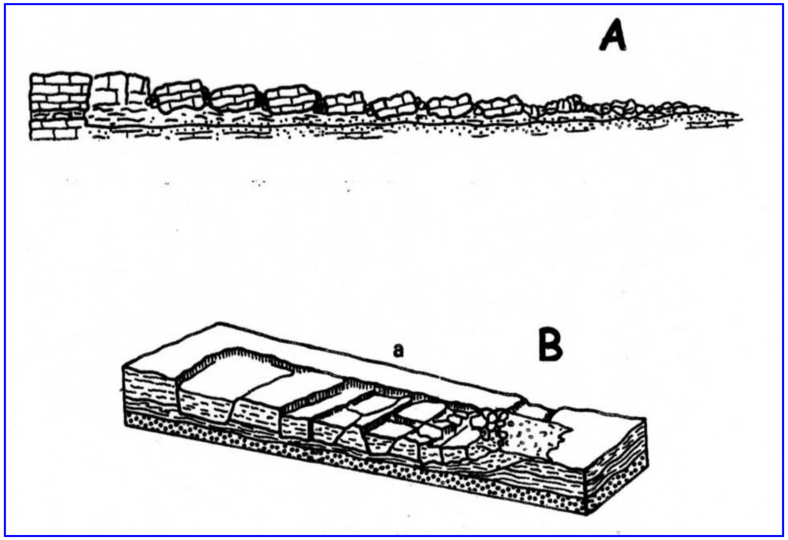
British Columbia, Canada

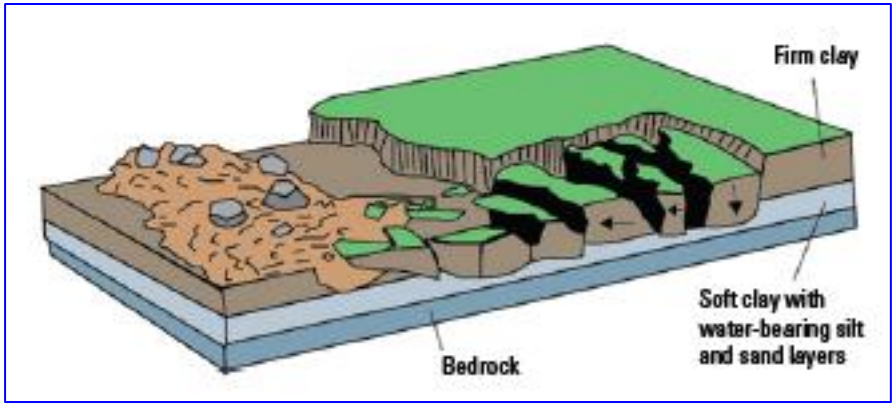
Lateral spreading

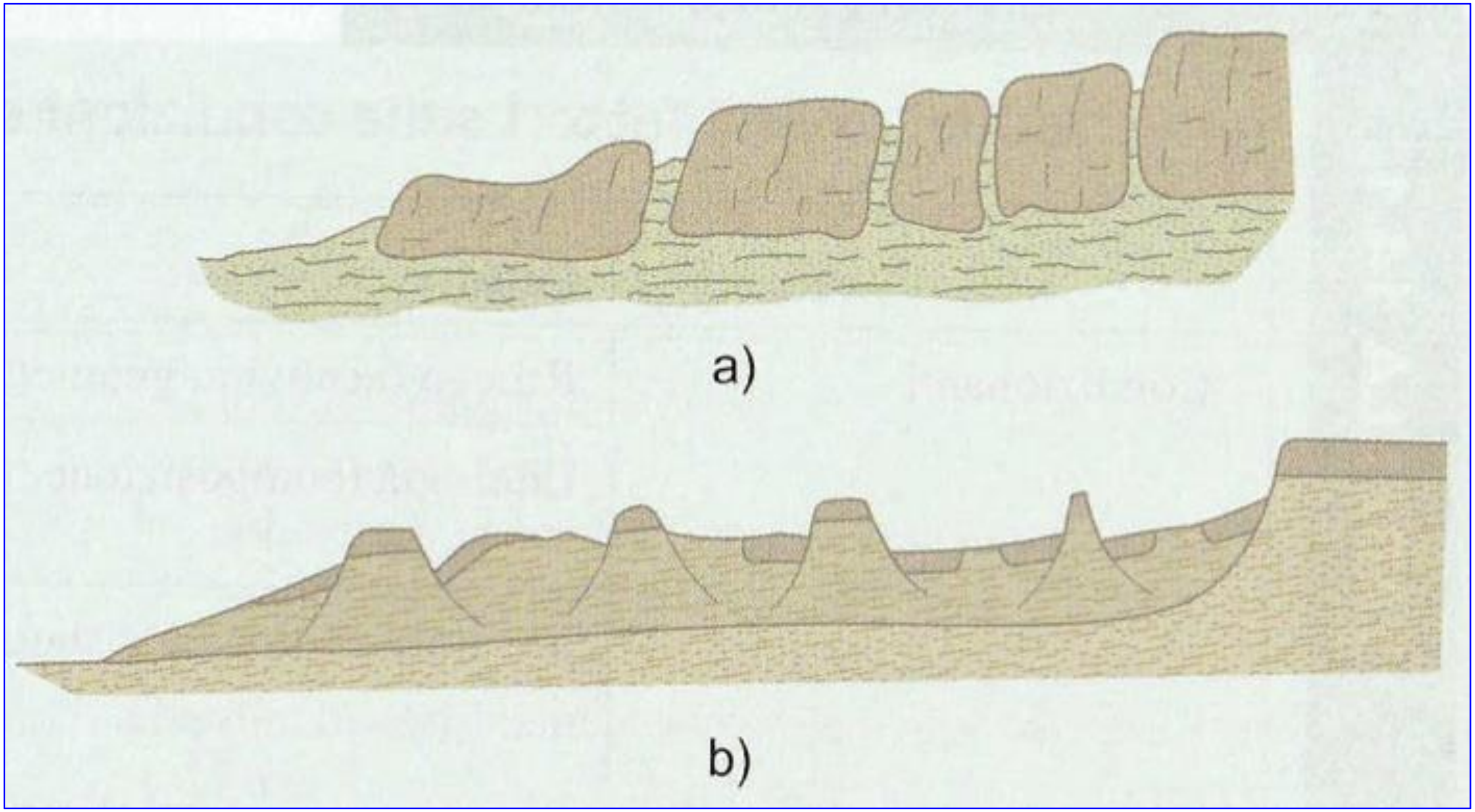
Movements, diffuse within a fractured rock mass, occurring in the two following modalities:

A – it is not possible to recognize a **basal surface of failure**, or a zone with well-defined plastic deformations;

B – lateral spreading of the rock or of the soil is due to **liquefaction** and/or to **plastic deformations** in the material below.





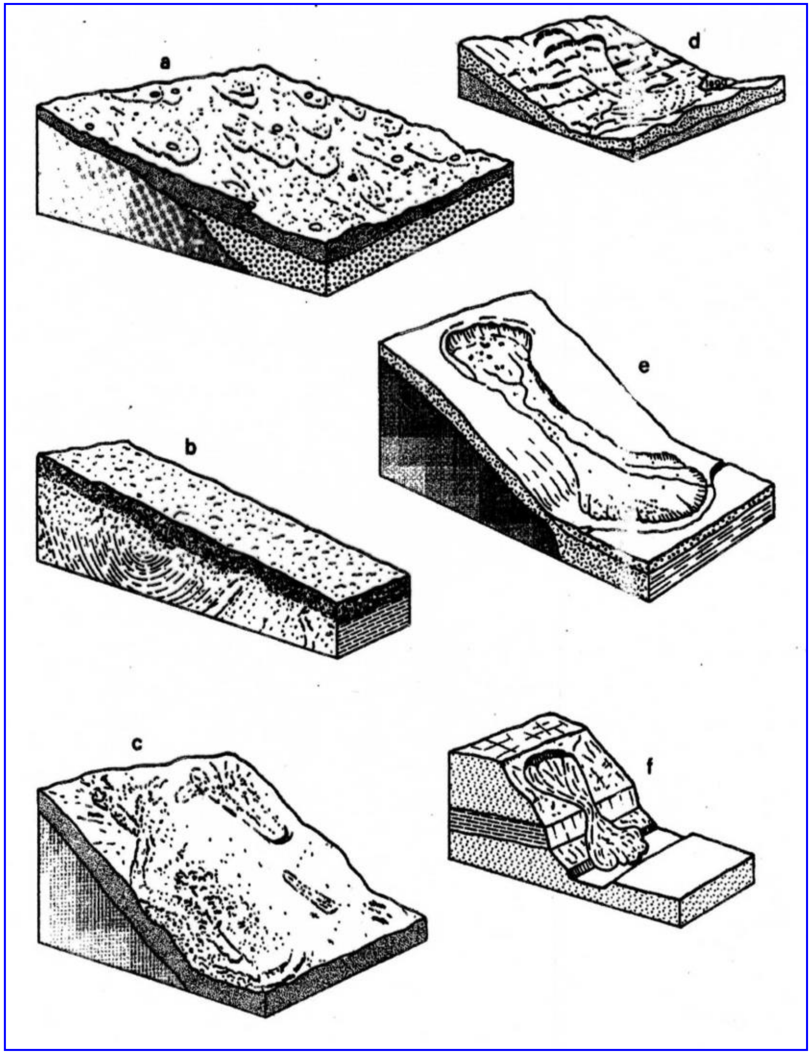


Gonzalez de Vallejo, 2005

Lateral spreading by: a) flow and extrusion of the underlying material; b) liquefaction.

Lateral spreading may affect **slopes with low to very low gradient**, even flat slopes. This character differentiates lateral spreading by all other types of slope movements.

Flow



Movements within the displaced mass such that the form of the moving material or the apparent distribution of velocity and displacements are similar to those of **viscous fluids**.

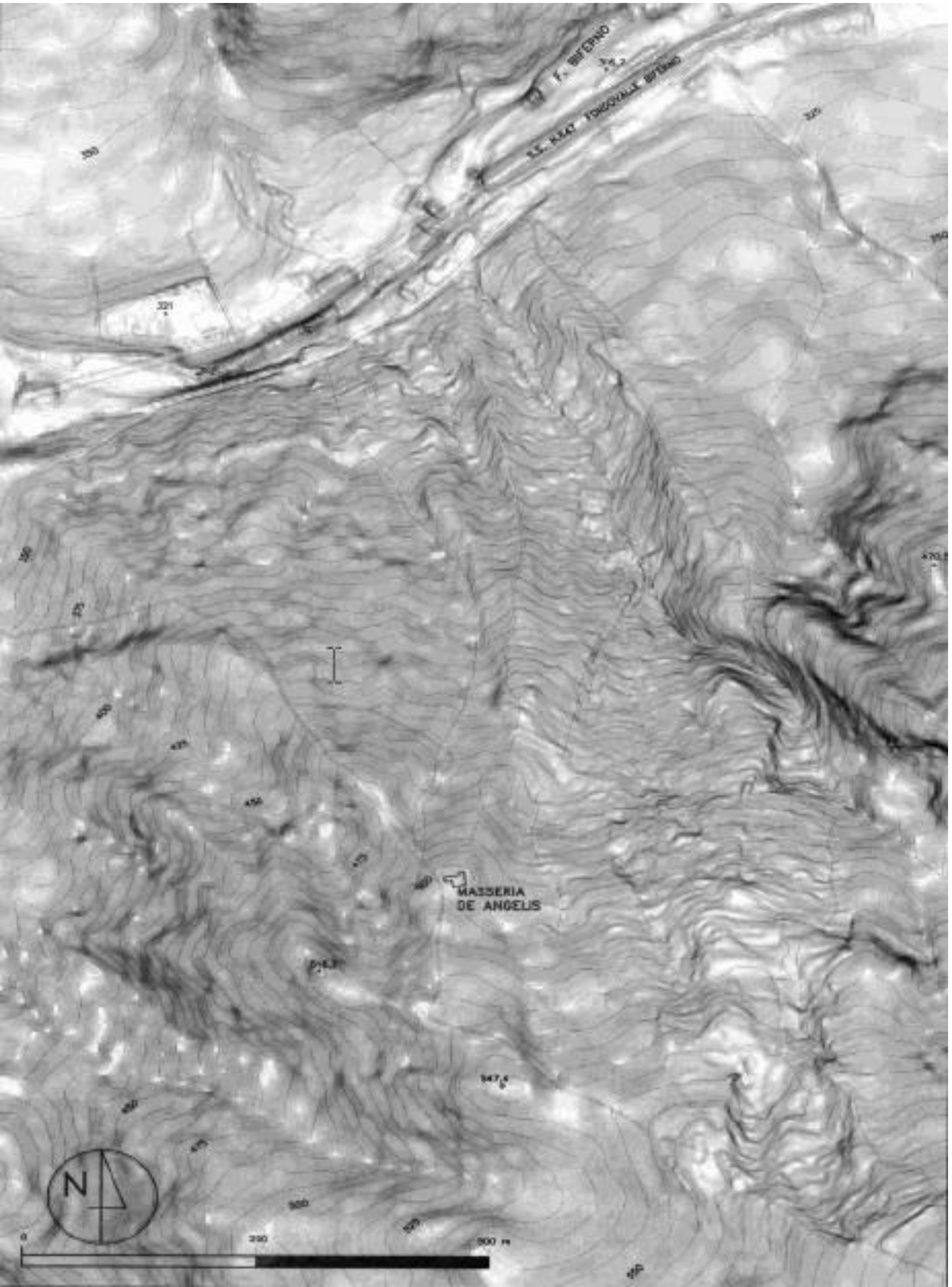
The failure surface are **typically not visible** within the moving mass, or they have short life.

The **boundary** between the moving mass and the in place material may be a clear surface of differential movement, or a zone of distributed displacements.

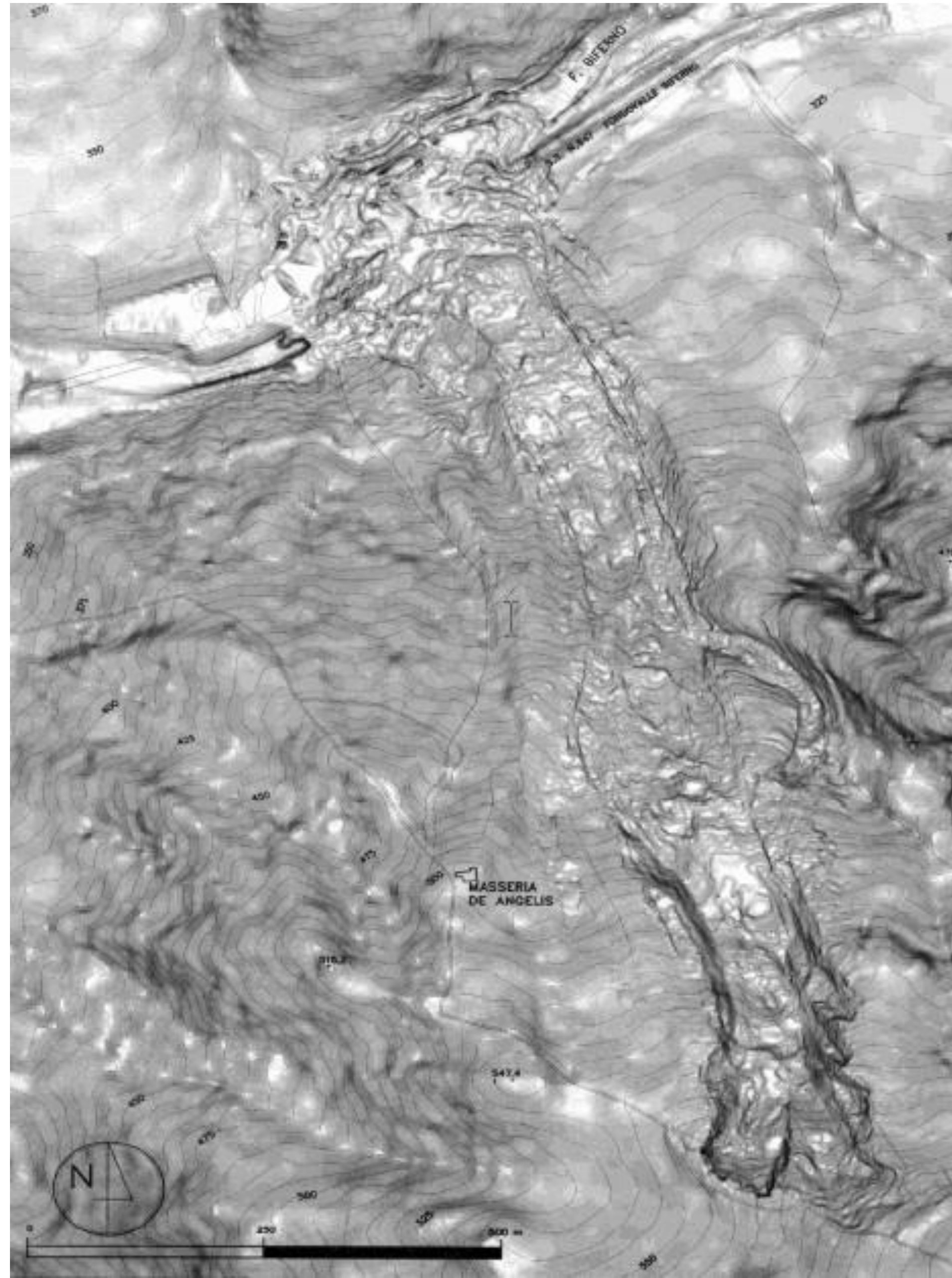
Flow

The flow at locality Covatta, catchment of the River Biferno (Molise)

Before



After



Slumgullion earthflow, San Juan Mountains, Colorado

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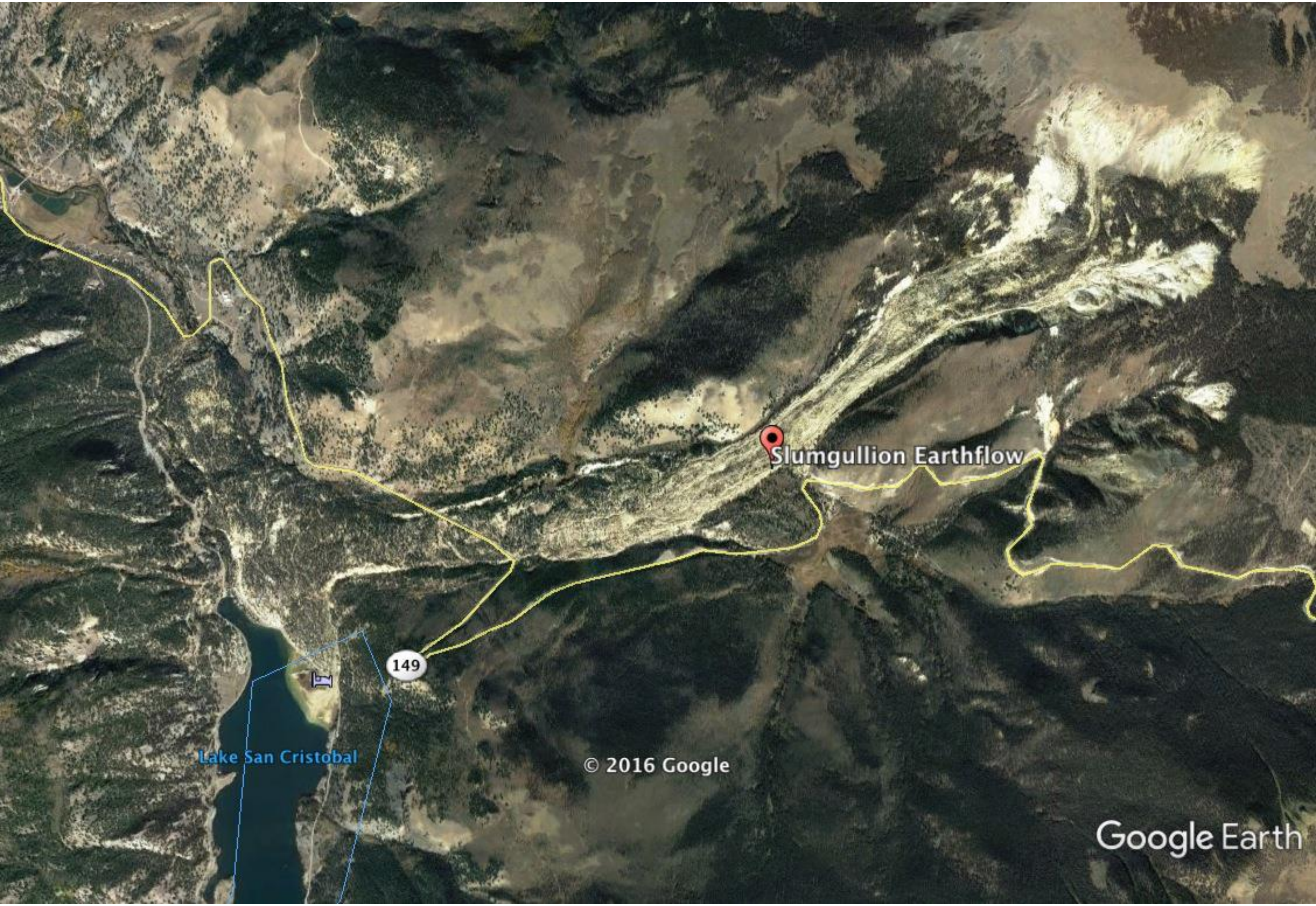
Slumgullion earthflow, San Juan Mountains, Colorado


Slumgullion Earthflow
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Lake San Cristobal
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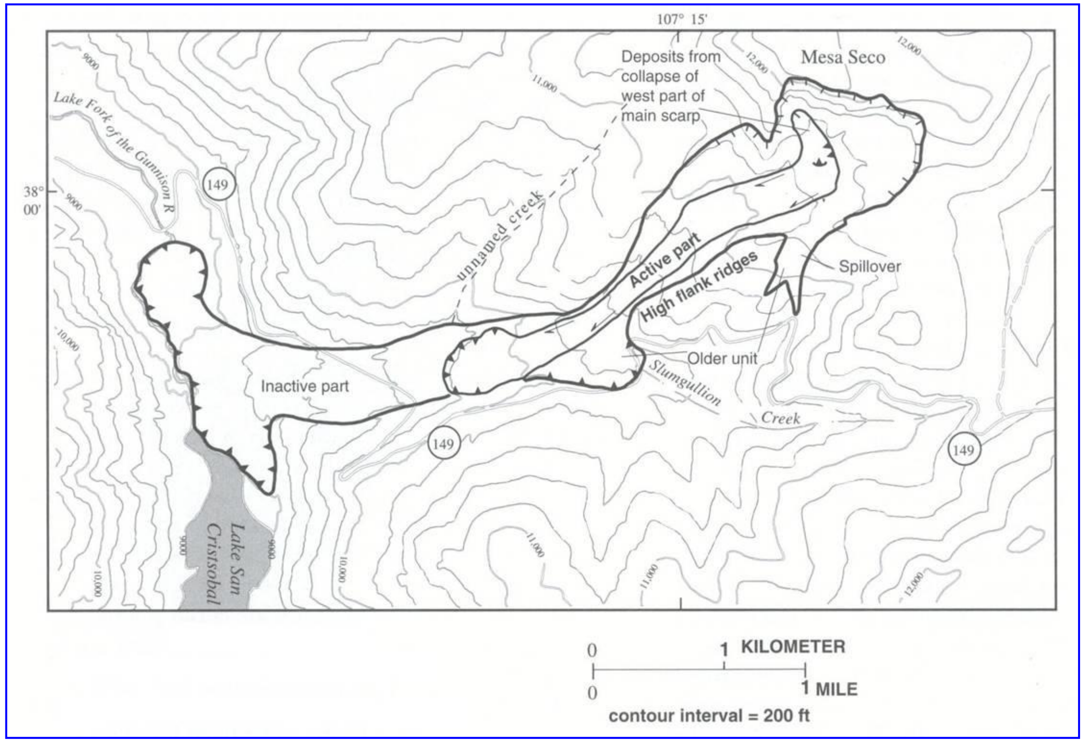
Slumgullion earthflow, San Juan Mountains, Colorado



	Area	*Length*	*Width*	*Average slope*	*Thickness*	*Volume*
Dimensions of the inactive landslide	4.74 km^2	6.8 km	1.130 m 290 m	8°	40 m 140 m	168 x 10^6 m^3
Dimensions of the active landslide	1.46 km^2	3.9 km	150 m 430 m	11°	13 m 48 m	19.5 x 10^6 m^3

Parise and Guzzi, 1992

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Flows: main elements

Distinguishing feeding area, transport sector, and accumulation zone.

Feeding area: single or multiple. Often it coincides with a different category of landslide (es., slump, or slide).

Sector of transport: typically, a narrow and elongated channel, with lower width than the uphill and downhill sectors. It generally represents the longest portion of the flow.

Accumulation zone: characterized by a clear morphological bulge, deriving from the landslide material accumulation. Possibility of more than one internal foot, due to many impulses in the flow movement.

Flows with multiple alimentation areas

Alimentation with several source areas, that later merge within a unique main channel

Wide landslide feet in the final sector of the landslide, showing evidence of several phases of (partial or total) movement.

Flows: main elements

Flows follow the pre-existing morphologies.

Variations in the gradient of a body of a flow typically depend upon changes in the slope below, above which the flow is moving.

Distinction among:

Open slope (hillslope) flows: they move along the slope following the highest gradient, or along unchannelized preferential paths.

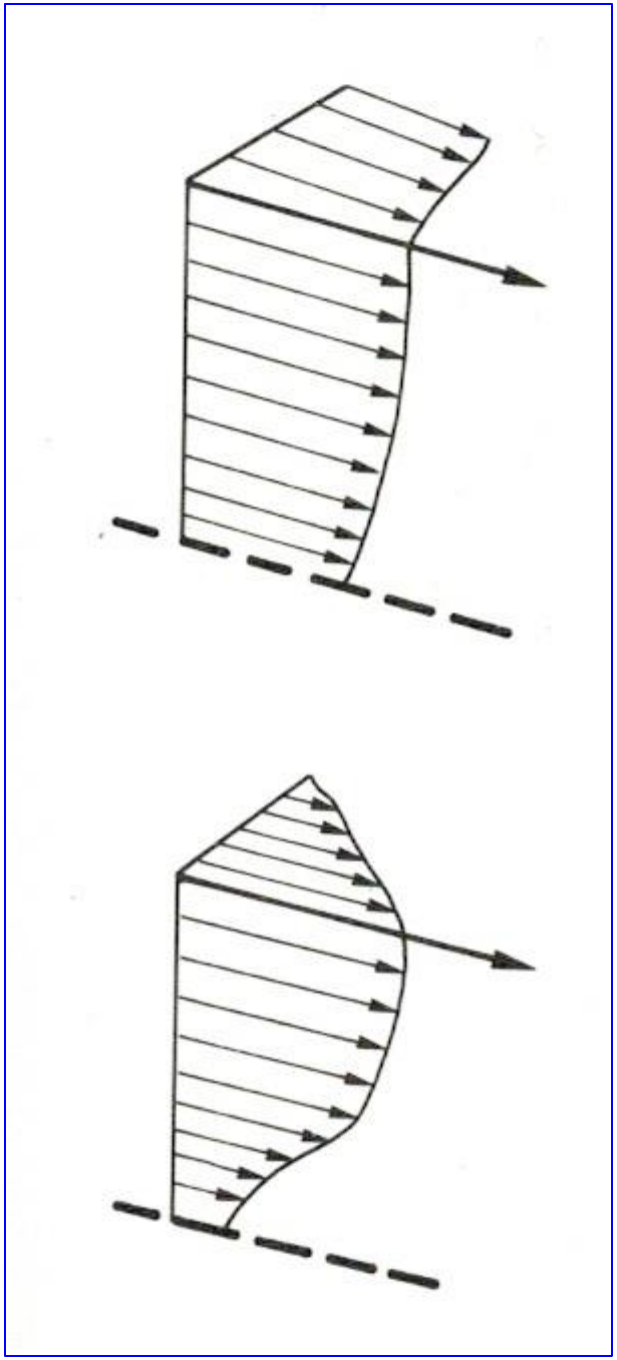
Channelized flows: they move along pre-existing incisions or valleys. When the volume is not high, they stay within the channel; or, they move outside of it.

Kinematics

Translational and viscous flows

Translational flows: movement like sliding of a rigid body, with clear shear surfaces and uniform vectors of movement. Velocity between 0.5 and 20 m/year.

Viscous flows: viscous-type movement (definition by Varnes, 1978). Vectors of movement may change also transversally. Velocity between 0.001 and 3 m/day.



Possibility of cases where viscous flows are superimposed over translational flows

Flow

Flow-type movements in granular materials

1. **Debris flows**
2. **Flow-Slides**
3. **Rock avalanches**

Flow-type movements in fine granular materials

4. **Mud Slides**

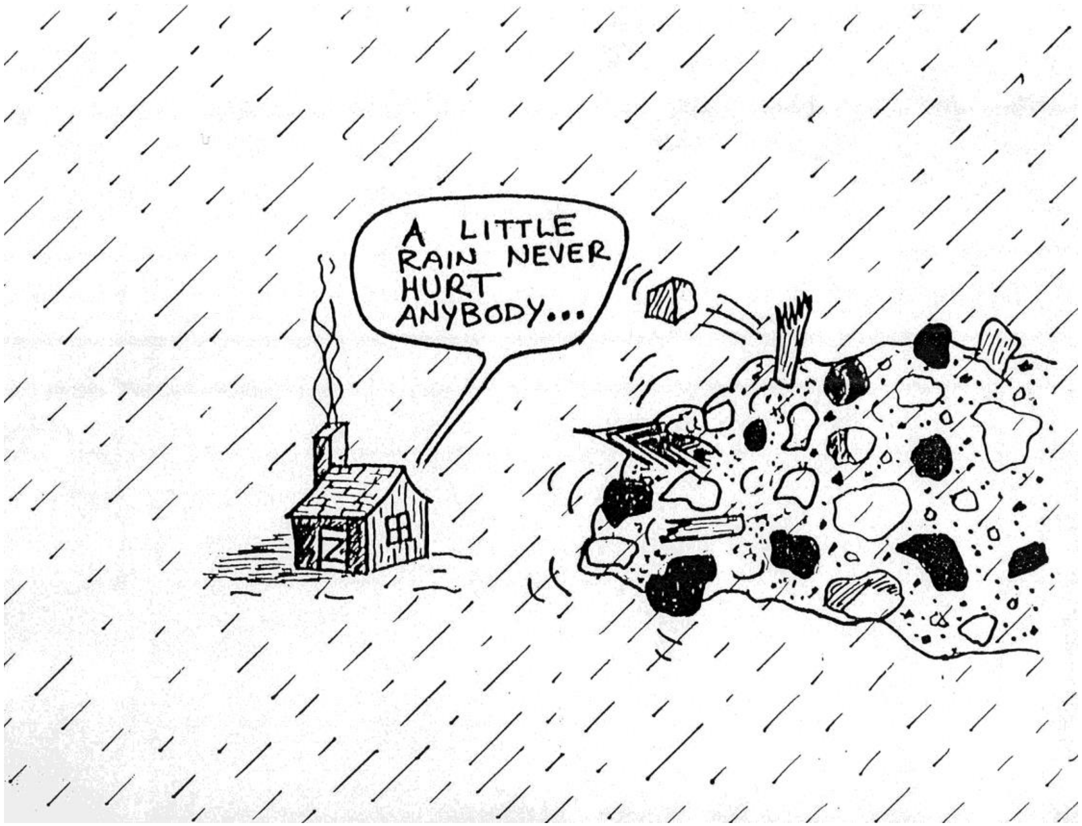
Hungr et al., 2001; Hutchinson, 2003


Debris Flows

Definition
Flow, from very rapid to extremely rapid, of rock debris of various size, mainly saturated, with low clay fraction and cohesion.

- Channelized debris flows
- Hillslope debris flows

Link with rainfall



Cinque Terre, October 25, 2011

Cevasco et al.

Cinque Terre, October 25, 2011

Cevasco et al.

Soil slips

- Surficial movements (max 1,5 m)
    - Limited length of the phenomenon
        - Rapid response after significant rainstorms

Differences between the classification by Varnes (1978) and by Cruden & Varnes (1996)

- ✓ **Complex Landslides** are canceled (the term “complex” now refers to a style of activity)
- ✓ Changes in the **scale of velocity** of landslide movement
- ✓ Definition of **style, state and distribution of activity**, following the proposals by the international scientific community

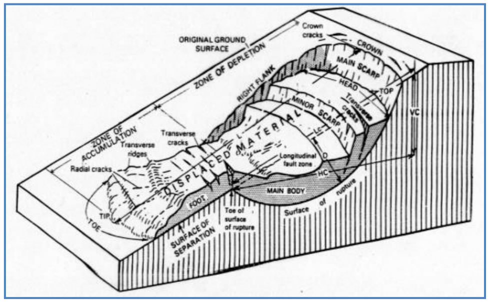
Fall

Topple

Slide

Lateral Spreading

Flow



ACTIVITY

State of activity

describes what is known about chronology of movement.

Unesco Working Party on World Landslide Inventory, 1993

STATE OF ACTIVITY	DISTRIBUTION OF ACTIVITY	STYLE OF ACTIVITY
Active	Retrogressing	Complex
Reactivated	Advancing	Composite
Suspended	Widening	Multiple
Inactive: dormant	Confined	Successive
Abandoned	Enlarging	Single
Stabilized	Diminishing	
Relict	Moving	

Distribution of activity

describes modalities of evolution of the landslide.

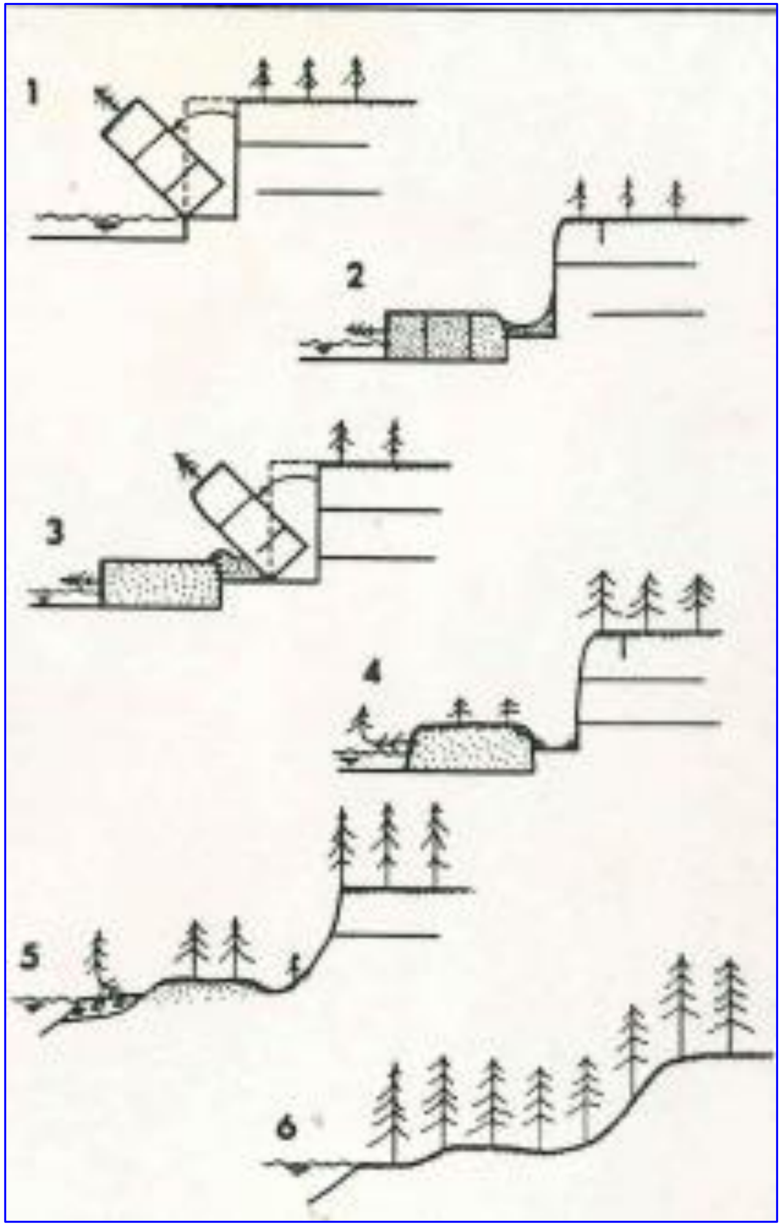
Style of activity

indicates how different movements within the landslide might contribute to its overall movement.

STATE OF ACTIVITY

describes what is known about chronology of movement.

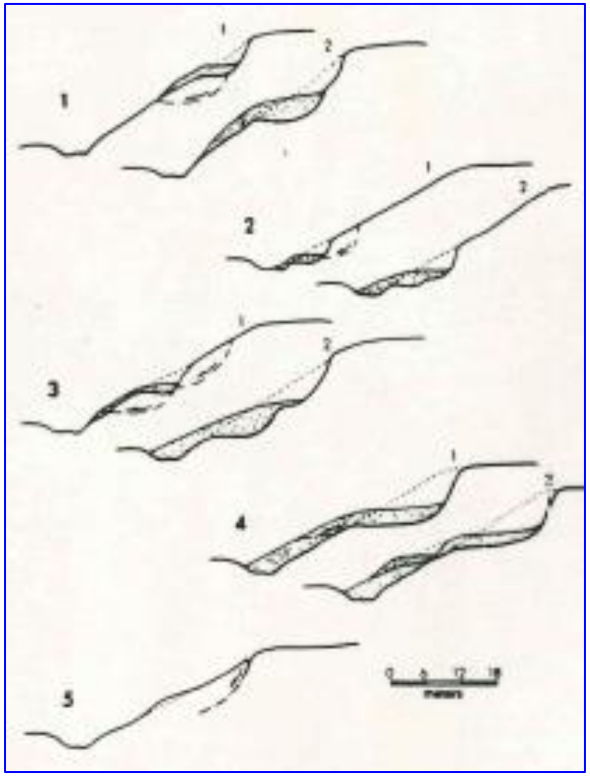
1. **Active** – erosion at the foot of the slope causes toppling of a block
2. **Suspended** – fracture in the crown area
3. **Reactivated** – another block is toppling
4. **Dormant** – depleted mass is re-occupied by vegetation and modified by weathering processes
5. **Stabilized** – fluvial deposits stabilize the landslide toe, that begins to be re-occupied by tree cover
6. **Relict** –uniform tree cover on the slope



DISTRIBUTION OF ACTIVITY

describes modalities of evolution of the landslide.

1. **Advancing**
2. **Retrogressing**
3. **Widening**
4. **Diminishing**
5. **Confined**



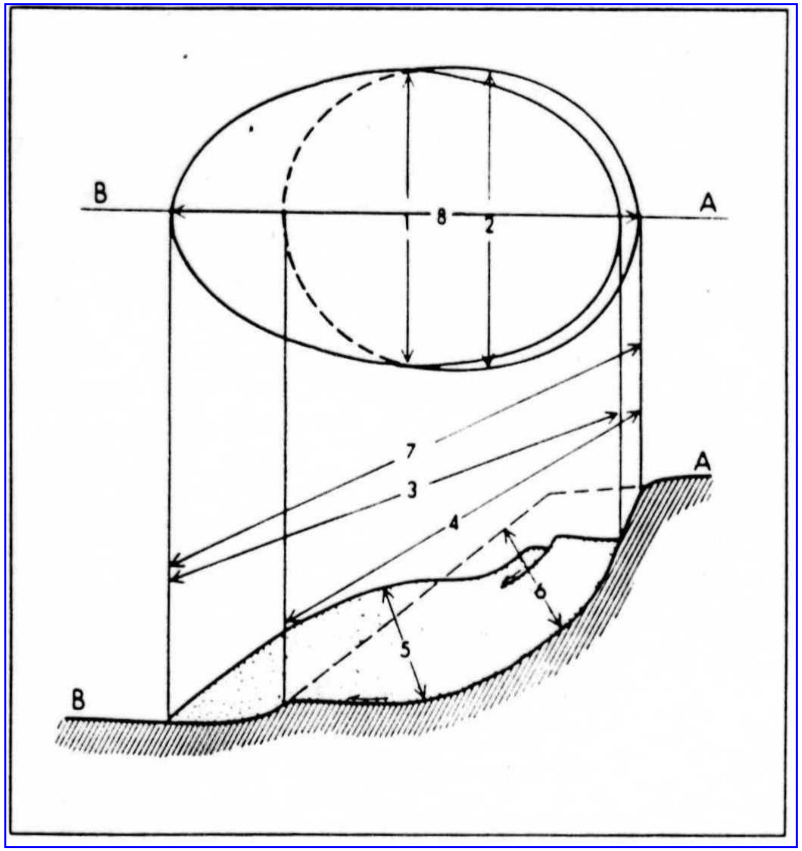
STYLE OF ACTIVITY

indicates how different movements within the landslide might contribute to its overall movement.

1. **Complex**
2. **Composite**
3. **Successive**
4. **Single**

MORPHOMETRY

number	name
1	Width of displaced mass W_d
2	Width of surface of rupture W_r
3	Length of displaced mass L_d
4	Length of surface of rupture L_r
5	Depth of displaced mass D_d
6	Depth of surface of rupture D_r
7	Total length L
8	Length of center line L_{cl}



Landslide Velocity

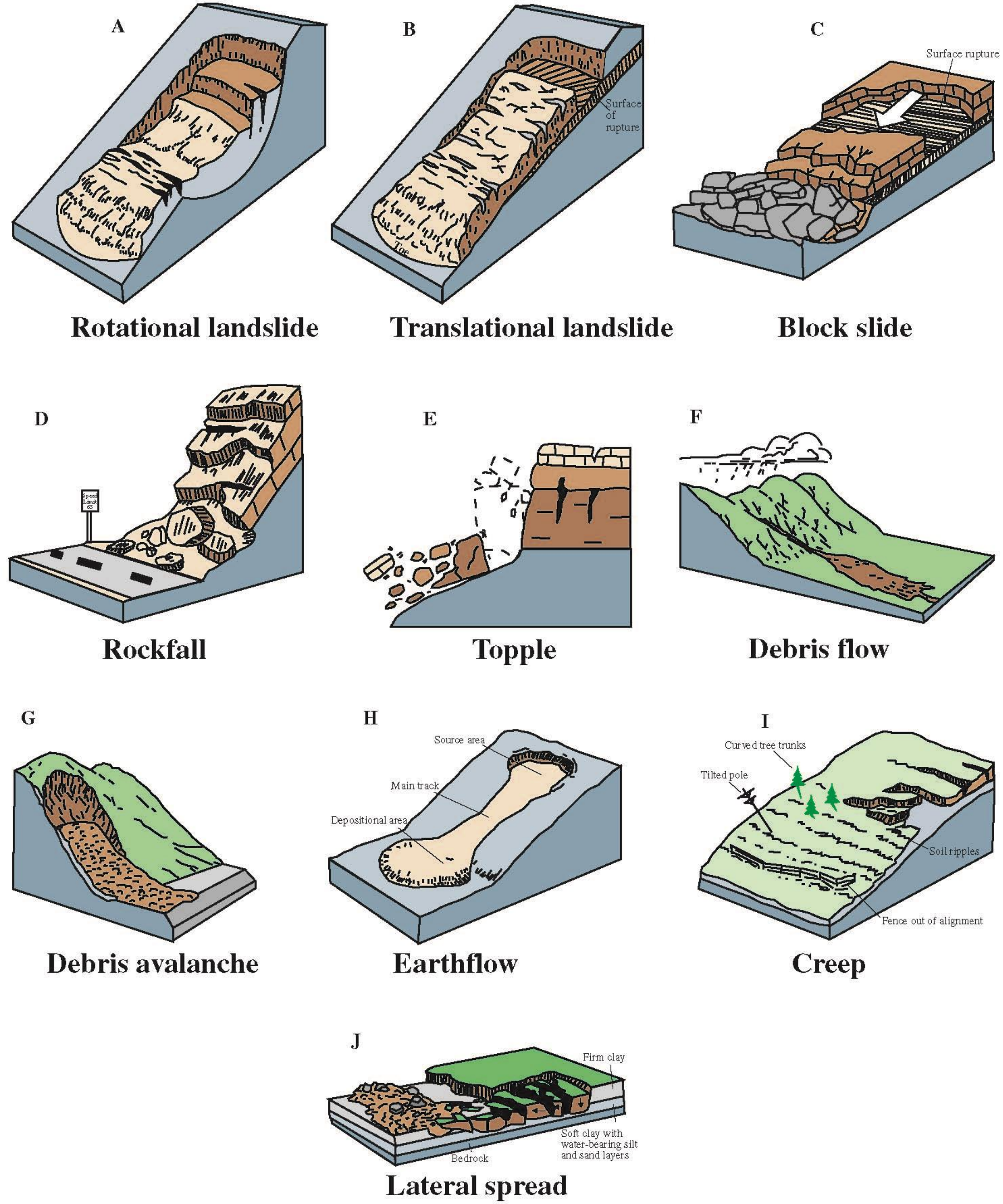
Examples of landslide velocities, and related damage (after Cruden & Varnes, 1996)

Velocity class	*Landslide*	*Bibl. Ref.*	*Estimated Velocity*	*Damage*
7	Elm	Heim (1932)	70 m/sec	115 casualties
7	Goldau	Heim (1932)	70 m/sec	457 casualties
7	Pupille	Bishop (1973)	31 m/sec	11 casualties, destroyed houses
7	Frank	Mc Connell & Brock (1904)	28 m/sec	70 casualties
7	Vajont	Mueller (1964)	25 m/sec	1900 casualties (indirect damagei)
7	Ikuta	Engineering News Record (1971)	18 m/sec	15 casualties, destroyed infrastructures
7	St. Jean Vianney	Tavanas et al. (1971)	7 m/sec	14 casualties, destroyed structures
6	Aberfan	Bishop (1973)	4.5 m/sec	144 casualties, buildings damaged
5	Panama Channel	Cross (1924)	1 m/min	Workers escaped
4	Handlova	Zaruba & Mencl (1964)	6 m/day	150 houses destroyed, total evacuation

Not only Varnes……

What about other landslide classifications?

And why could they be useful, too?



John Neville Hutchinson

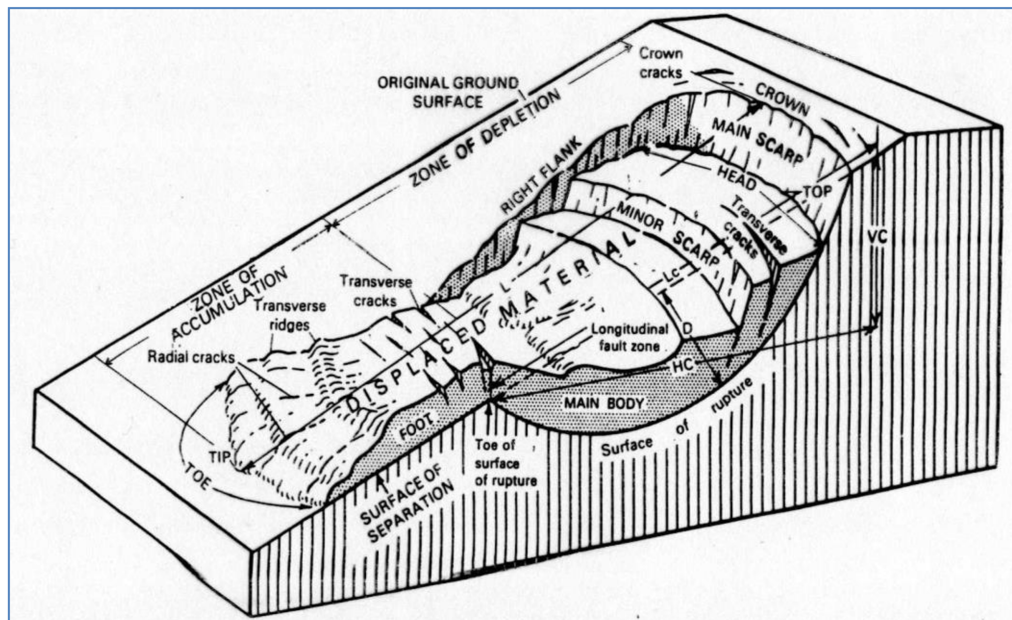
(1926-2011)

Hutchinson classification (1988)

HUTCHINSON J.N. (1988) *Morphological and geotechnical parameters of landslide in relation to geology and hydrogeology.* In: Bonnard C. (Ed.), Proceedings 5th International Symposium on Landslides, Lausanne, vol. 1, p. 3-35.

SKEMPTON A.W. & HUTCHINSON J.N. (1969) *Stability of natural slopes and embankment foundations.* Report 7th Int. Conf. Soil Mech. & Found. Engng., Mexico, State of the Art volume, p. 291-340.

Like Varnes, he does not take into account other geological hazards, such as subsidence, sinkholes, avalanches of snow or ice.



Hutchinson classification (1988)

Criteria for classifying

Attempt to combine morphological and geotechnical aspects of slope moviments.

Based upon morphology of slope movements, also taking into account the mechanisms, involved materials, and velocity of movement.

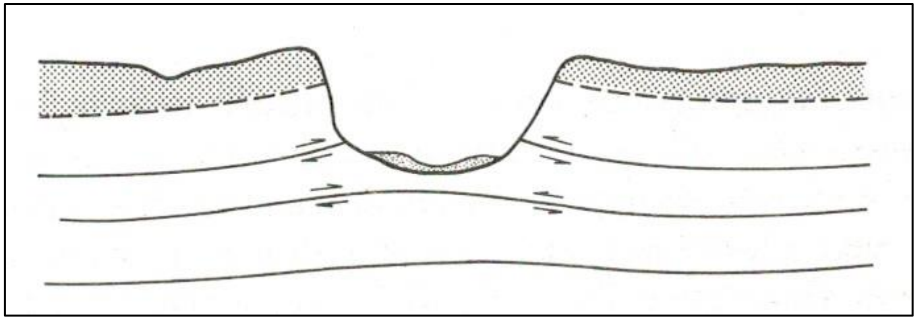
As concerns this latter aspect, the same velocity scale by Varnes (1978), and later by Cruden and Varnes (1996) is adopted.

Categories of slope movements according to Hutchinson (1988)

Based upon morphology

A. ***Rebounds***
B. **Creep**
C. ***Sagging***
D. **Landslides**
E. ***Debris movements of flow-like form***
F. **Topples**
G. **Falls**
H. **Complex slope movements**

Categories of slope movements according to Hutchinson (1988)



Swelling from the base upward, and from the flanks outward in an erosional valley.

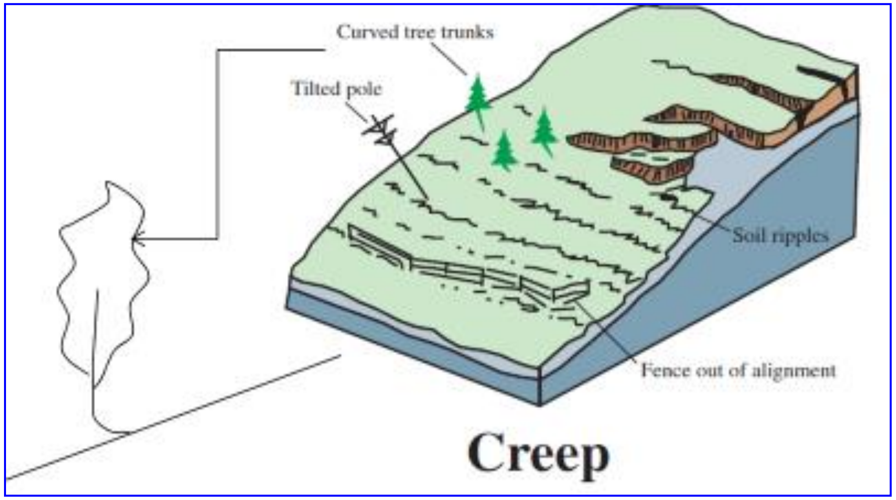
Rebounds

In response to anthropogenic excavations (rapid) or to natural phenomena (slow)

Creep

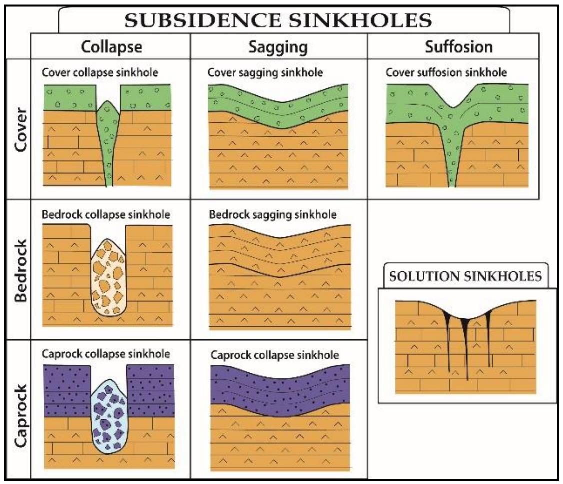
Creep = deformation that continues under constant stress

- Stat e of stress well below the failure strength of the material.
- Extremely slow movements.
- Shallow movement.
- Progressive pre-failure: type of *creep* accelerating the shear failures, due to progressive development of shear surfaces. It preceeds **(may preceed)** the general failure.



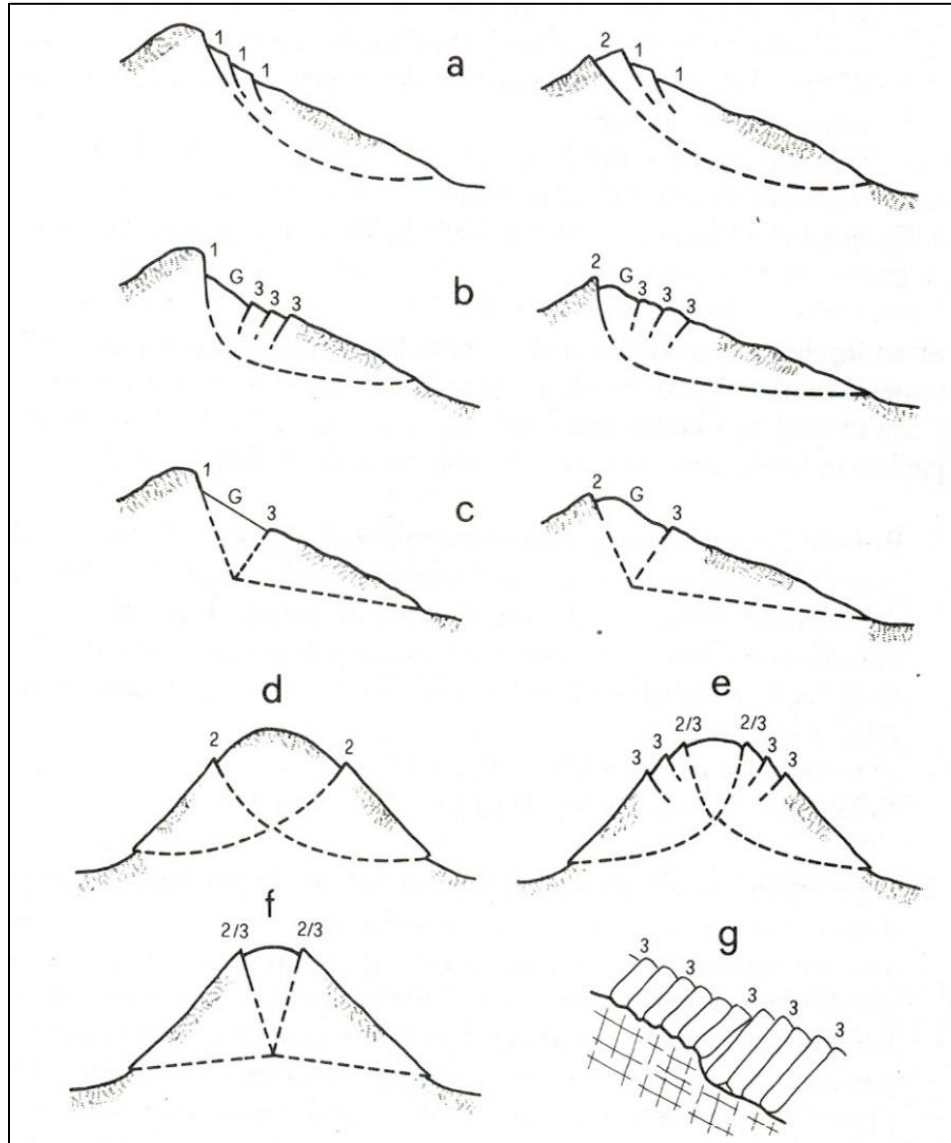
Categories of slope movements according to Hutchinson (1988)

Sagging



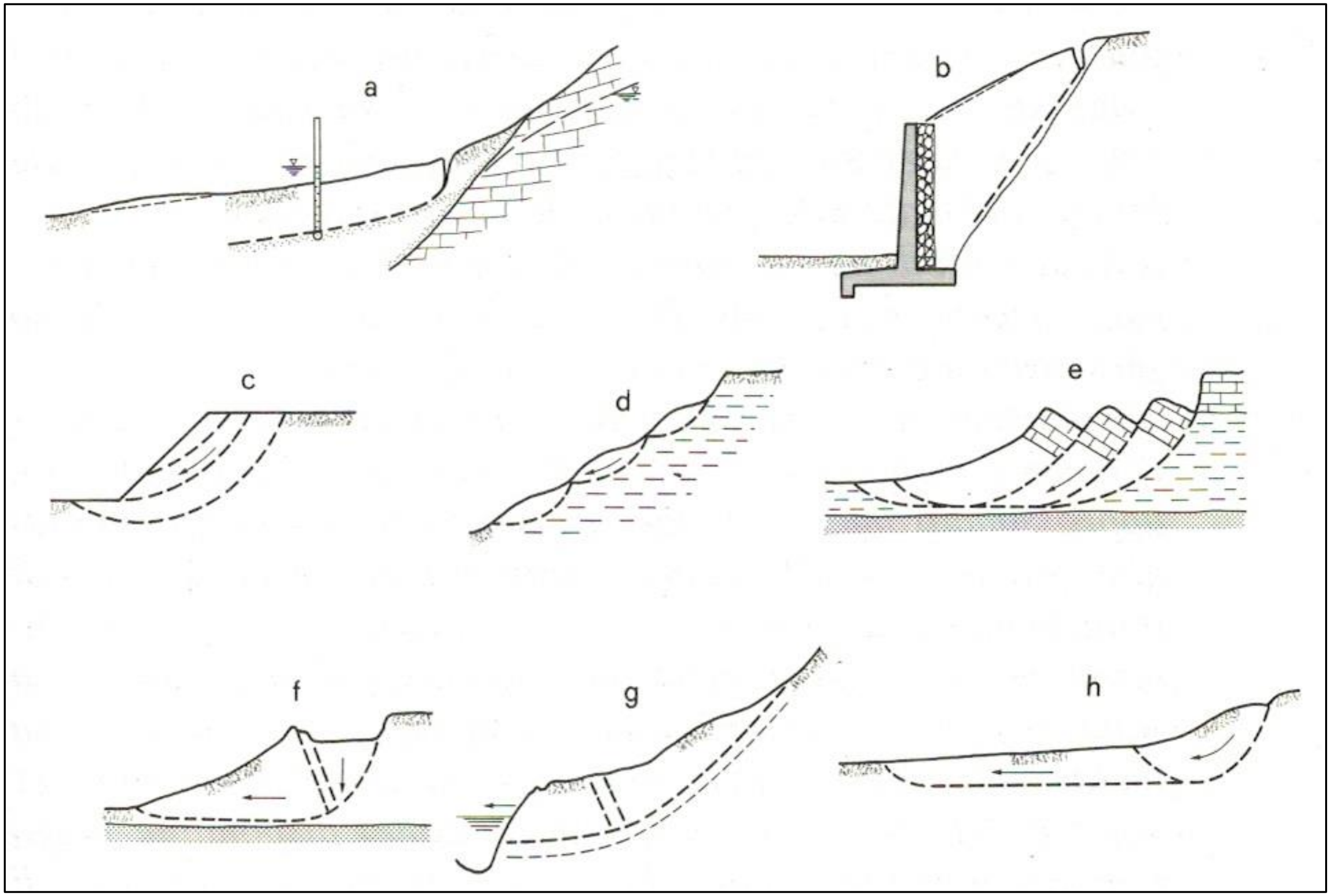
Gutiérrez, Parise, De Waele & Jourde, 2014, *A review on natural and human-induced geohazards and impacts in karst.* Earth Science Reviews 138, 61-88.

Deep-Seated Gravitational Slope Deformations *(DSGSD)*



Categories of slope movements according to Hutchinson (1988)

Landslides



Ratio depth/length (D/L) between 0,15 and 0,33.

Occurring along one or more well-defined surfaces, clearly separating the displaced mass by the undisturbed materials.

Categories of slope movements according to Hutchinson (1988)

Geotechnical considerations (**shear as the prevailing mechanism of failure**)

- ***First-time slide***
- ***Slides on pre-existing slip surfaces***
  - ✓ Involve re-activation of previous landslides
  - ✓ Pre-existing shear phenomena, but produced by other processes than landslide

Categories of slope movements according to Hutchinson (1988)

To define stability of a slope, or to design proper stabilization works, it is crucial to know **the available shear strength** along the most likely sliding surface.

Such strength is mainly controlled by nature and structure of the terrain particles, by their bonds (mineralogy and fabric), and by the pore pressure (water and/or air) in the voids.

In terms of effective tensions, in a saturated terrain:

$$\tau = c' + (\sigma_n - u) \tan \varphi'$$

Geotechnical classification by Hutchinson (1988)

It is mainly based on two parameters:

Fabric of the terrain

Conditions of pore pressure along the sliding surface

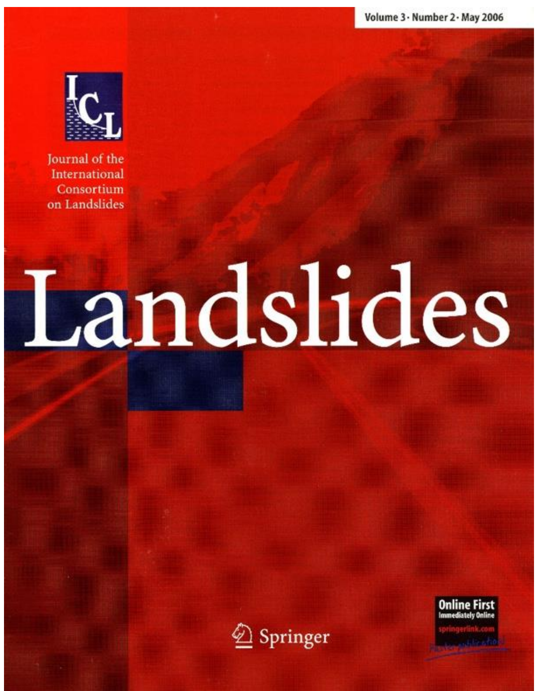
controlling the parameters of shear strength c′ and φ′

controlling the pore pressure u

$$\tau = c' + (\sigma_n - u) \tan \varphi'$$

Kyoji Sassa

SASSA K. (1989) *Geotechnical classification of landslides.* Landslide News, vol. 3, p. 21-24.



Geotechnical classification.

It defines landslides as ***shear phenomena of natural and man-made slopes***, explaining then through the concept of ***stress path***.

Classification by Sassa (1989)

I. Slides

II. Liquefaction

III. Creep

Type of Shear	Grain Size of Material		
	Rock ~20mm	Sandy Soil 20 – 0.074mm	Clayey Soil 0.074mm~
I. Slides A) Peak Strength Slide	North Nahanni (LN3, p.4)	Medellin (LN2, p.12)	Clay-Peak Strength Slide
B) Residual State Slide	Zentoku (LN3, p.23)	Sand-Residual State Slide	Muddy Creek (LN2, p.8)
II. Liquefaction	None	Okuli, USSR (LN3, p.7)	Quick Clay Landslide
III. Creep	Zentoku (LN3, p.23)	Soil Creep	Clay Creep

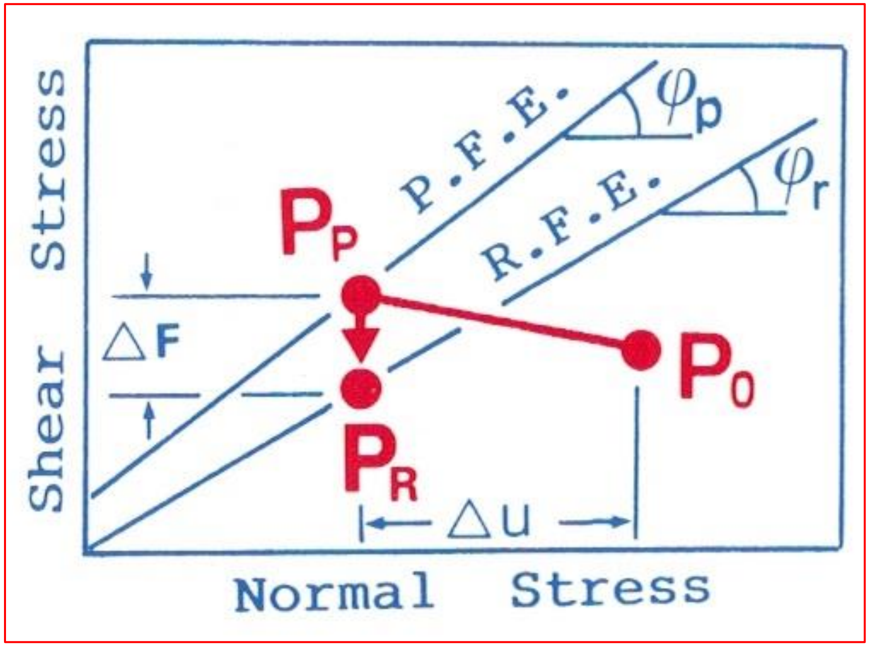
Classification by Sassa (1989)

Slides

P_0 = stress state in a generic point of the slope in condition of stability

P_P = start of sliding

ΔF = difference between applied shear strength and new shear strength; it is the force determining an acceleration in the already sliding mass



P.F.E. *(peak failure envelope):* envelope of failure values under max stress.

R.F.E. *(residual failure envelope):* envelope of failure values under residual shear strength condition.

Peak strength slide

書生

Shosei

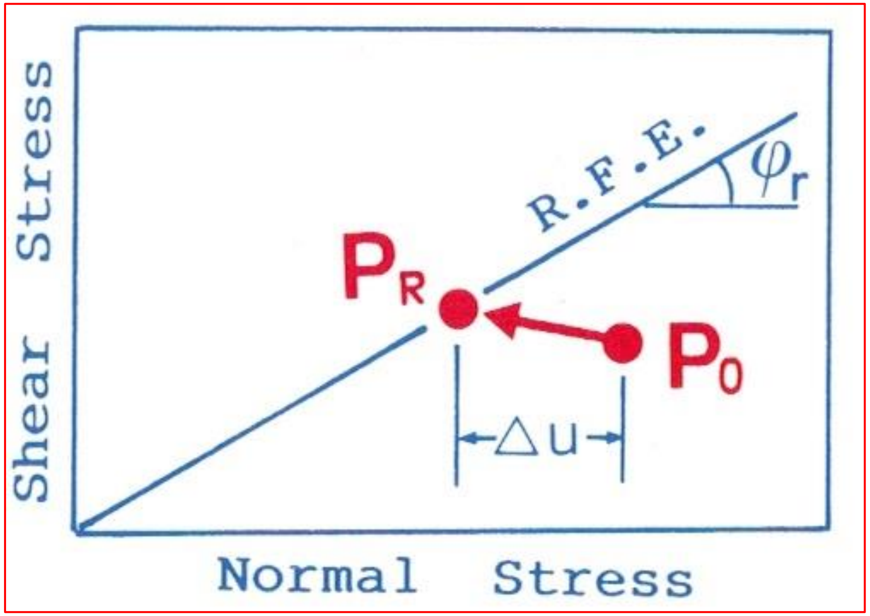
(newborn)

Classification by Sassa (1989)

Slides

When the sliding surface is already at residual strength values, the movement starts as the stress reaches the envelope R.F.E.

Shear strength does not decreases after failure; the effective stress and the strength remain about constant. Movements are slow, and even slight increases in the safety factor may stabilize the landslide.



P_0 = stress state in a generic point of the slope in condition of stability

R.F.E. *(residual failure envelope):* envelope of failure values under residual shear strength condition

Residual-state, or residual strength slide

Classification by Sassa (1989)

Peak strength slide

↓

First-time slide

Residual-state, or residual strength slide

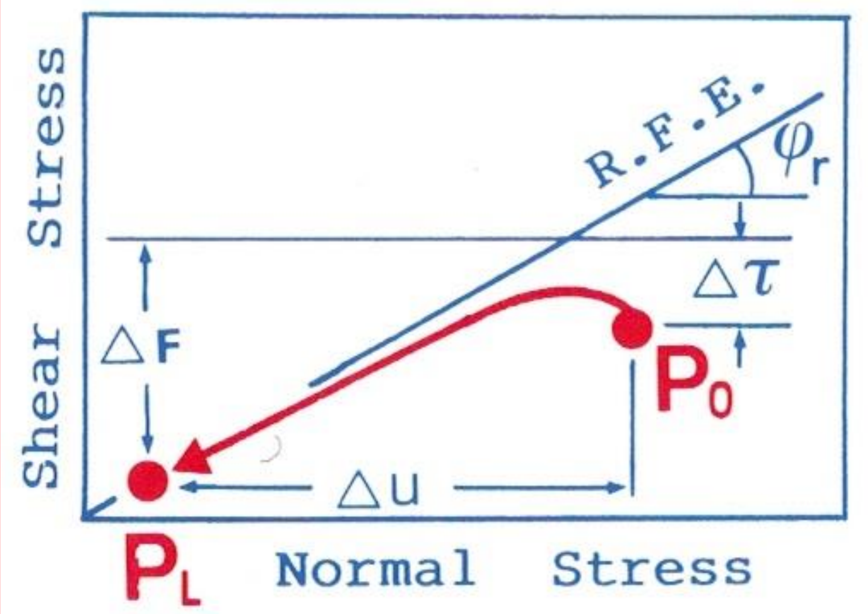
↓

Reactivated slide

Classification by Sassa (1989)

Liquefaction

If a poorly compacted terrain undergoes undrained stress, its solid parts collapses without opposing to the shear any strength due to friction (that is, without the stress reaches the failure envelope). Effective stress decreses rapidly until point P_L along R.F.E., very near to the axes origin. Shear strength is so small that may be compared to that of a viscous fluid.



P_0 = stress state in a generic point of the slope in condition of stability

R.F.E. *(residual failure envelope):* envelope of failure values under residual shear strength condition

Landslides in <u>quick clays</u> are a type of liquefaction, occurring without the need of quick increase of the stress such as those caused by shaking

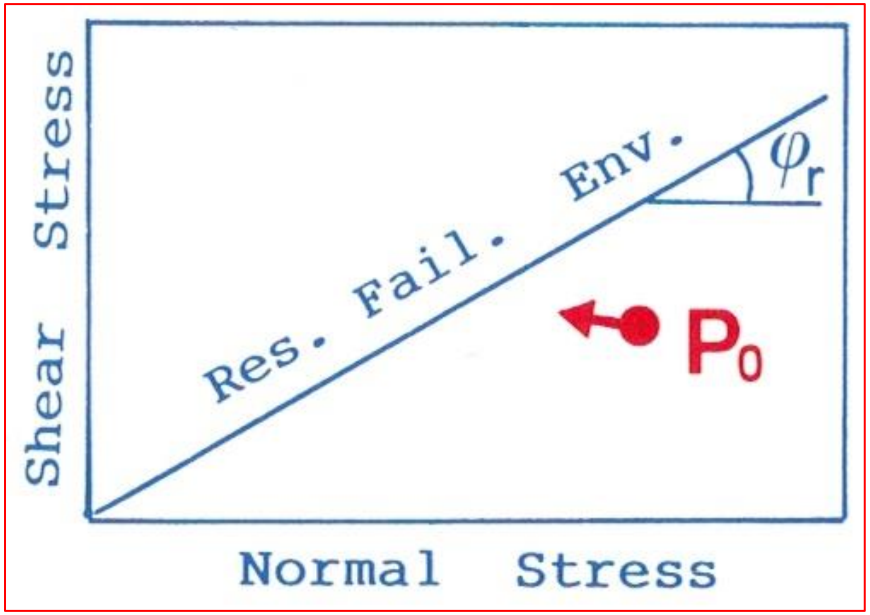
Quick clays, sensitive clays

Classification by Sassa (1989)

Creep Deformation under constant stress

In natural slopes the stress is not constant, due to water level fluctuations. As concerns landslides, *creep* may be considered as the deformation occurring without significant changes in the stress state.

The figure shows the stress in a point of a body subjected to *creep*: the failure envelope is not reached, but slow movements may be caused by oscillations in the stresses.



P_0 = stress state in a generic point of the slope in condition of stability

R.F.E. *(residual failure envelope):* envelope of failure values under residual shear strength condition

Factors

Predisposing

All those elements working in predisposing the slope to a possible instability condition

Preparatory

These concern the meteo-climatic and anthropogenic sectors: all those processes that, repeating daily, seasonally, etc., create preparatory situations to the phenomena, and move the slope toward the actual trigger, that is transient

Triggering

All causes acting to start the instability, that until that specific moment has not yet began

Factors

In other words, **predisposing factors** (geological-structural and geo-mechanical characters) define the attitude to a certain process, not yet seen as concerns the climatic aspects or the anthropogenic pressure.
Preparatory processes add to predisposition, increase in time, and represent the macro-category linking the instability to climatic actions and to anthropogenic activities (i.e., rainfall intensit, multi-year cycles, etc.).
Eventually, **triggering factors** are the intense actions (earthquakes, rainstorms, anthropogenic activities) determining the onset of a landslide.

Preparatory factors are those strongly dependant upon time, and therefore they influence the hazard.
Triggering and predisposing factors are less conditioned by time, being guided by processes working over much longer temporal scales.

Causes of landslide events

1. Geological causes
2. Geomorphological causes
3. Physical causes
4. Anthropogenic causes

Are they predisposing, preparatory or triggering?

Physical causes

- ✓ Intense rainfall
- ✓ Snow melting
- ✓ Prolonged precipitations
- ✓ Rapid lowering of water table
- ✓ Seismic shaking
- ✓ Volcanic eruptions
- ✓ Freeze-thawing
- ✓ Weathering

Typically considered as triggers

But....could they also be preparatory?

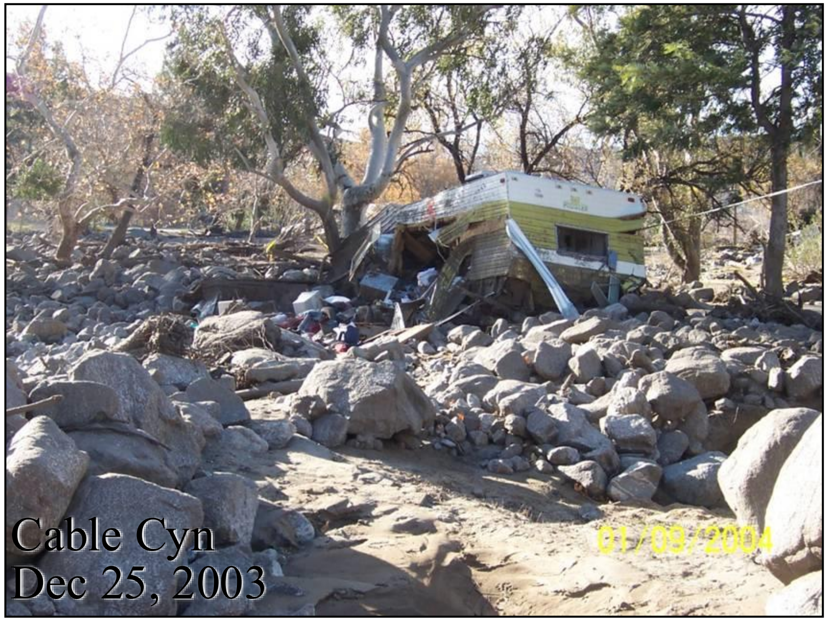
Mamayes landslide, Puerto Rico, 1985
The landslide destroyed 120 houses, causing the loss of 129 people. Caused by a rainstorm, but also favored by leakage from water pipes and sewer systems.

Erosion and landslides in recently burned areas

Fire burning above San Bernardino, Oct 2003

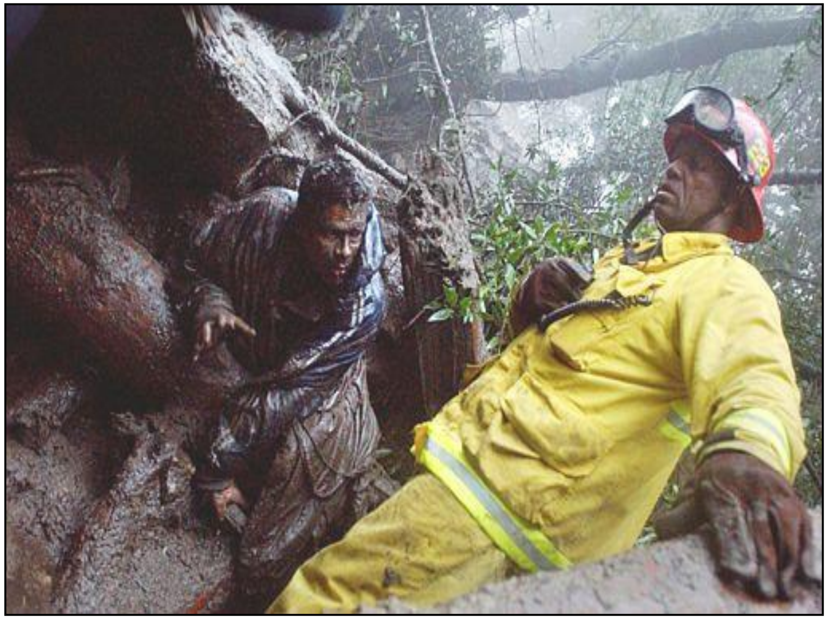

Sporting Goods

Debris flows



Cause significant damage to life and property

Durango, CO 2002



Waterman Cyn
Southern CA
12/25/03

Wildfire:

- Consumption of rainfall-intercepting canopy and of soil-mantling litter and duff
- Intensive drying of the soil
- Combustion of soil-binding organic matter
- Generation of fine wood ash and water-repellent soils
- Fining of grain-size distribution

Results in dramatic changes in erodibility, infiltration, and runoff

Unit-area peak discharges measured following wildfires have shown between 1.45 and 870-fold increases over pre-fire rates

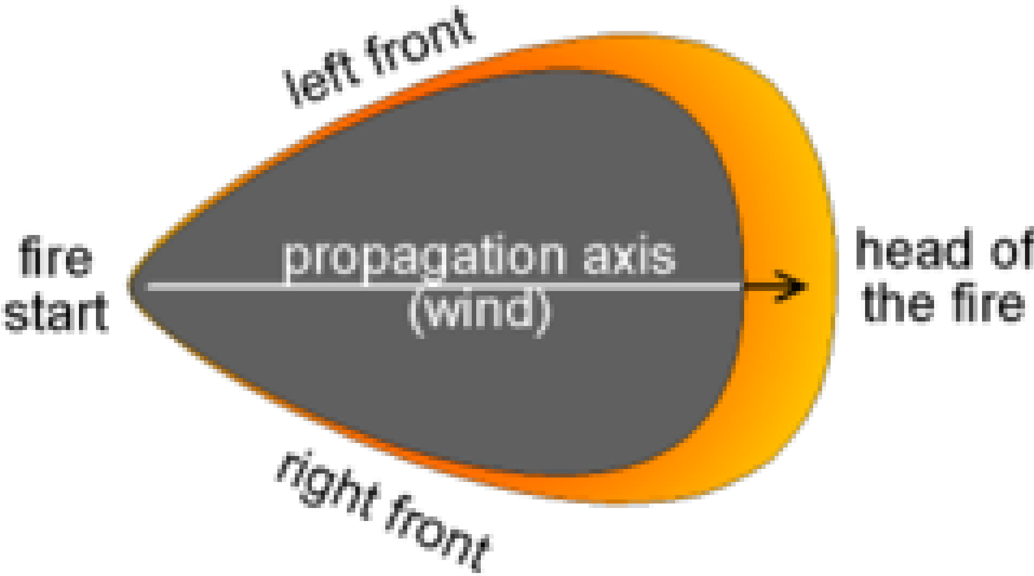
What wildfires cause:

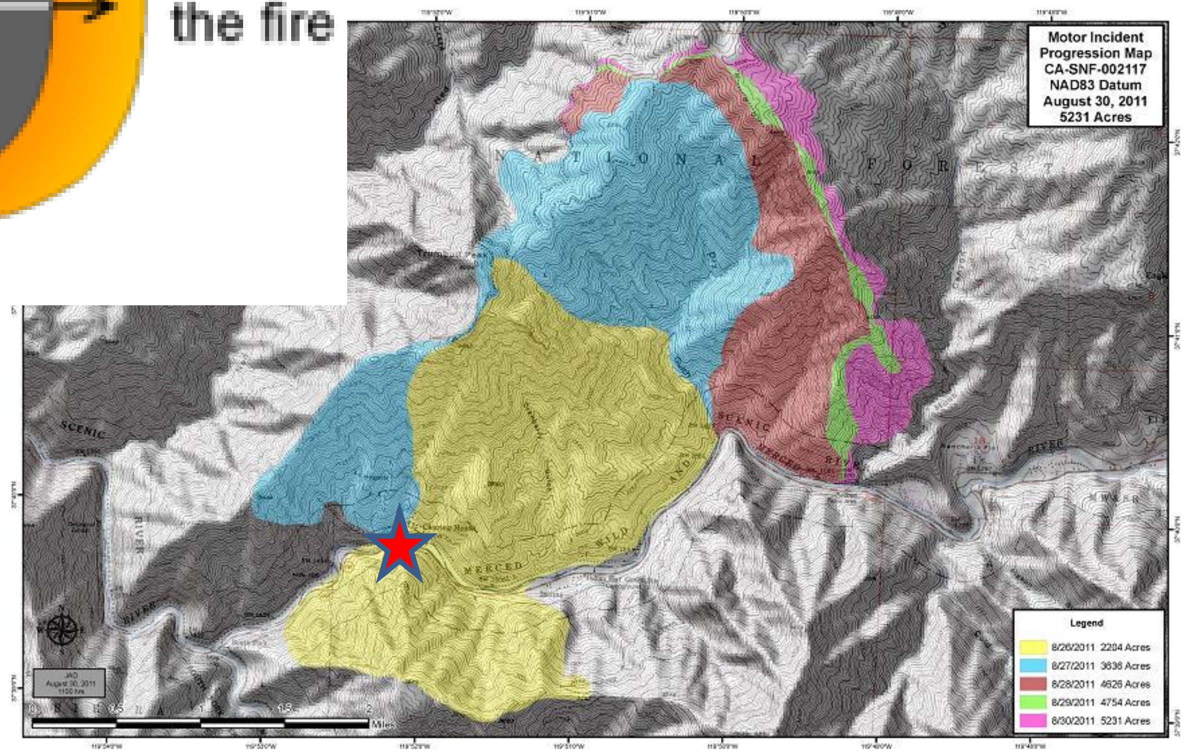
- **Consumption of vegetation**
- **Enhancing the erosive power of overland flow**
- **Accelerated erosion of material from hillslopes**

High potential to transport and deposit large volumes of sediments, both within and down-channel from the burned area

Modeling Fire Behavior

- Topography
- Wind Speed and Direction
- Vegetation Pattern (fuel)



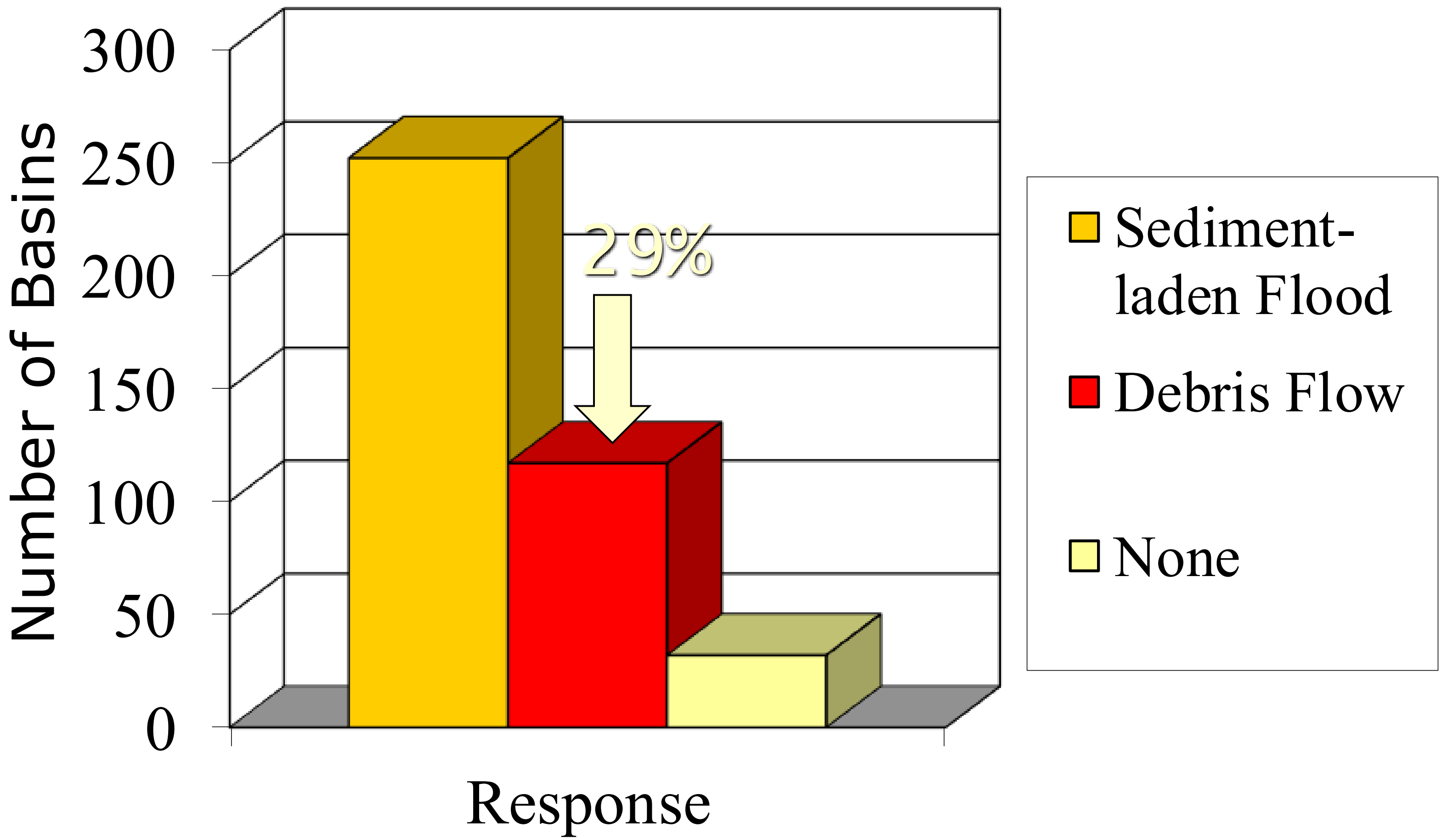


De Graff et al., 2013

What response do we have to expect?

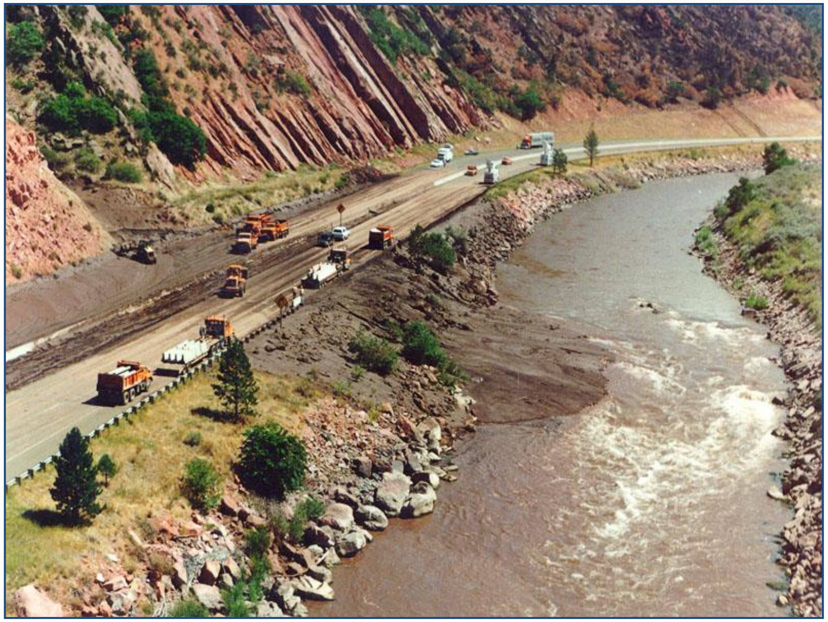
Differences in the deposits left by debris flows and other processes

Short-term response of monitored basins



- Debris flows not the most frequent response
- Set of conditions that indicate specific susceptibility to debris flows?

Empirical tools for assessing post-fire debris flow hazards



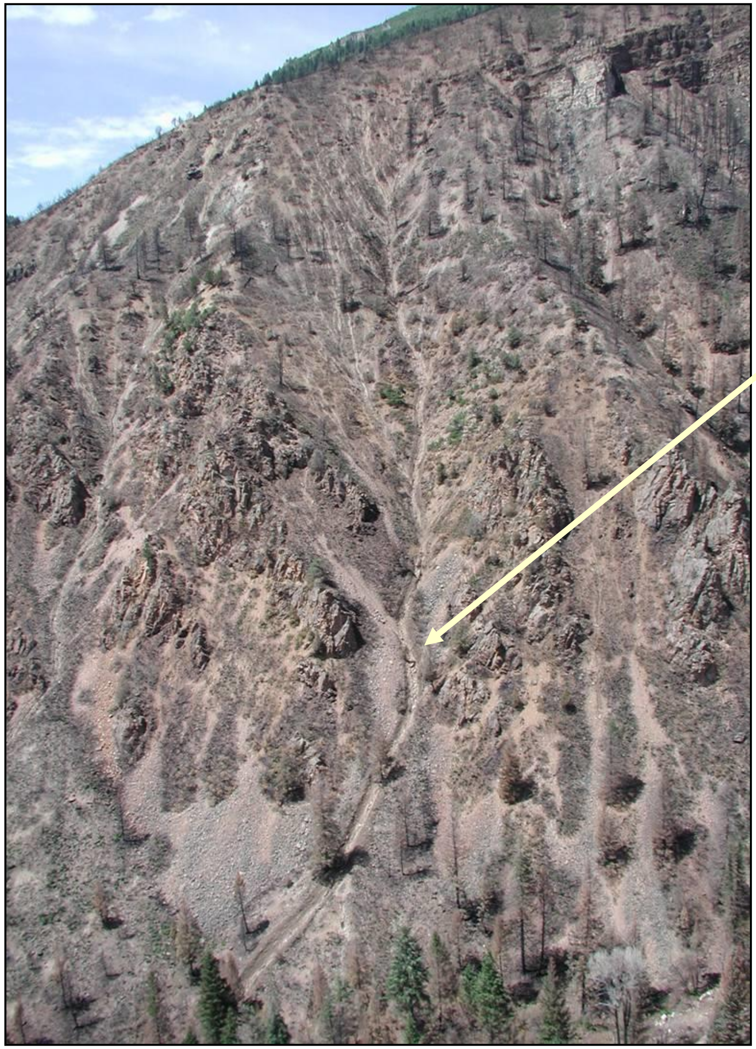
- Where?
  - Probability of debris flow for a given basin
- How big?
  - Volume at basin mouth
- Where is it going?
  - Inundation modeling

Approach:
Compare and contrast conditions in basins that produced sediment-laden streamflow

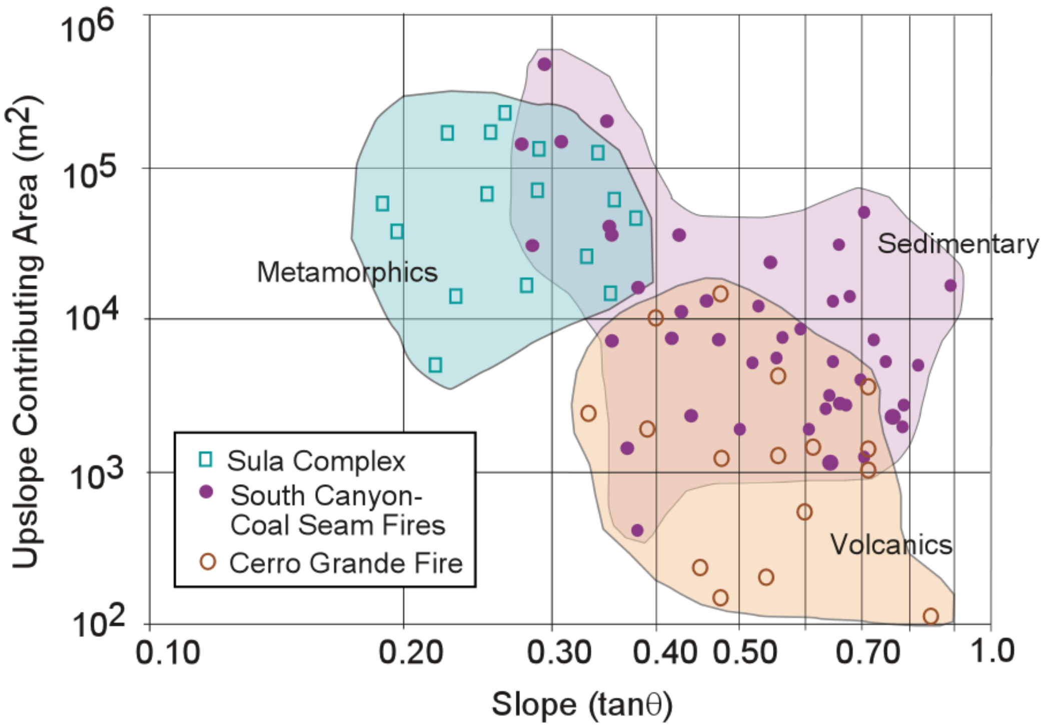
With those that produced
Debris Flow

Coal Seam Fire, August, 2002 - Colorado

Hillslope Material Availability



Abundant loose, unconsolidated materials on hillslopes and in channels



Initiation processes:

1. Runoff-dominated erosion by surface overland flow

2. Infiltration-triggered failure and mobilization of a discrete landslide mass

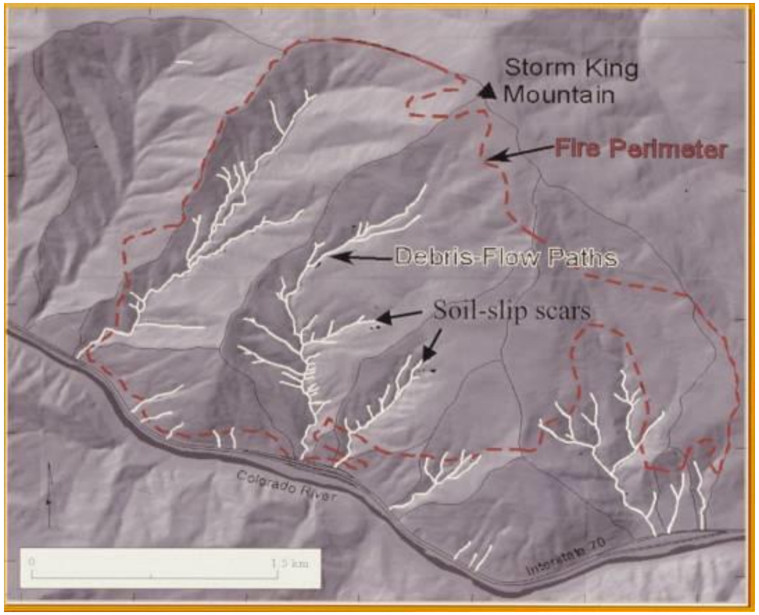
Parise and Cannon, 2012

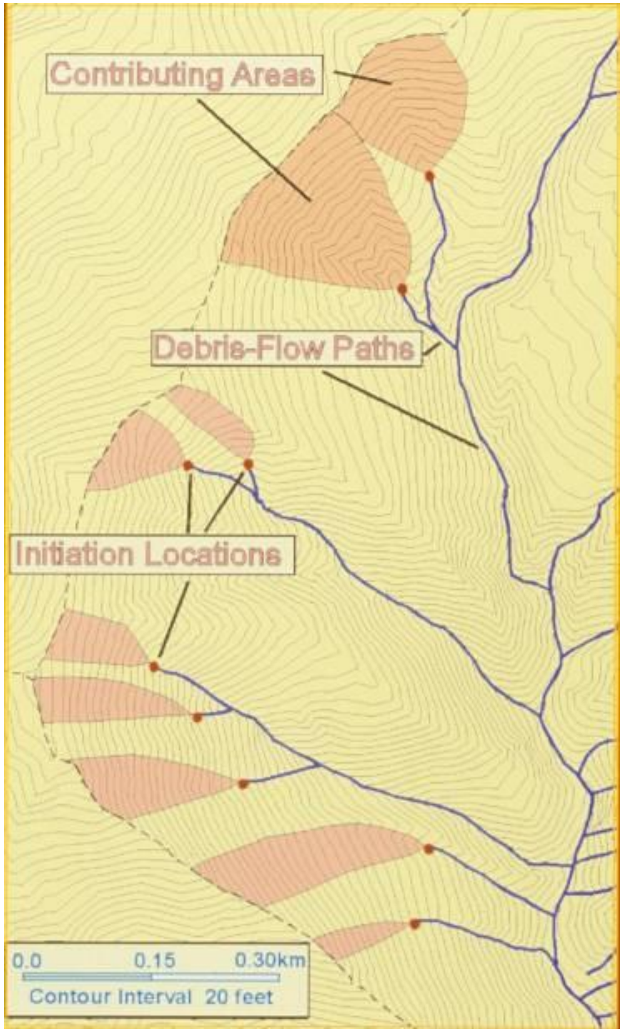
Further up

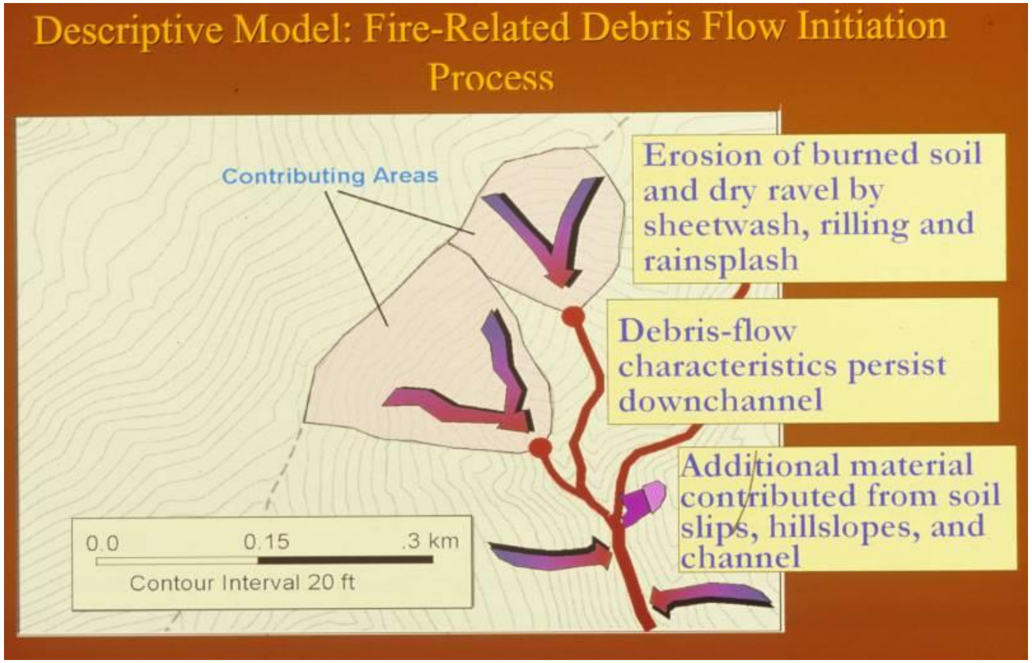
Further still….

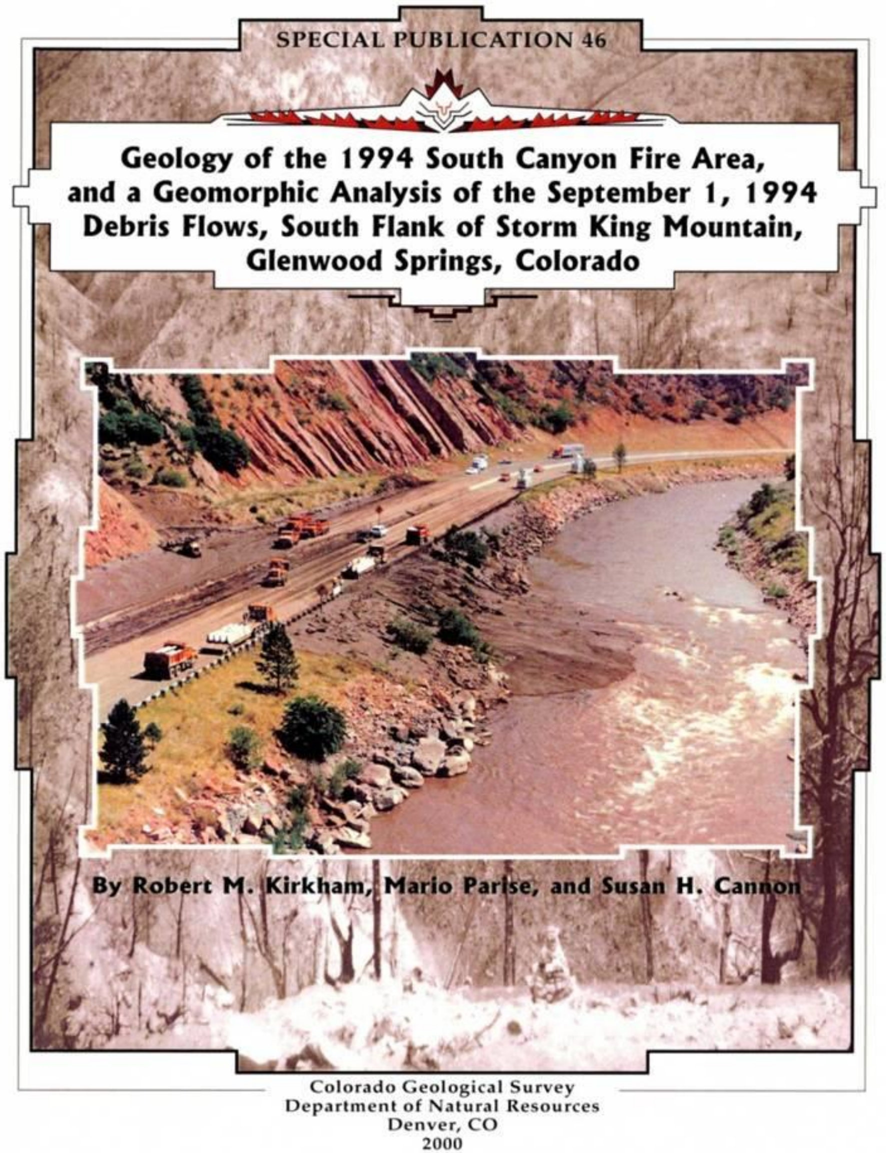
Basin Heads

Storm King Mountain, Colorado, USA





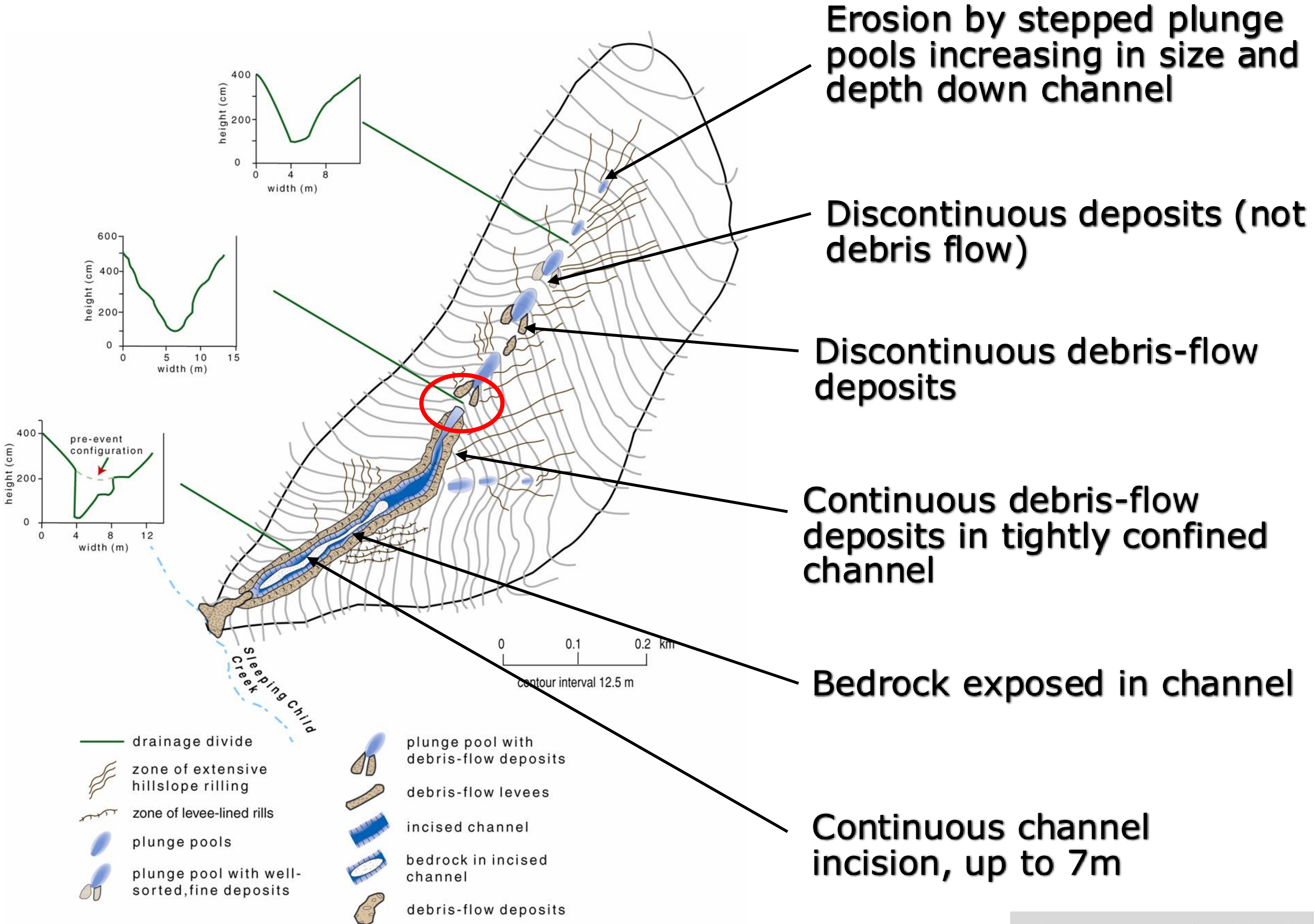




Including an eyewitness account of the September 1, 1994 debris flows

Kirkham et al., 2001; Cannon et al., 2003

Sleeping Child Creek watershed, Montana



Cannon et al., 2013

Runoff-dominated erosion by surface overland flow

Rainfall conditions

In response to high-intensity, short-duration storms, within two years of the fire.

Debris flows have occurred in response to storms with durations as short as 18 minutes, and during 10-day-long, greater than 100-year recurrence interval storms.

Most debris flows producing storms are between about 30 min and 24 hr in duration.

Known times of debris-flow occurrence within a storm:
after as little as 6 min of rainfall at intensities of 95 mm/hr,
and up to 5 hr of rainfall at intensities of 6 mm/hr.

Infiltration-triggered failure and mobilization of a discrete landslide mass

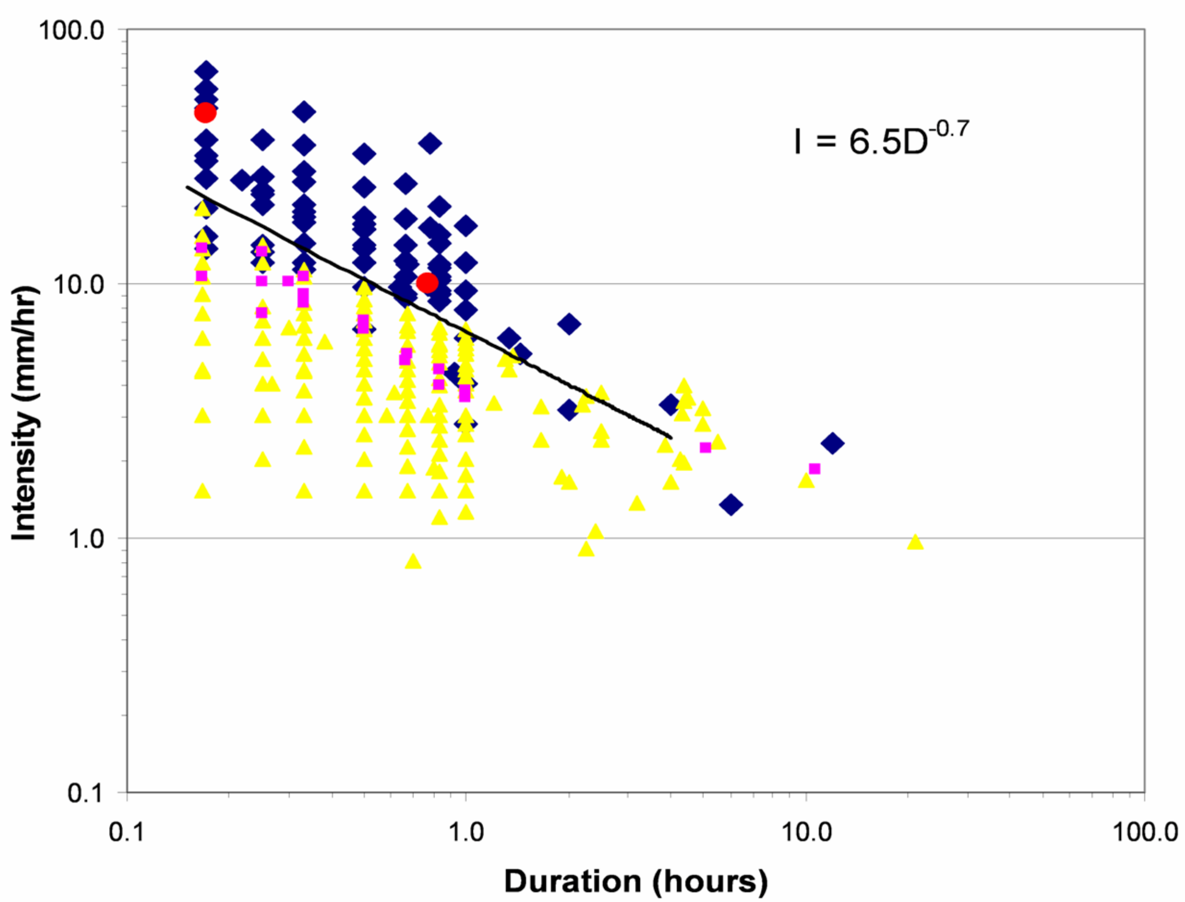
Lower percentage (16%)

Processes:

- Increase in soil moisture
- Decay of regolith-anchoring roots
- Increased peak flows

Can landslide failures be indeed attributed to fires?

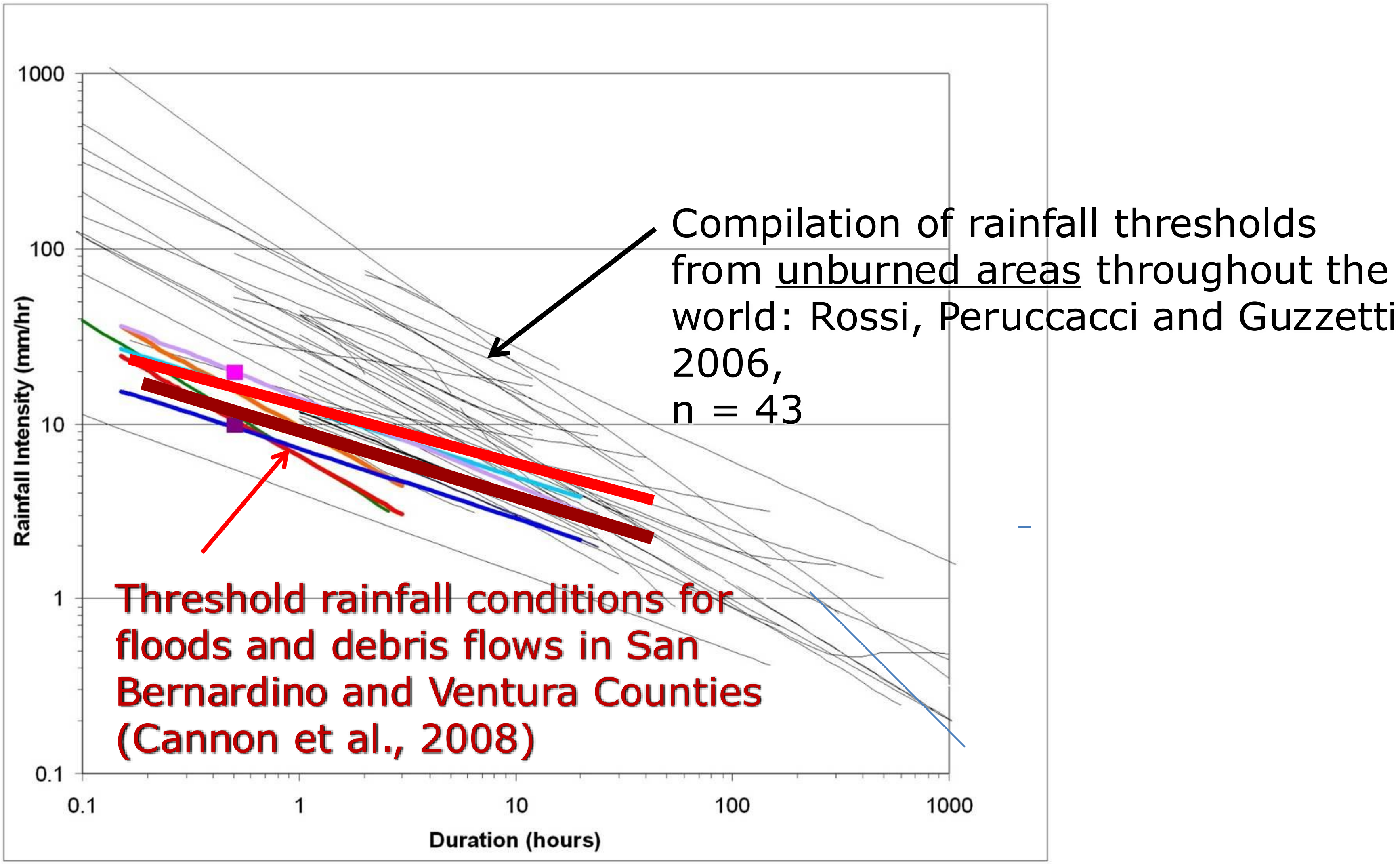
Rainfall intensity-duration thresholds



Cannon et al., 2003

Blue diamonds: storm rainfall from rain gages near basins that produced debris flows.
Pink squares: storm rainfall from rain gages near basins that produced sediment-laden flows.
Yellow triangles: storm rainfall from rain gages near basins that showed minimal or no response.
Red dots: rainfall conditions preceding known times of the occurrence of a debris flow.

Post-fire debris flows triggered by storms: < 2 to 5 year recurrence



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Advanced Studies in Rainfall-Induced Soil Degradation, Failure and Landslide Hazards

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This Special Issue aims to advance process-based understanding of rainfall-induced soil degradation and failure, and to clarify their roles in landslide development in natural and engineered slopes.

Keywords

- rainfall-induced landslides
- soil degradation and failure
- runoff–infiltration partitioning
- infiltration–groundwater interaction
- hydro-mechanical coupling
- physics-based early warning

Submission Deadline:
31 December 2026

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