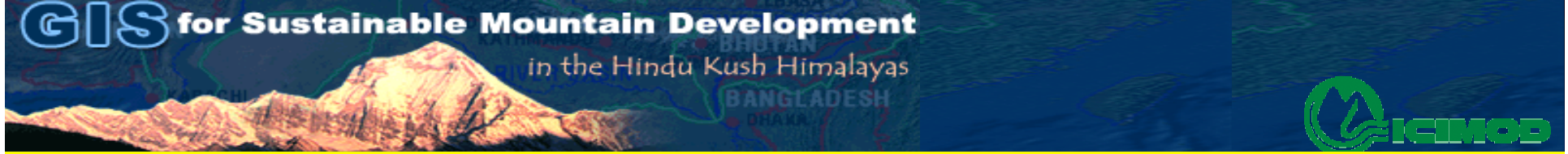

Training/workshop on

"Earthquake Vulnerability and Multi-Hazard Risk Assessment: Geospatial Tools for Rehabilitation and Reconstruction Effort"

Islamabad, Pakistan March 2006

AN APPROACH TO THE CLASSIFICATION OF SLOPE MOVEMENTS

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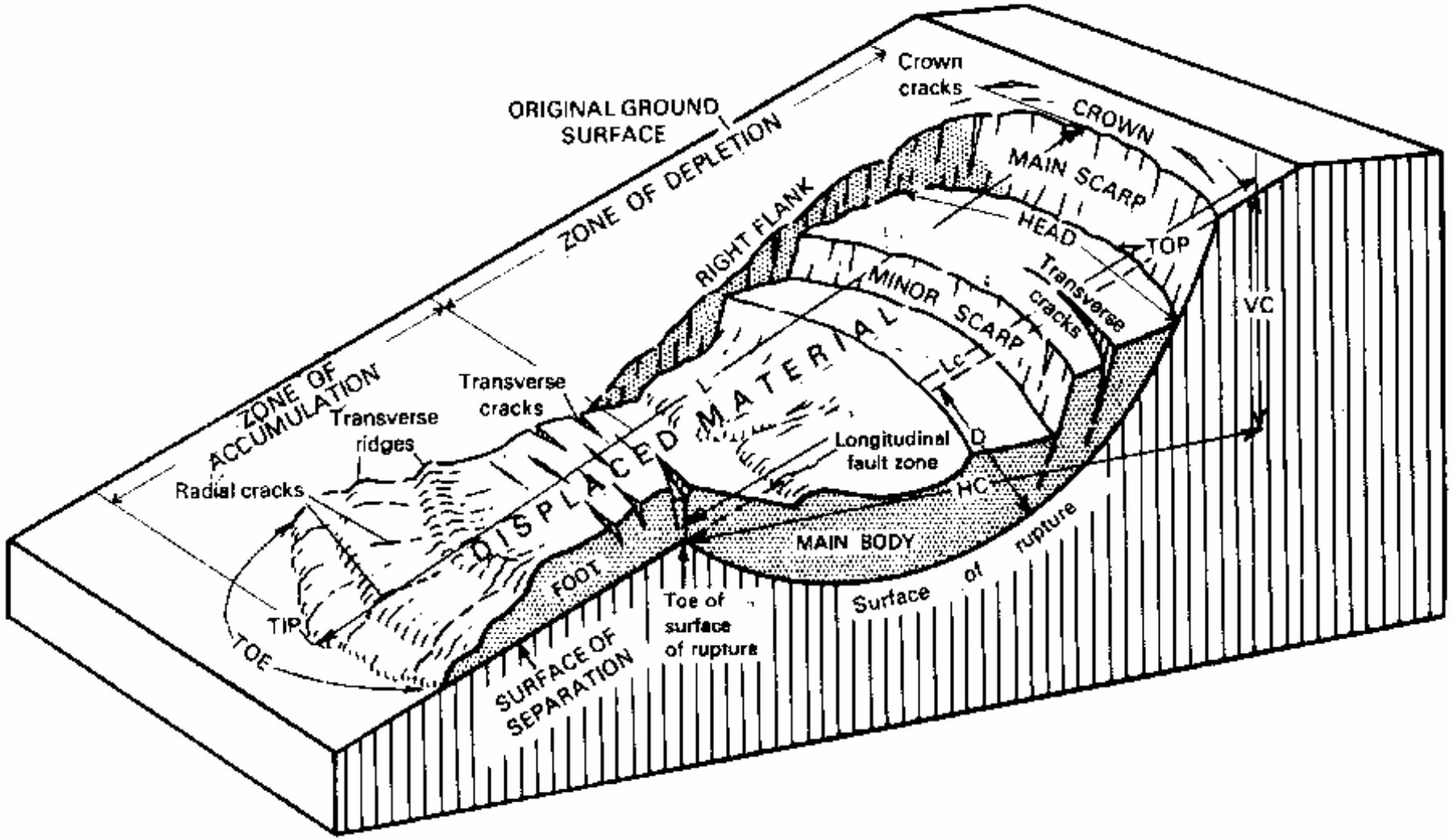
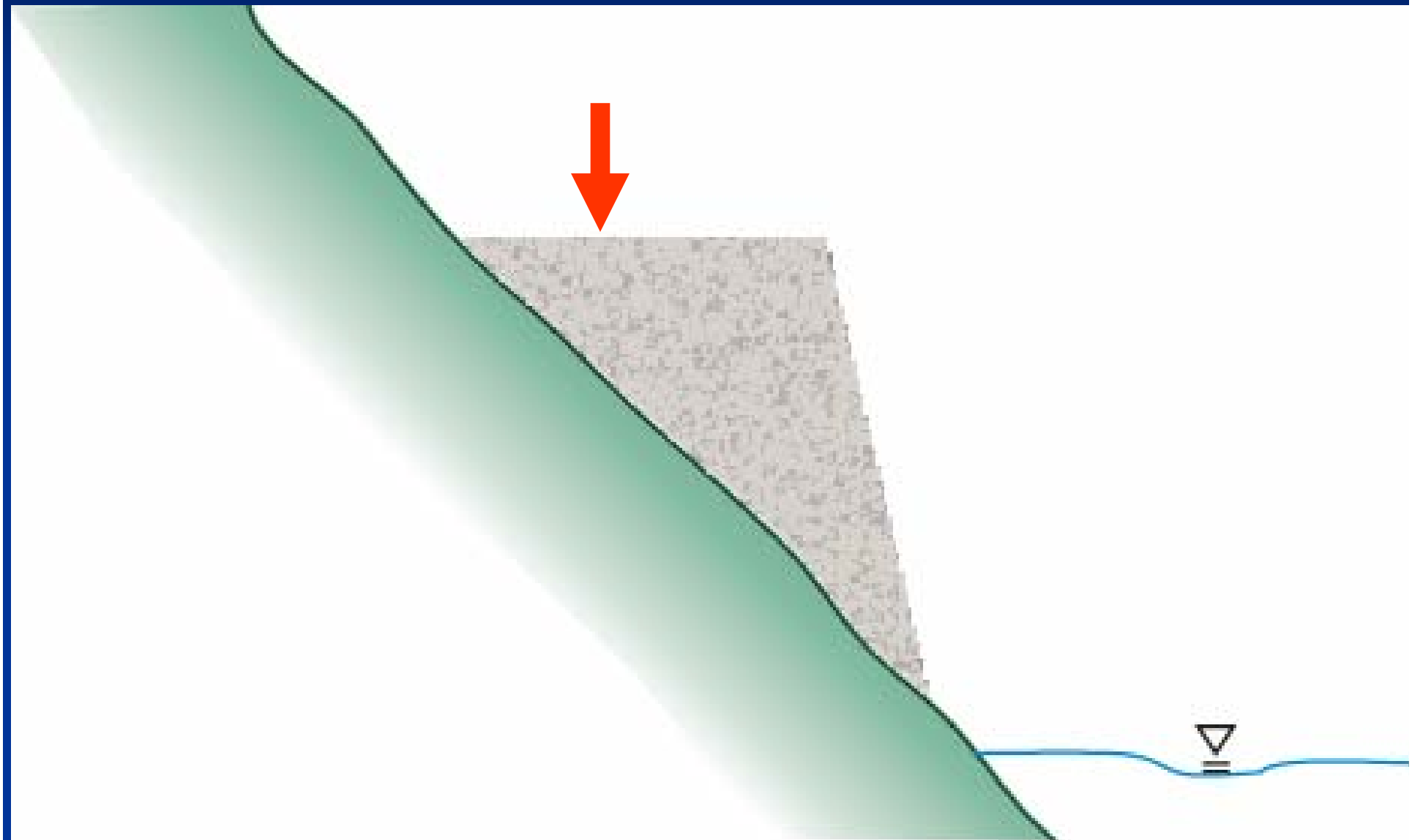
Landslide is defined as the movement of a mass of rock, debris or earth down the slope, when the shear stress exceeds the shear strength of the material.



Shear strength/Shear stress



The factors contributing to trigger the landslide

The factors contributing to an increase of the shear stress are:

- removal of lateral and underlying support (erosion, previous slides, road cuts and quarries)
- increase of load (weight of rain/snow, fills, vegetation)
- increase of lateral pressures (hydraulic pressures, roots, swelling of clay)
- transitory stresses (earthquakes, vibrations of trucks, machinery, blasting)
- regional tilting (geological movements).

Factors related to the decrease of the material strength are:

- decrease of material strength (weathering, change in state of consistency)
- changes in intergranular forces (pore water pressure, solution)
- changes in structure (decrease strength in failure plane, fracturing due to unloading)

Landslide activity classes:

1: active,

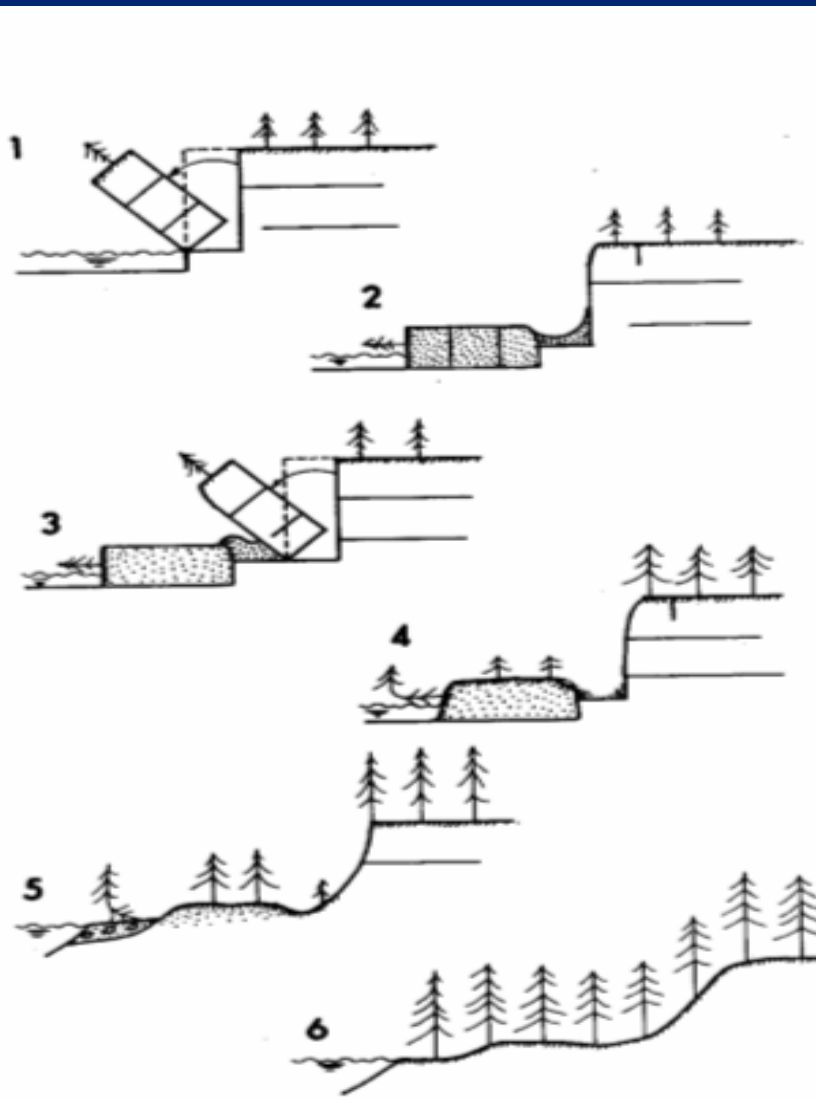
2: suspended,

3: reactivated,

4: dormant,

5: stabilized,

6: relict.



Classification of Slope Instability

Discriminating Factors for classification of mass-movements (slope instability)

- Type of material
- Type of movement
- Water content in the material
- Velocity
- Morphology / morphometry
- Geology
- Climate
- Activity

Different authors have used in different discriminating factors for the classification of mass-movements (slope instability):

- Sharpe(1938):

material	earth	↔	rock
movement	flow	↔	slip
velocity	slow	↔	very rapid
content	water/ice		

- Varnes (1978):

Material:	bedrock,	debris,	earth
Movement:	fall, topple, slide, flow, complex		
Secondary:			
water content:	dry	↔	wet
Velocity:	slow	↔	rapid

- Coates (1977):

Material:	bedrock, regolith, sediment
Movement:	slide, flow, fall
Secondary:	size of material coherence

- Crozier (1973):

Type of movement and Morphometry

- Sharpe(1938):

material	earth	↔	rock
Movement	flow	↔	slip
Velocity	slow	↔	very rapid
content	water/ice		

Velocity Classes landslide	mm / sec	m / hour	m / year
extremely rapid	5×10^{3}	10^{4}	
very rapid	50	10^{2}	
Rapid	5	1	16×10^{3}
Moderate	5×10^{-3}	10^{-2}	160
Slow	50×10^{-6}	10^{-4}	1 x 6
very slow	0.5×10^{-6}	10^{-6}	16×10^{-3}
extremely slow			

- Classification based on Hutchinson

Sagging

Sagging is defined as large scale deep seated deformations, under influence of gravity, occurring in competent rocks and occurring in zones where erosion has created deep valleys and therefore an unstable situation (Hutchinson, 1988).

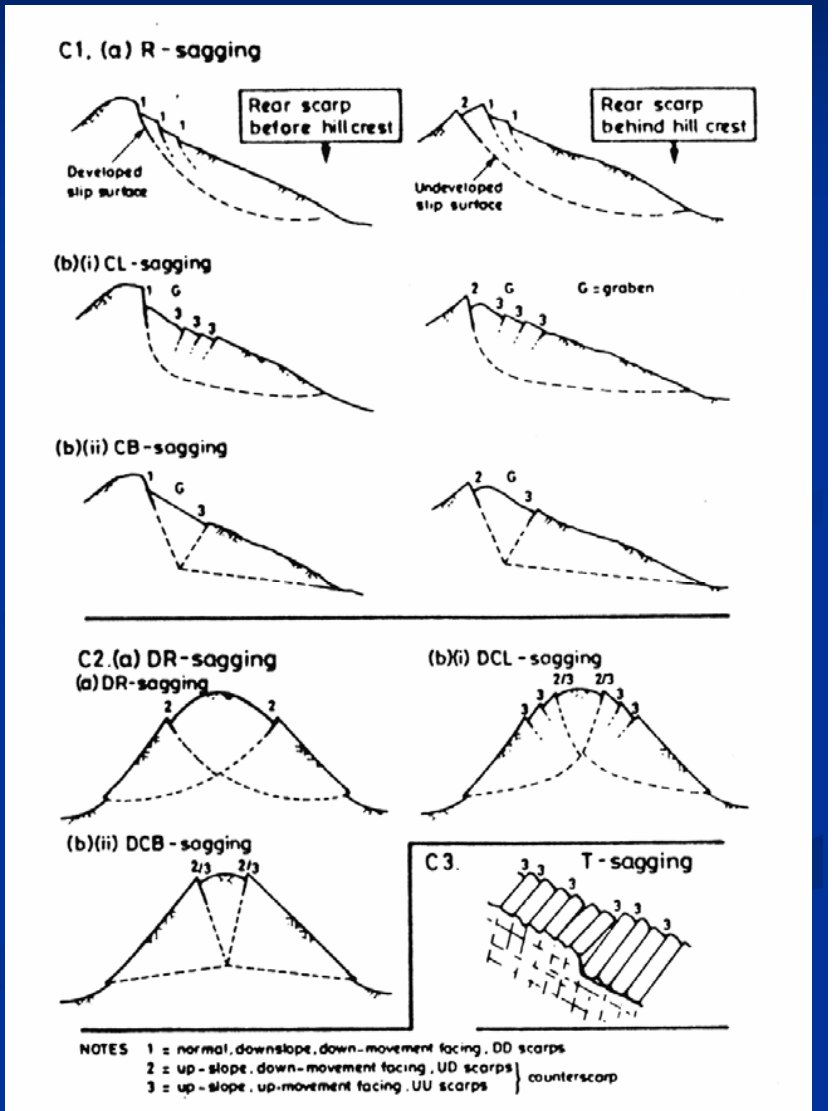
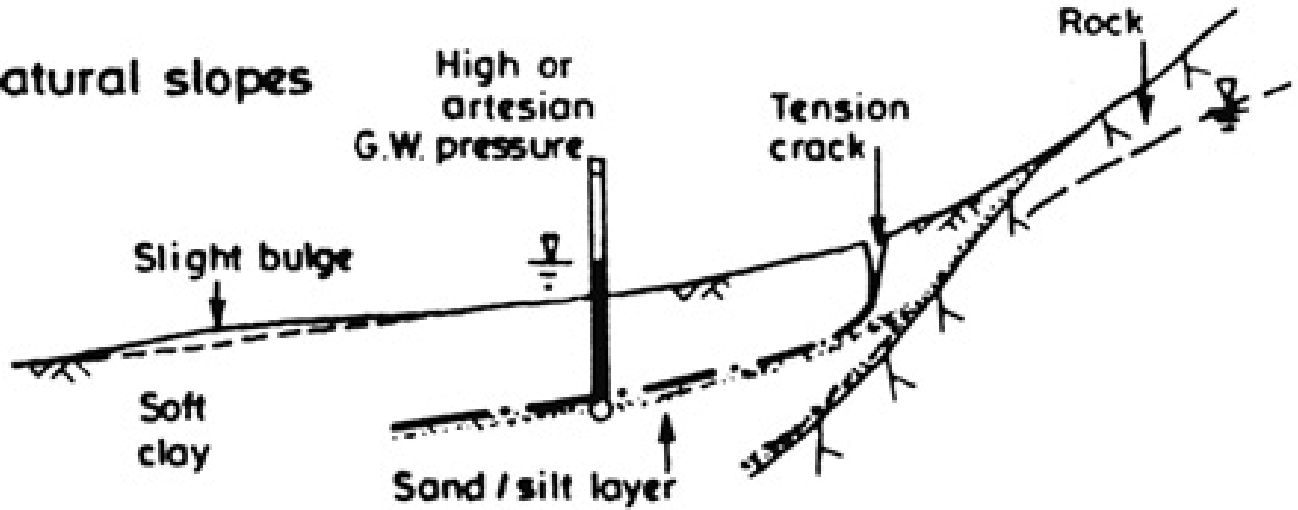


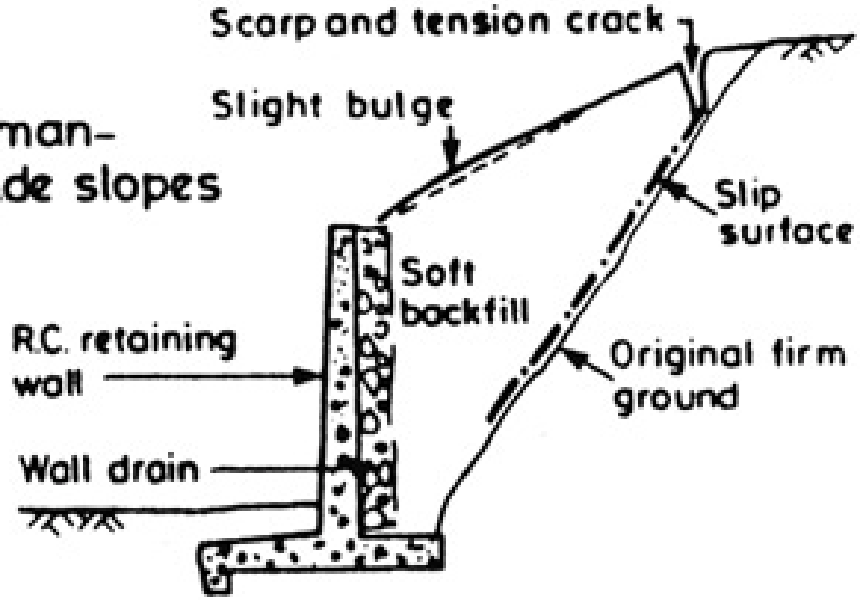
Figure 2. Main types of sagging

D1 Confined failures

(a) In natural slopes

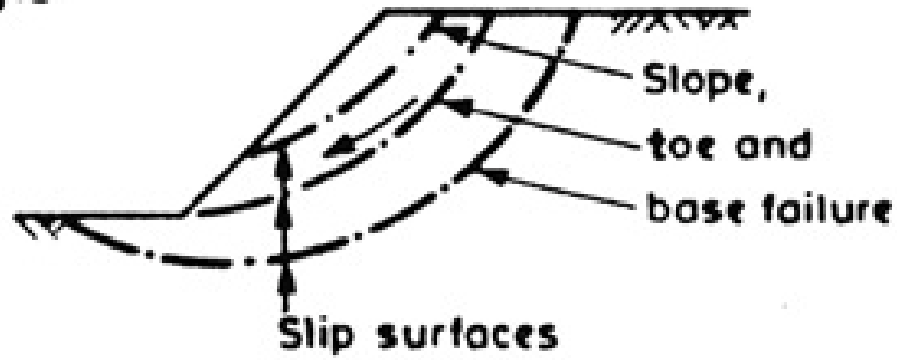


(b) In man-made slopes

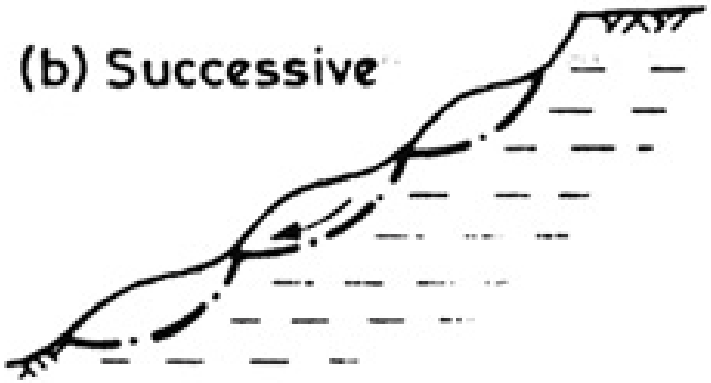


D2 Rotational slips

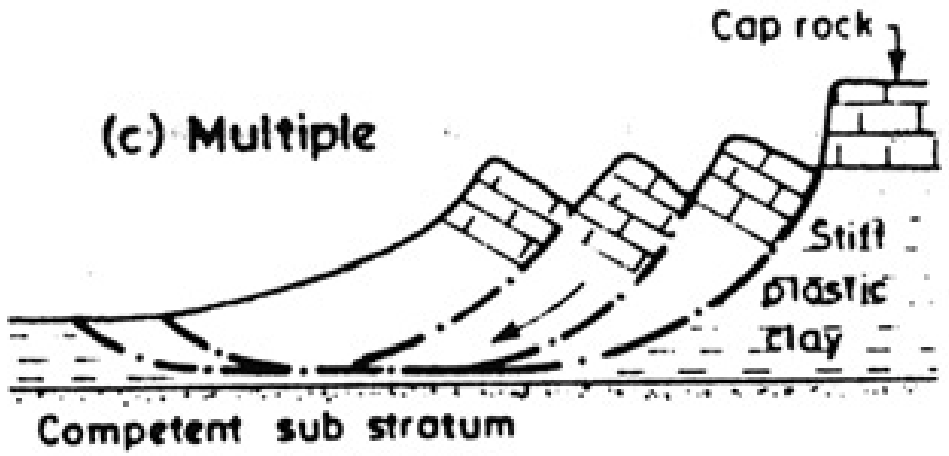
(a) Single



(b) Successive



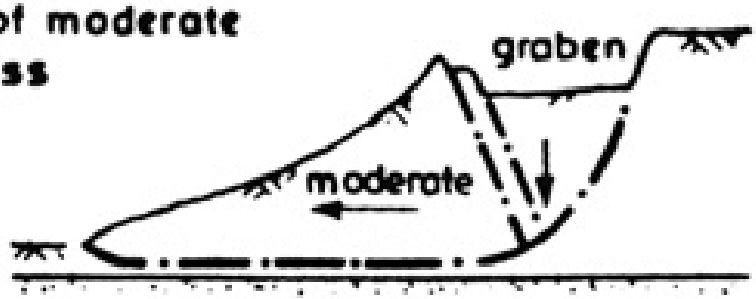
(c) Multiple



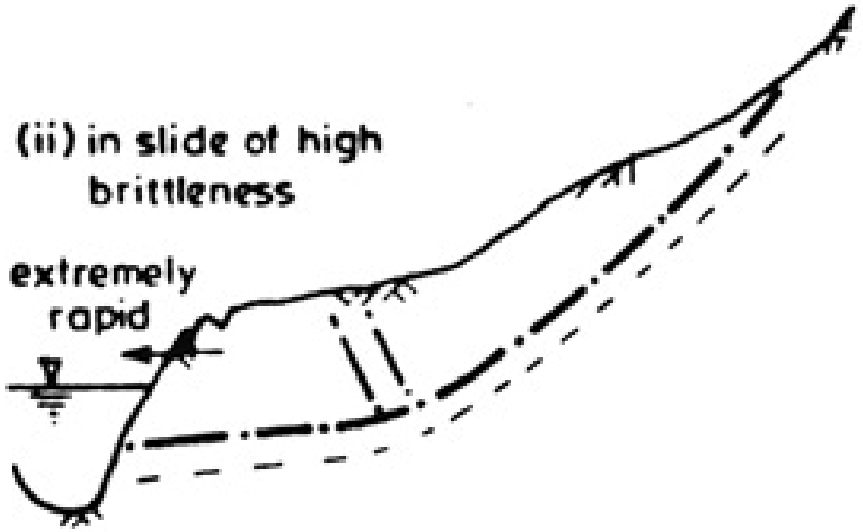
D3 Compound slides

(a) Released by internal shears

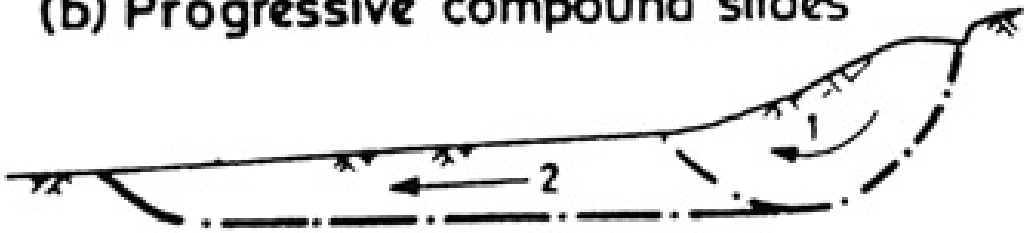
(i) in slide of moderate brittleness



(ii) in slide of high brittleness

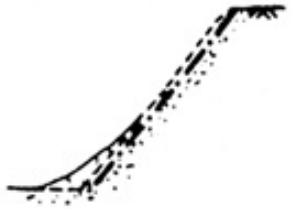


(b) Progressive compound slides

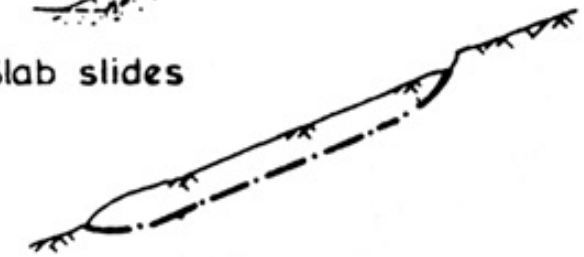


D4 Translational slides

(a) Sheet slides

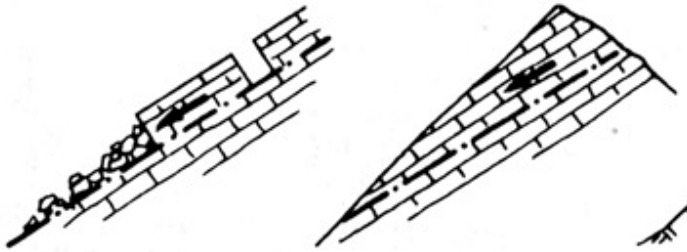


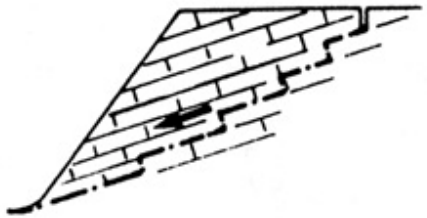
(b) Slab slides



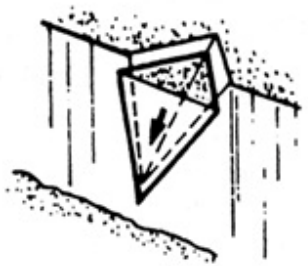
(d) Rock slides

(i) Planar slides





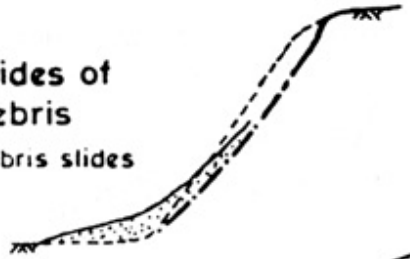
(ii) Stepped slides



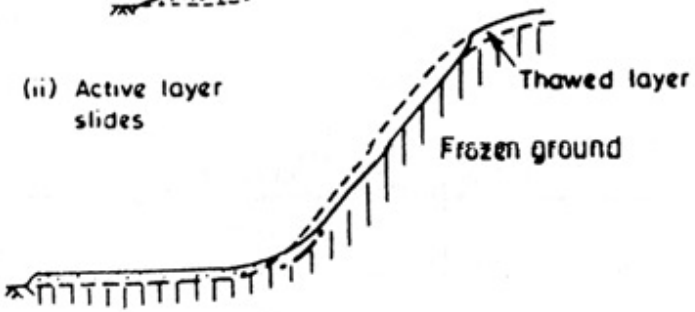
(iii) Wedge failures

(e) Slides of debris

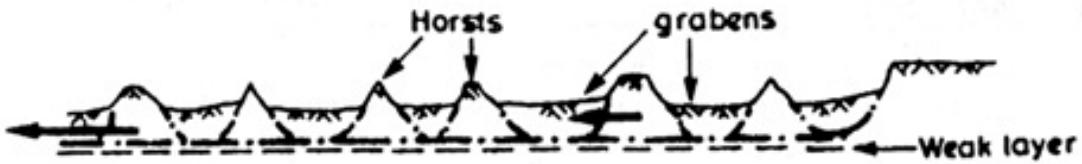
(i) Debris slides

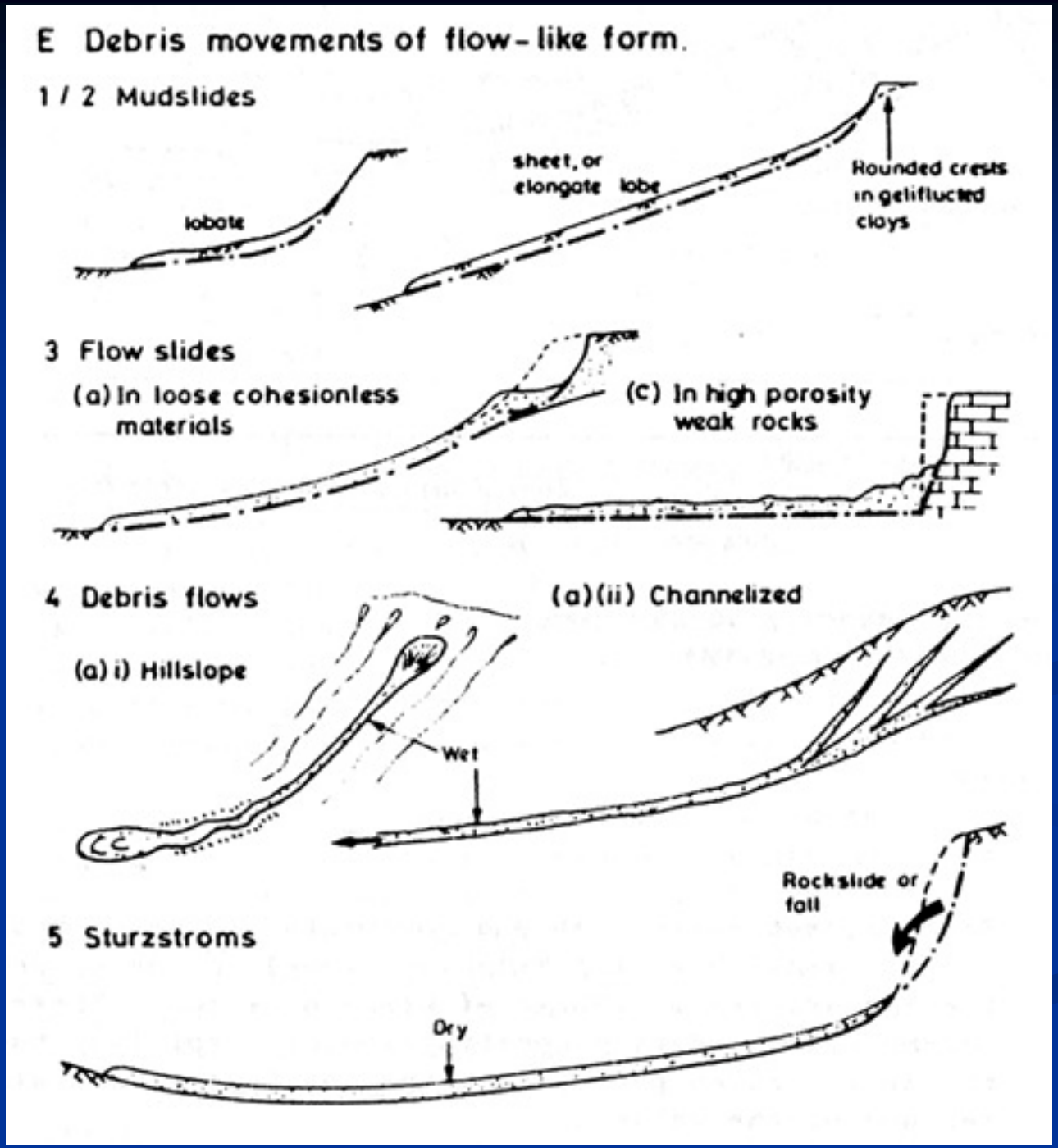


(ii) Active layer slides



(f) Sudden spreading failures

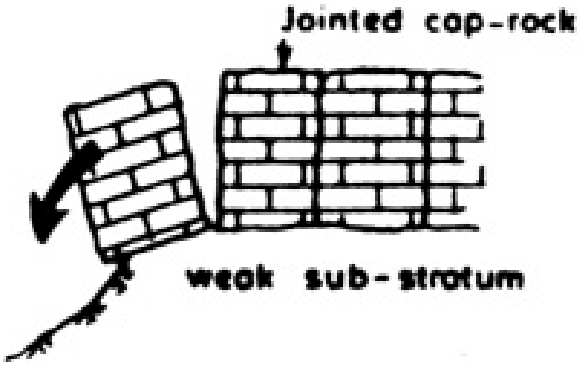



E Debris movements of flow-like form.
1 / 2 Mudslides
lobate
sheet, or elongate lobe
Rounded crests in geliflucted clays
3 Flow slides
(a) In loose cohesionless materials
(c) In high porosity weak rocks
4 Debris flows
(a) i) Hillslope
(a) (ii) Channelized
Wet
Rockslide or fall
5 Sturzstroms
Dry

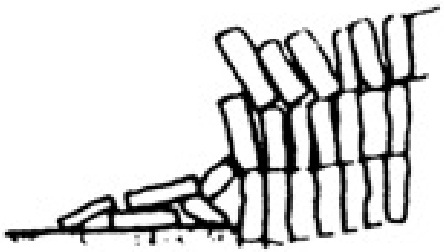
F Toppling failures

1 Bounded by pre-existing discontinuities

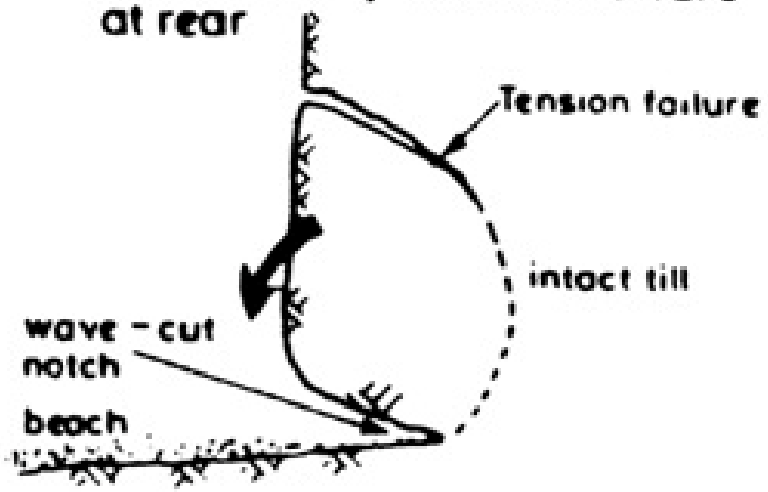
(a) Single



(b) Multiple



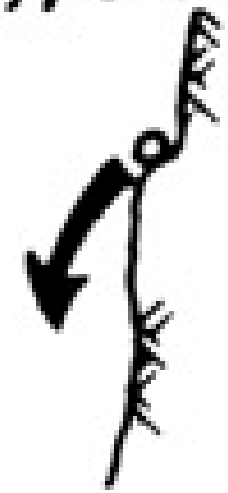
2. Released by tension failure at rear

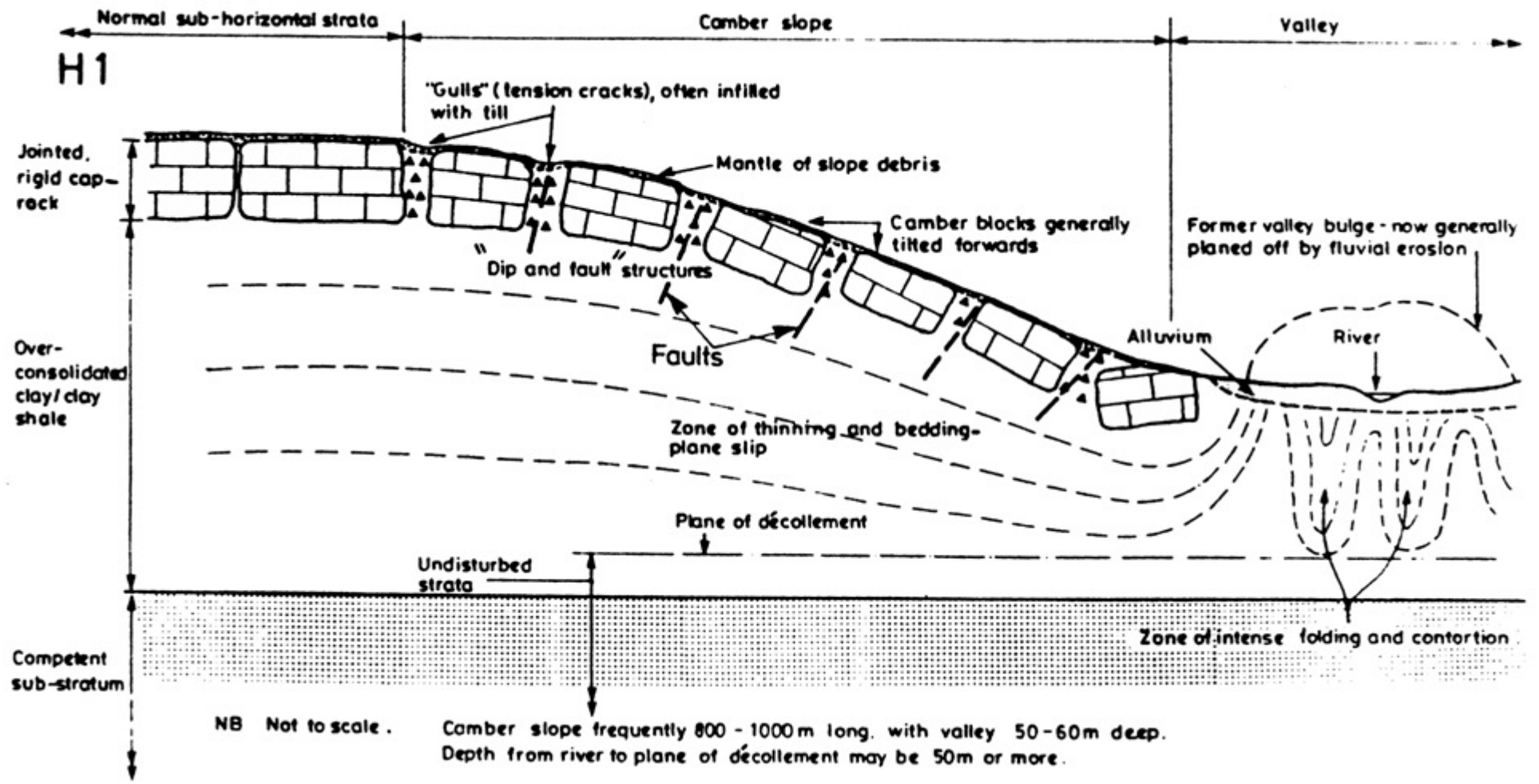


G Falls

1. Primary; rock and soil falls

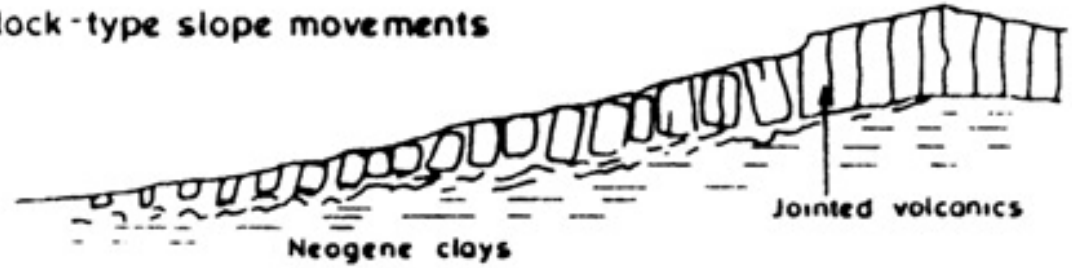
2. Secondary; stone falls



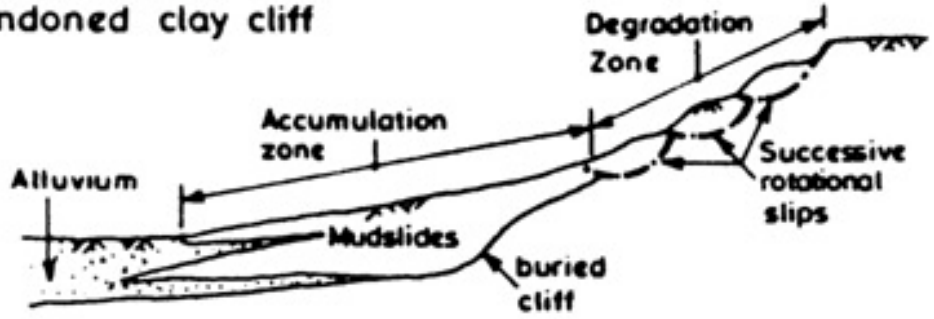

Normal sub-horizontal strata
Camber slope
Valley
H1
"Gulls" (tension cracks), often infilled with till
Jointed, rigid cap-rock
Mantle of slope debris
Camber blocks generally tilted forwards
Former valley bulge - now generally planed off by fluvial erosion
"Dip and fault" structures
Faults
Alluvium
River
Over-consolidated clay/clay shale
Zone of thinning and bedding-plane slip
Plane of décollement
Undisturbed strata
Zone of intense folding and contortion
Competent sub-stratum
NB Not to scale.
Camber slope frequently 800 - 1000 m long, with valley 50 - 60 m deep.
Depth from river to plane of décollement may be 50m or more.

H Complex slope movements

2 Block-type slope movements



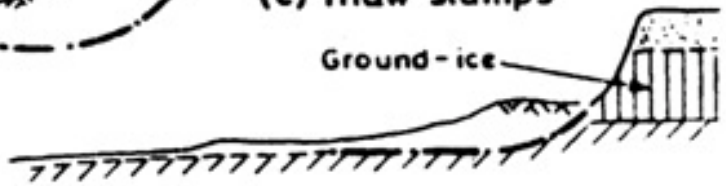
3 Abandoned clay cliff



4 Slides with mudslides or flows at toe

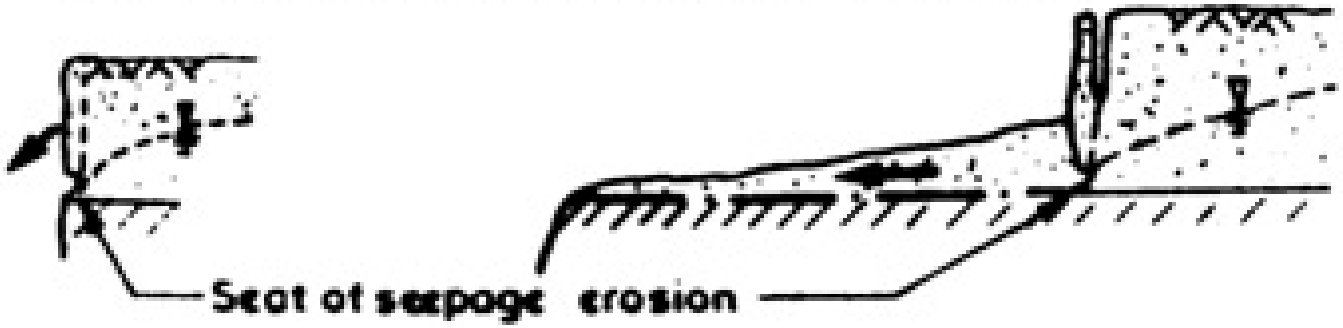
(a) Slump earthflows

(c) Thaw slumps

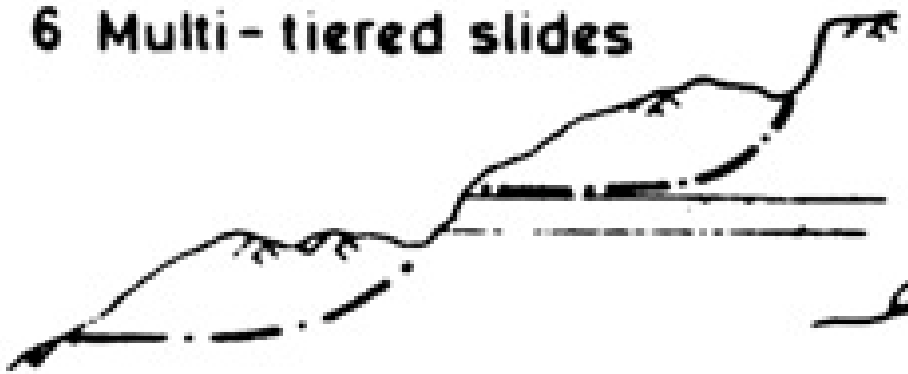


(b) Multiple rotational quick-clay slides

5 Slides caused by seepage erosion



6 Multi - tiered slides



7 Multi – storied slides

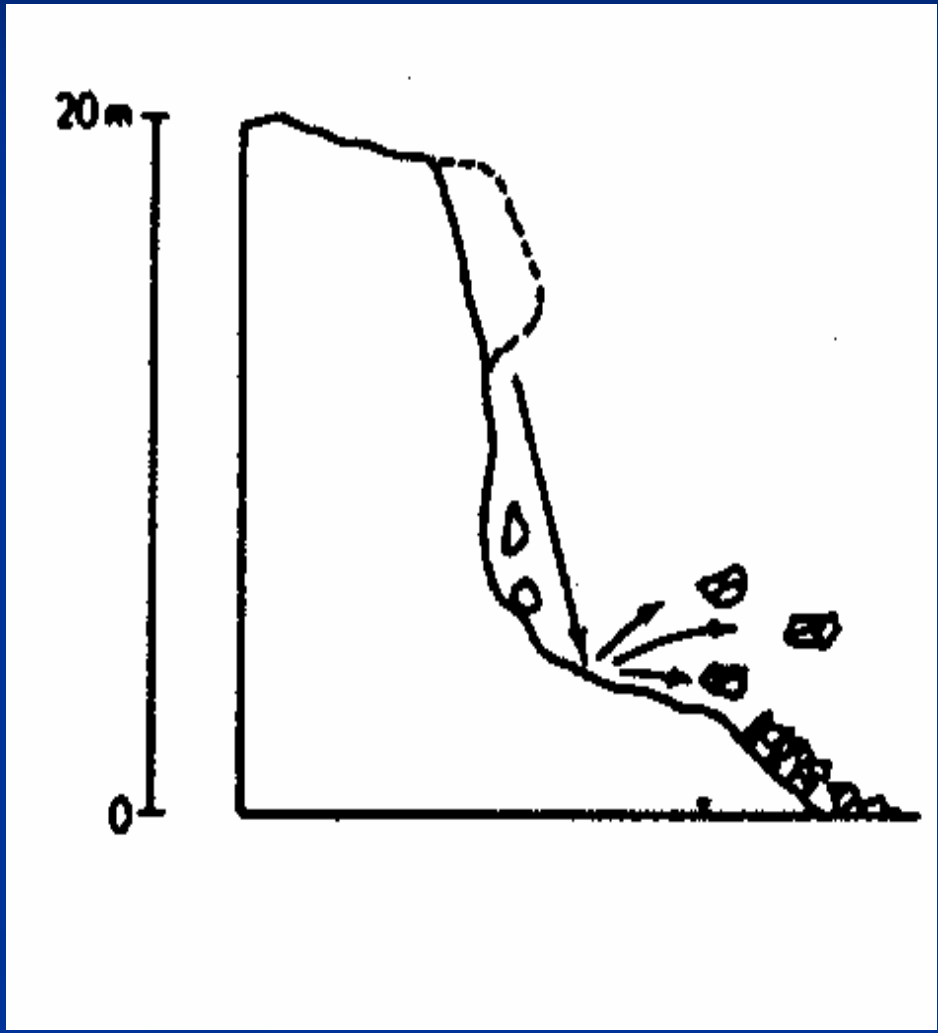
Types of Landslide

- six distinct types of landslide based on movements are:

  fall, topple, slide, sagging, spread, and **flow like forms.**

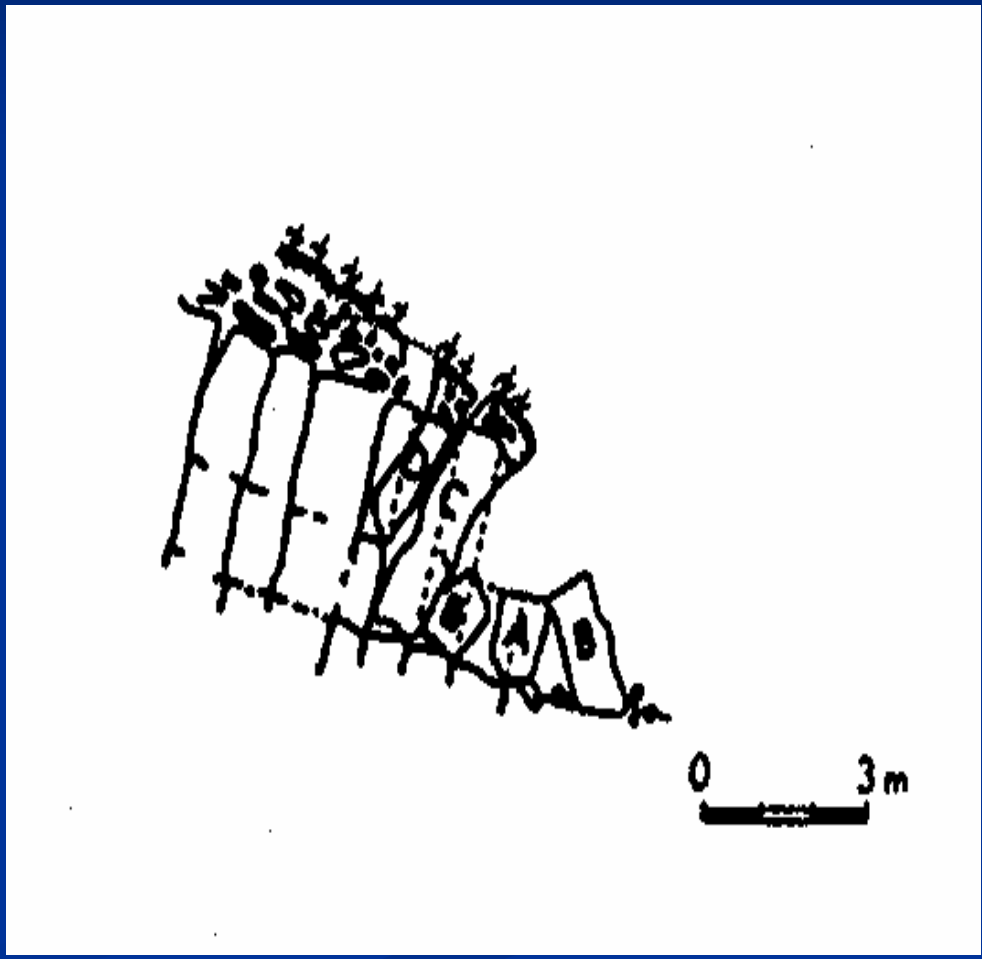
Fall

- Falls comprise a detachment of soil or rock from a steep slope and the more or less free and extremely rapid descent of the material.
- the movement is largely through the air, alternated with the bouncing or rolling on the slope.



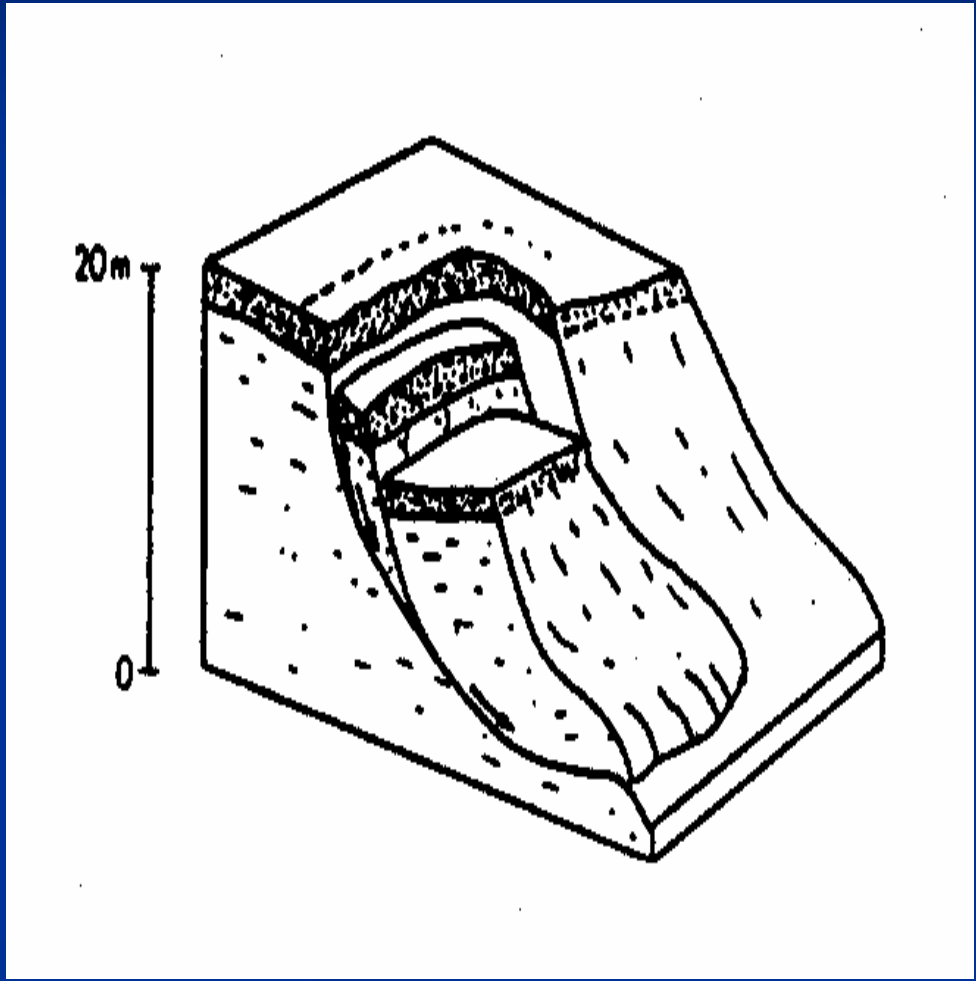
Topple

- A topple is a forward rotation out of the slope of a mass of soil or rock about a point below the centre of gravity of the displaced mass.
- The process is, identically to fall, associated with very steep slopes. Topples may lead to the sliding of the displaced mass, but toppling is mostly occurring in combination with fall. The process in rock slopes is generally controlled by steep inclined discontinuities more or less parallel to the free toppling face.

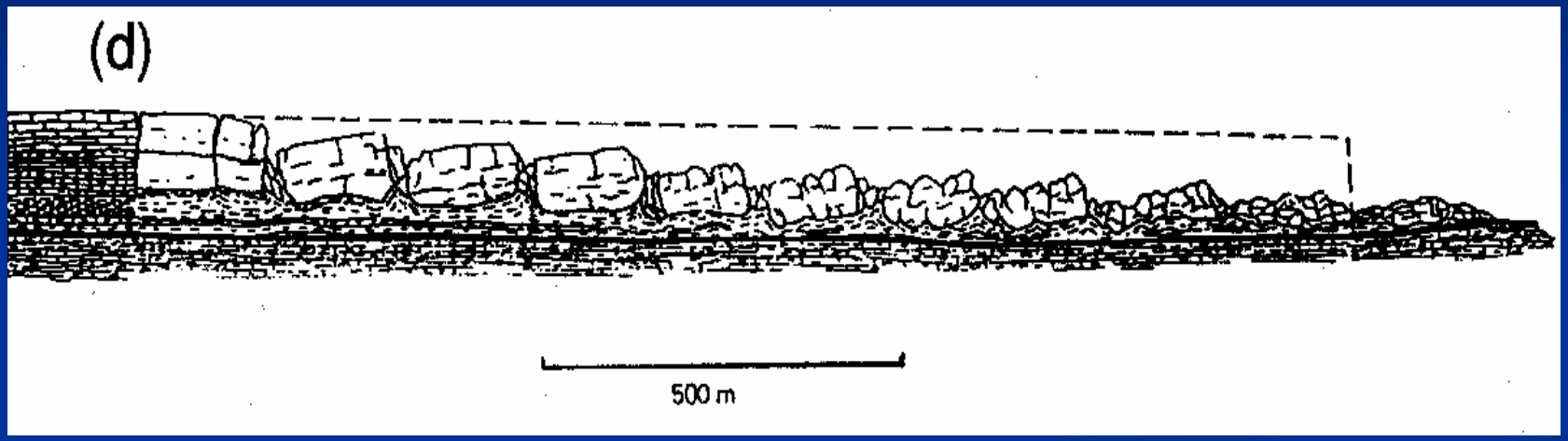


Slide

- A landslide in the restricted sense of the word is a generally rapid to very rapid downslope movement of soil or rock bounded by a more or less discrete failure surface which define the sliding mass.
- An essential element of sliding is that the movement takes place as a unit portion of land, which implies that there are no movements within the slipped block



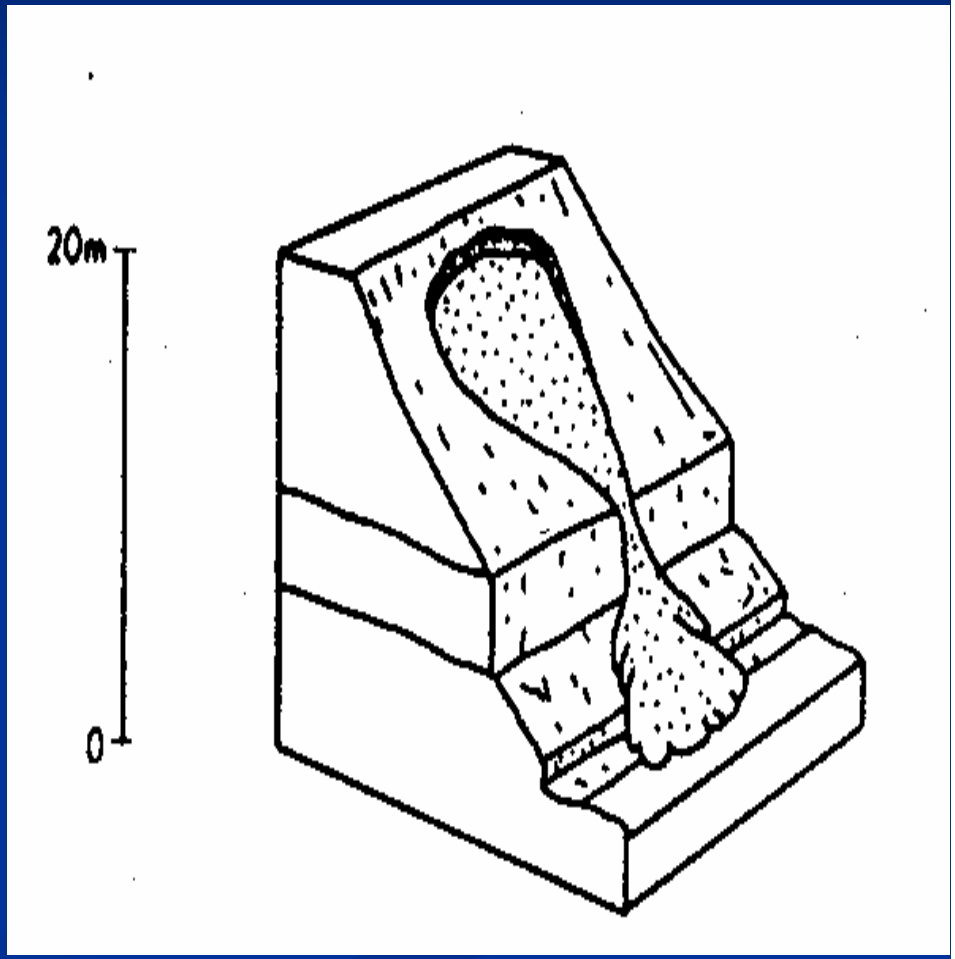
Spread

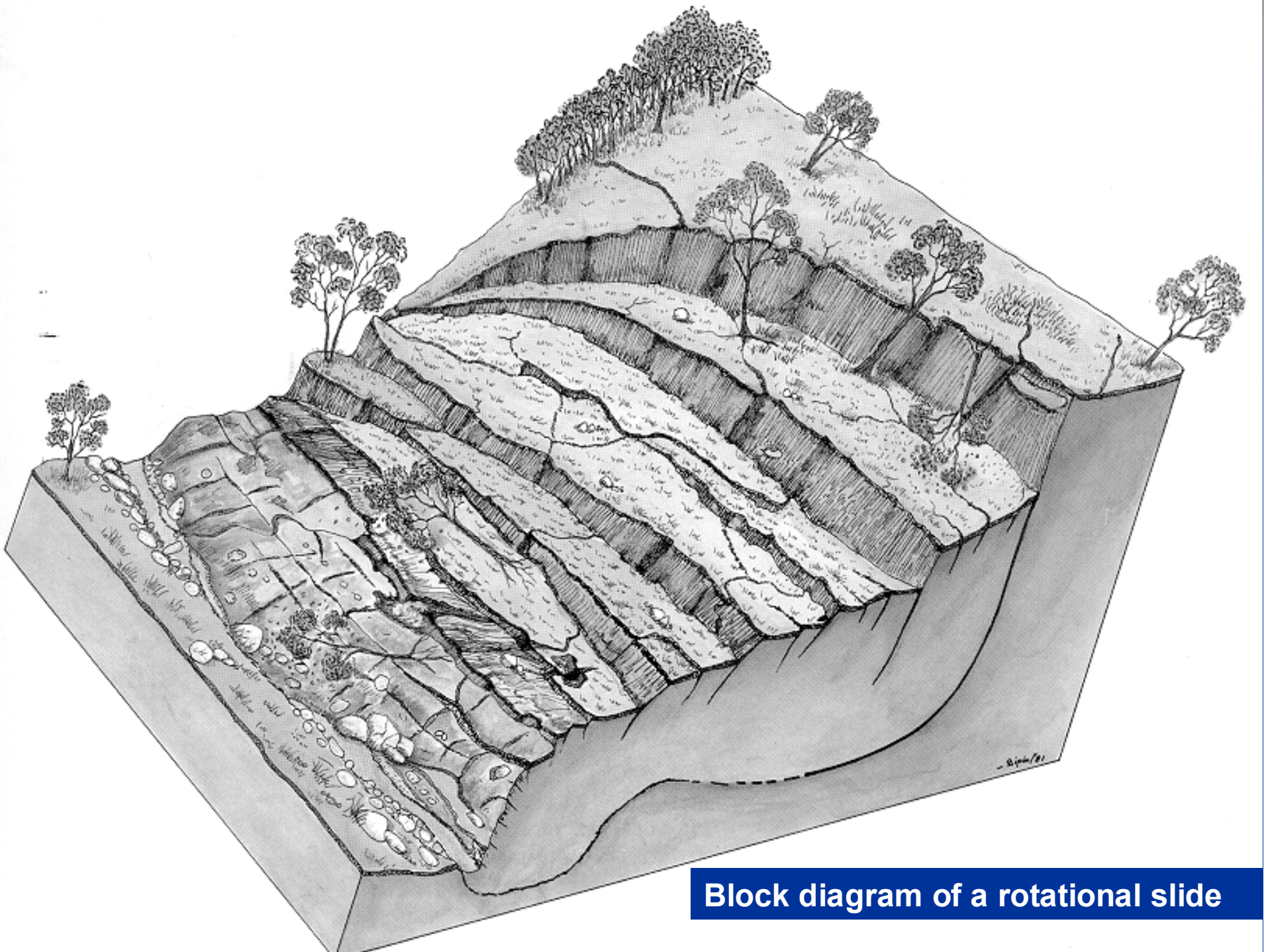


- Spread is defined here as an extension of a cohesive soil or rock mass combined with a general subsidence of the broken mass of cohesive material into softer underlying material. From the definition it is clear that the horizontal (lateral) component is more important than the vertical movement.
- Common are block spreads, large joint controlled blocks are sliding into the valley.
- Eg. liquefaction, which implies the abrupt lowering to zero of the cohesion and the effective stress and therefore a behaviour as a liquid of the underlying layer
- an earthquake, causes a change in internal structure, the abrupt increase of the porewater pressure and this results in the liquefaction.

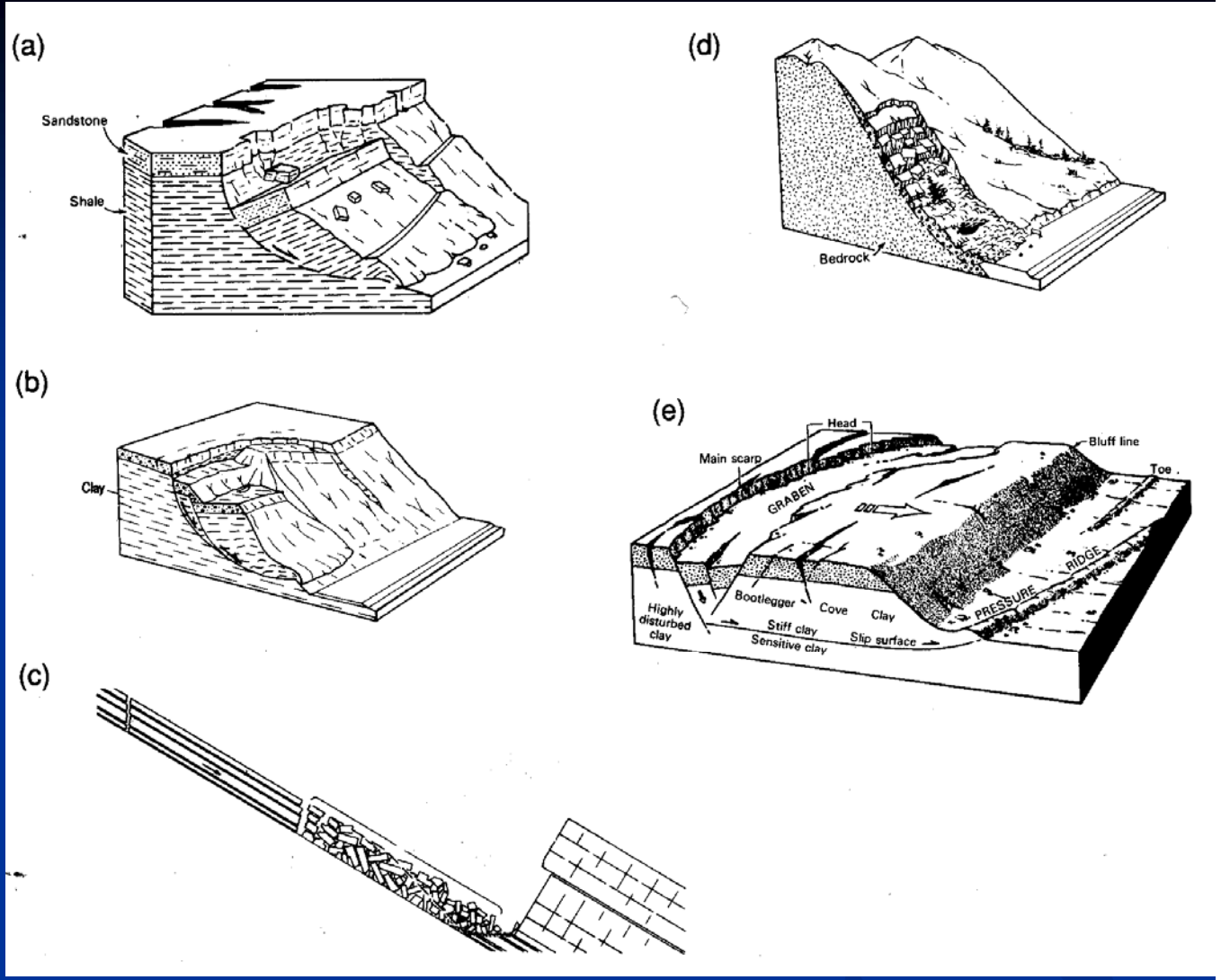
Flows or debris movements of flow-like form

- A very large variety of mass movements of flow-like form exist and they grade into all other types of slope movements. Debris flows can be generated from debris slides or by extreme forms of streamflow erosion.
- Earthflows are often originated by large slides whereby the more or less saturated sliding material disintegrates and continues its way down in flow-like form. It has been observed that slab slides are grading into solifluction and in the same way creep can accelerate to debris slides (progressive failure).
- Creep is a very to extremely slow diffuse slope movement, occurring under the effect of a continued stress close to the ultimate or peak stress. The movement can be deep seated and continue, which is the case in moderate to steep slopes in rather soft rocks.





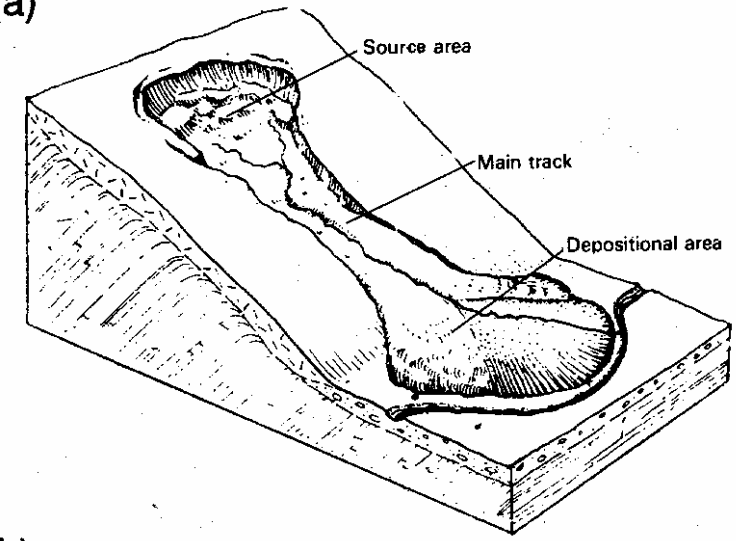
Block diagram of a rotational slide



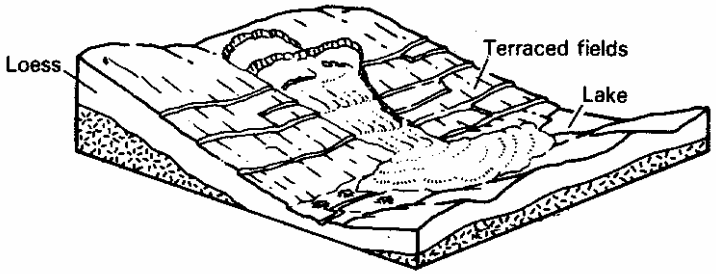
Different types of slides

a: rotational rock slide;
b: rotational earth slide;
c: translational rock slide (upper portion is rock block slide);
d: debris slide;
e: translational earth slide (Varnes, 1978)

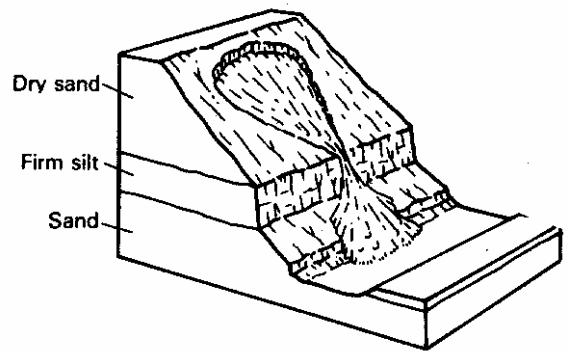
(a)



(b)



(c)



Examples of flows:

a: slow earth flow,

b: Loess flow,

c: dry sand flow (Cruden and Varnes, 1996)

Strurzstroms

- are a rather exceptional form of dry rock flows originated by an enormous rock slide or fall, liberating an extreme high amount of kinetic energy. Due to this a dust cloud is formed of a high density which will move along the slope, through valleys over the ground surface. A sturzstrom is in this respect comparable to pyroclastic flows, where a enormous column of warm very hot volcanic tephra mixed with gases and water vapour collapses and flows down along the slopes of the volcano.