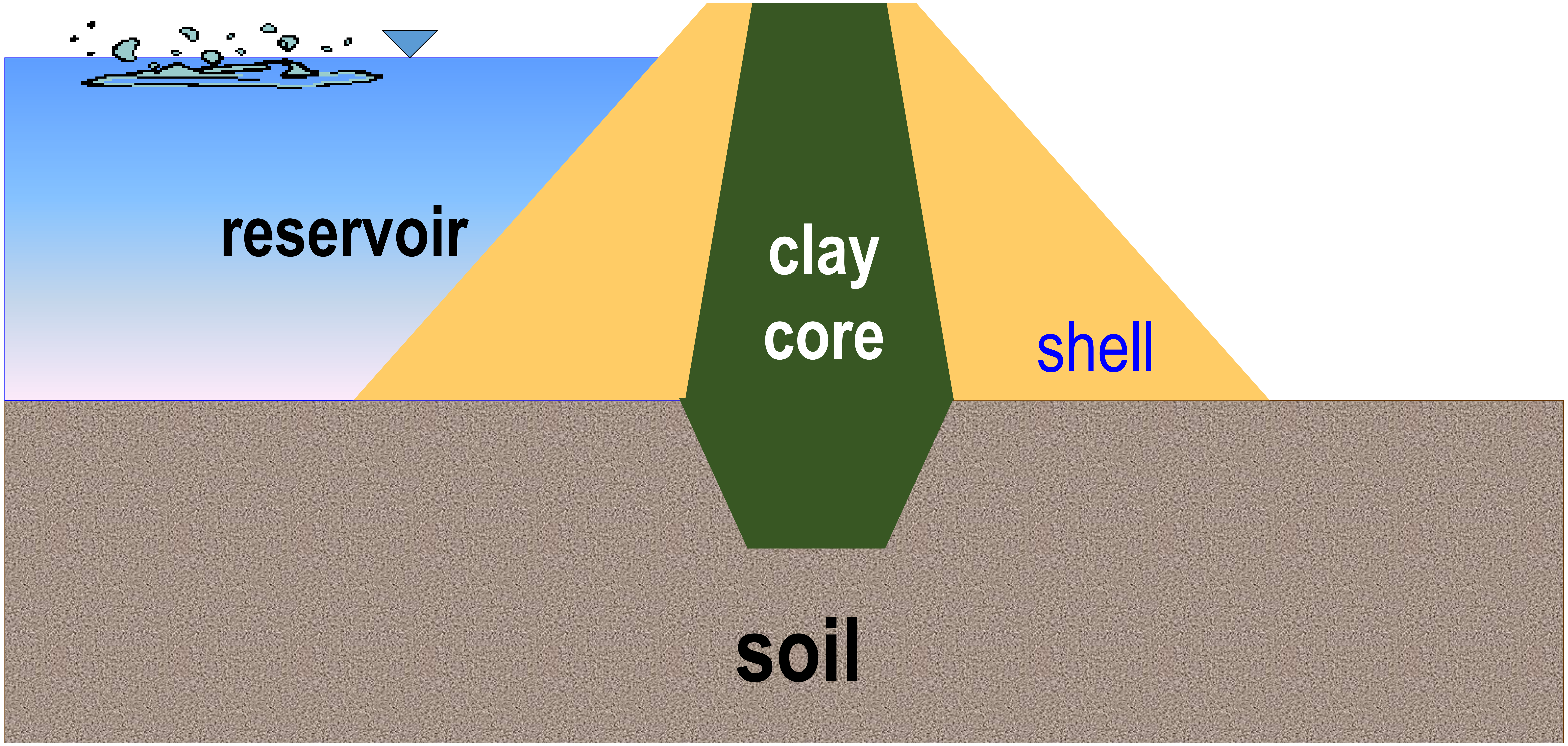
GEOLOGY IN ENGINEERING:

SURFACE EXCAVATIONS

Introduction

Engineering works impose one / more **engineering processes** on ground:

1. **LOADING** the ground – e.g. ***weight of Dam***



Introduction.....contd.

Typical ground reaction, for static loading may include:

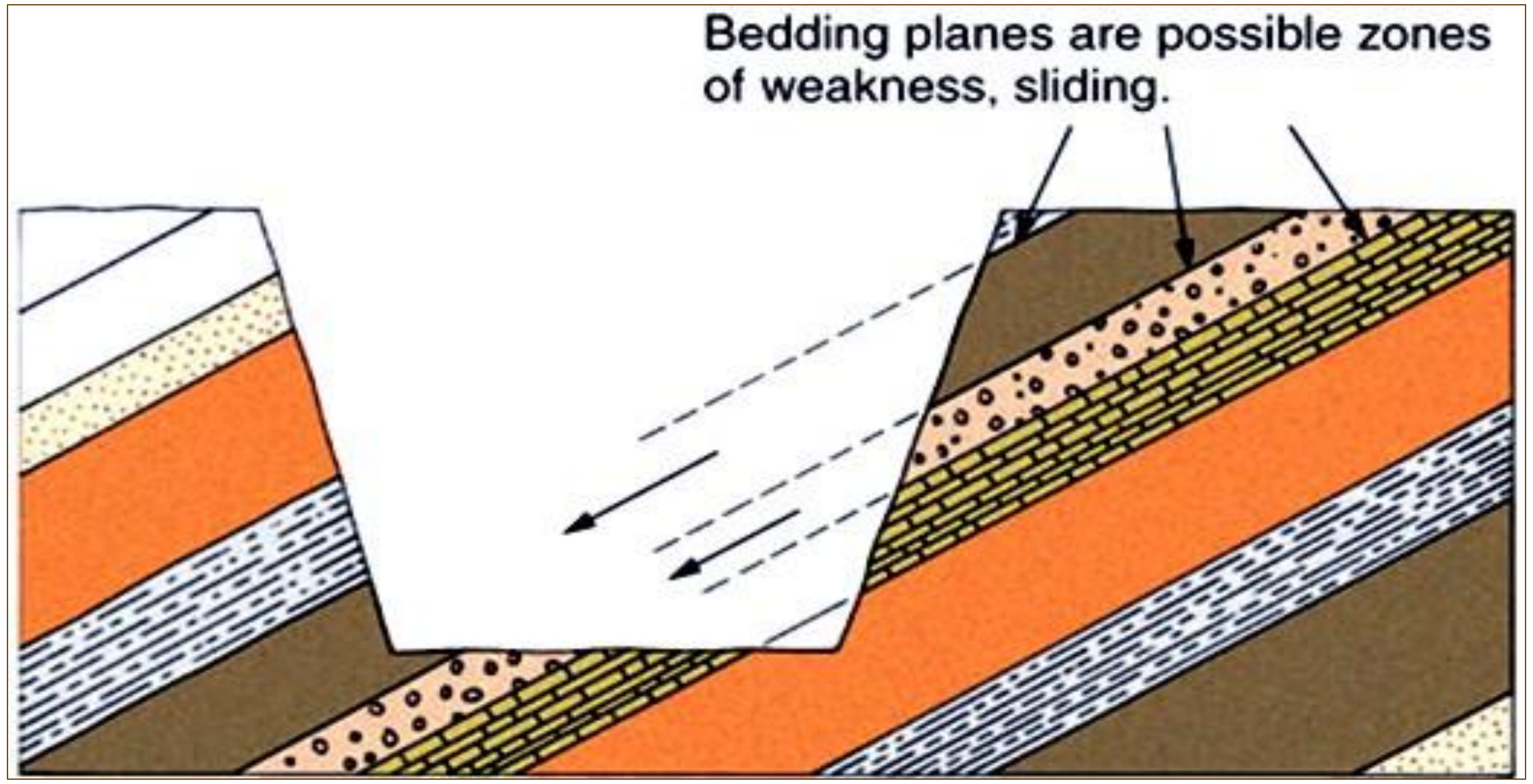
- ✓ELASTIC deformation, leading to SETTLEMENT of the **load-imposing** structure

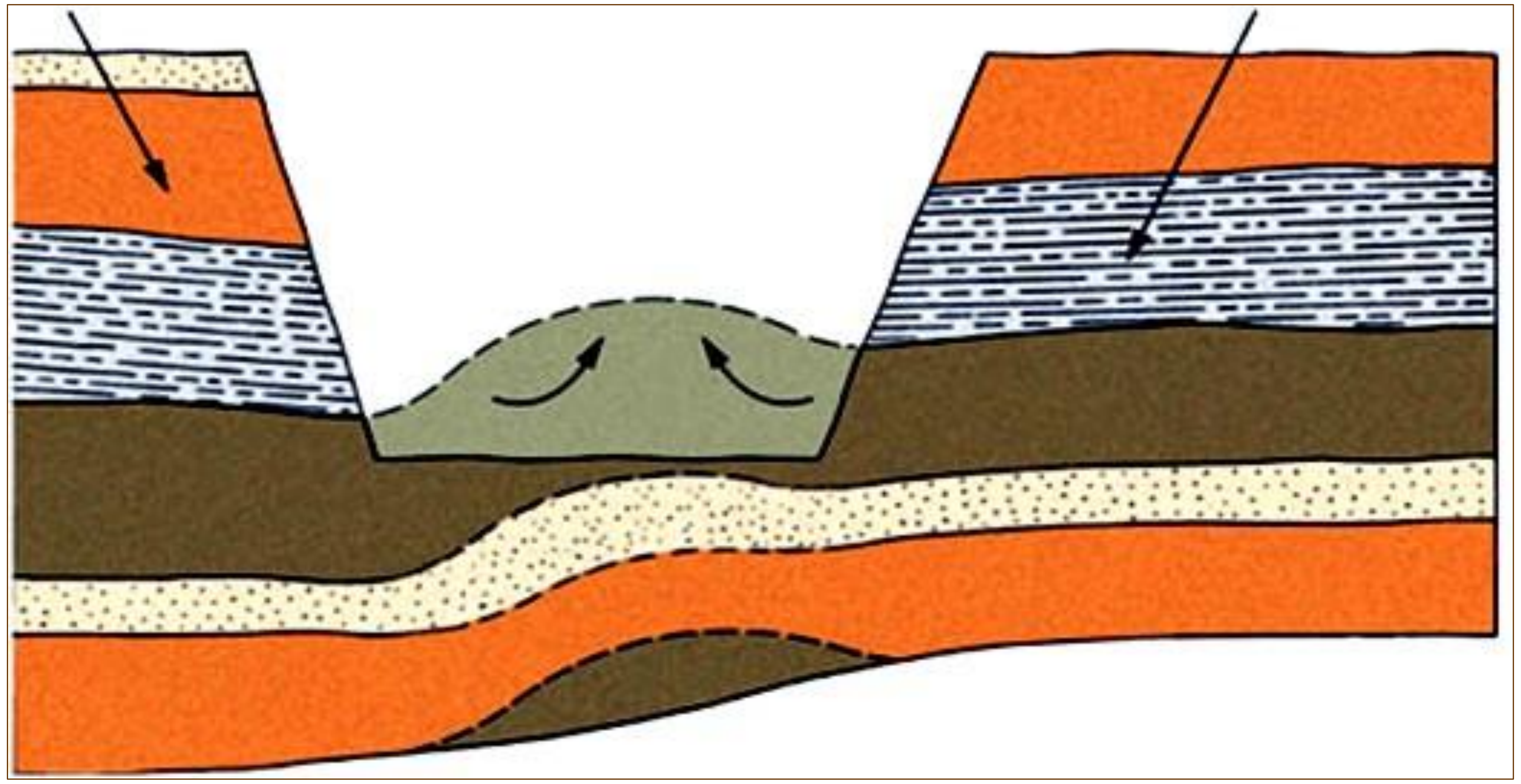
- ✓FAILURE in SHEAR of ground if foundation pressure exceeds load-carrying capacity of ground.

Introduction.....contd.

2. **WITHDRAW OF SUPPORT** from ground (***surface excavation***) –This may cause ground around the excavation to lose support because of removed material, and may result in:

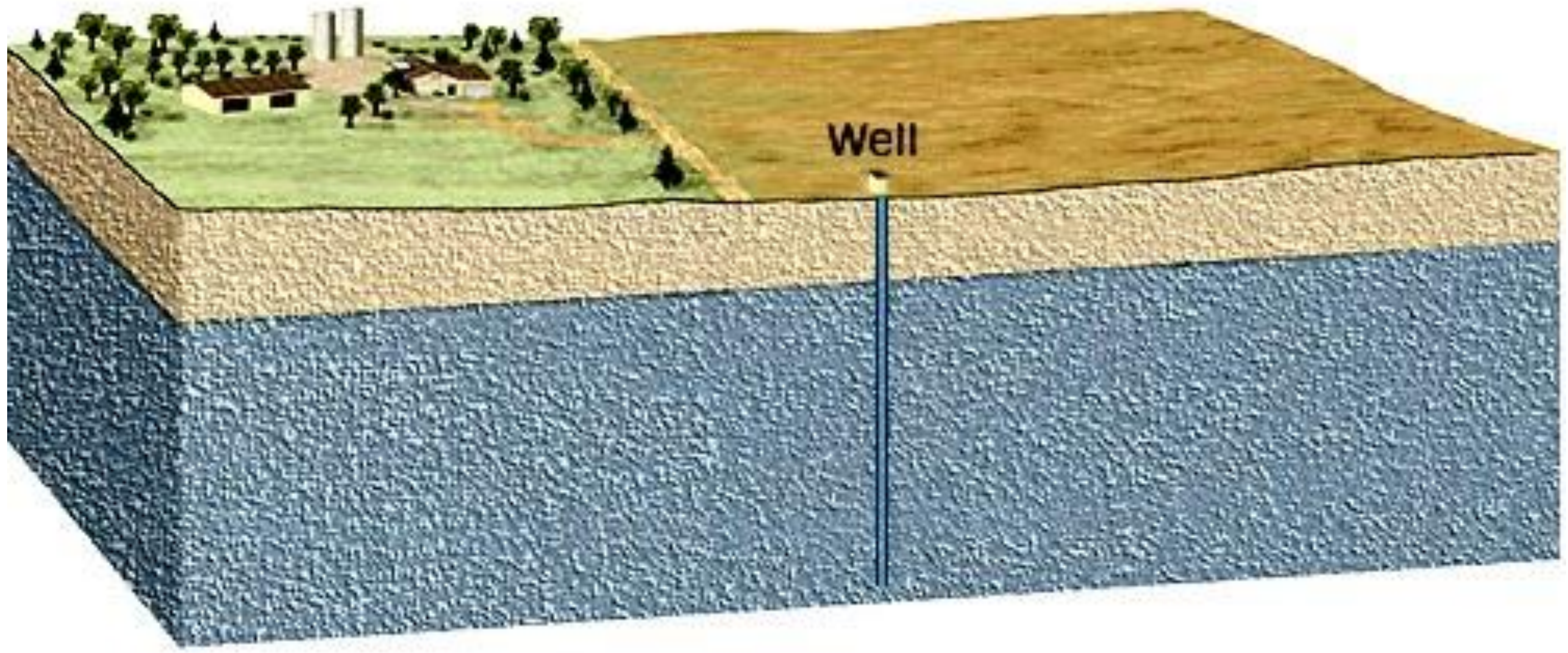
- *DEFORMATION / FAILURE of excavated slope*
- *UPWARDS heave of floor of excavation*





Introduction.....contd.

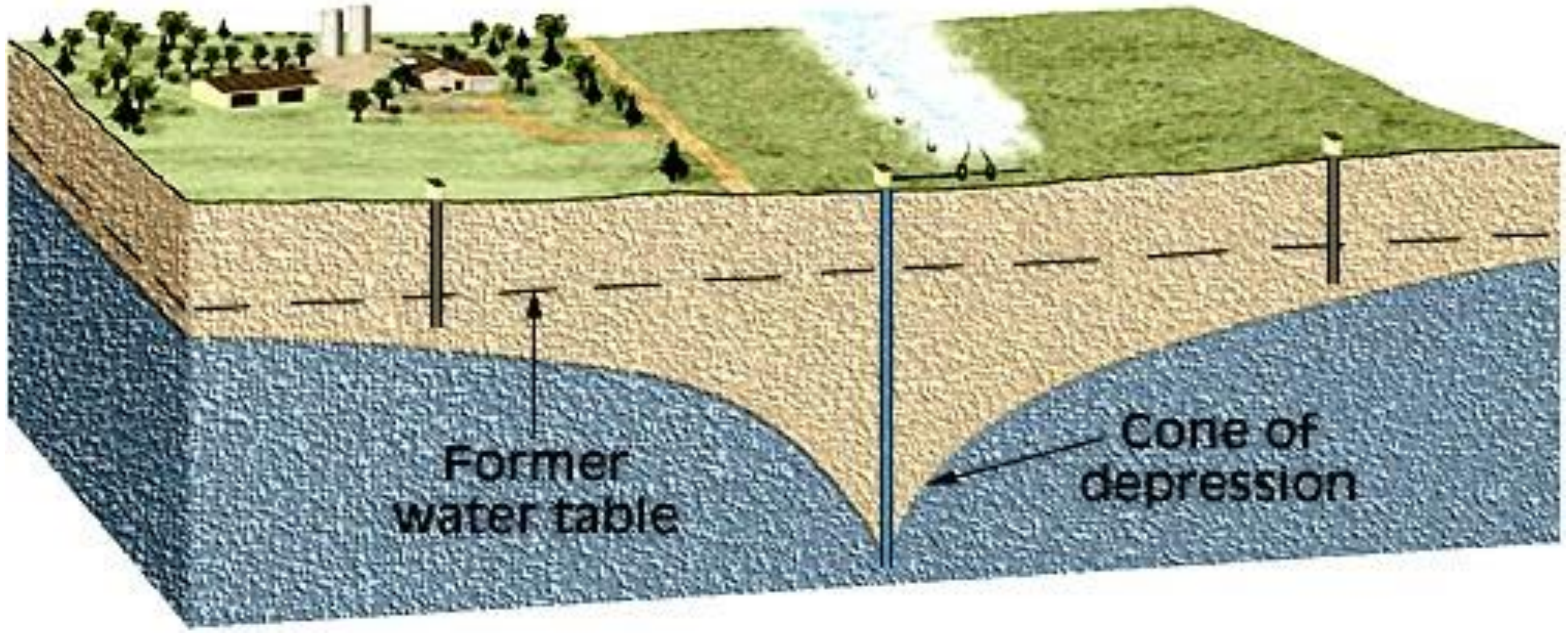
3. **CHANGE IN FLUID PRESSURES** in the ground – e.g. *pumping water from a well.*



Groundwater table at rest.

Removal of pore water pressure by pumping water out results in consolidation of previously satd. Mats.

This may result in SURFACE SUBSIDENCE. Pumping fluids into ground already under stress may induce SEISMICITY.



Introduction.....contd.

Response to each engineering process requires:

- ✓ Knowledge of material properties and
- ✓ Mass Fabric / mass properties

…in order to calculate the MAGNITUDE & NATURE of response – **REACTION**.

In this lecture, we shall deal with **two engineering processes:**

1. Loading the ground, and
2. Withdrawal of support from the ground by surface excavations

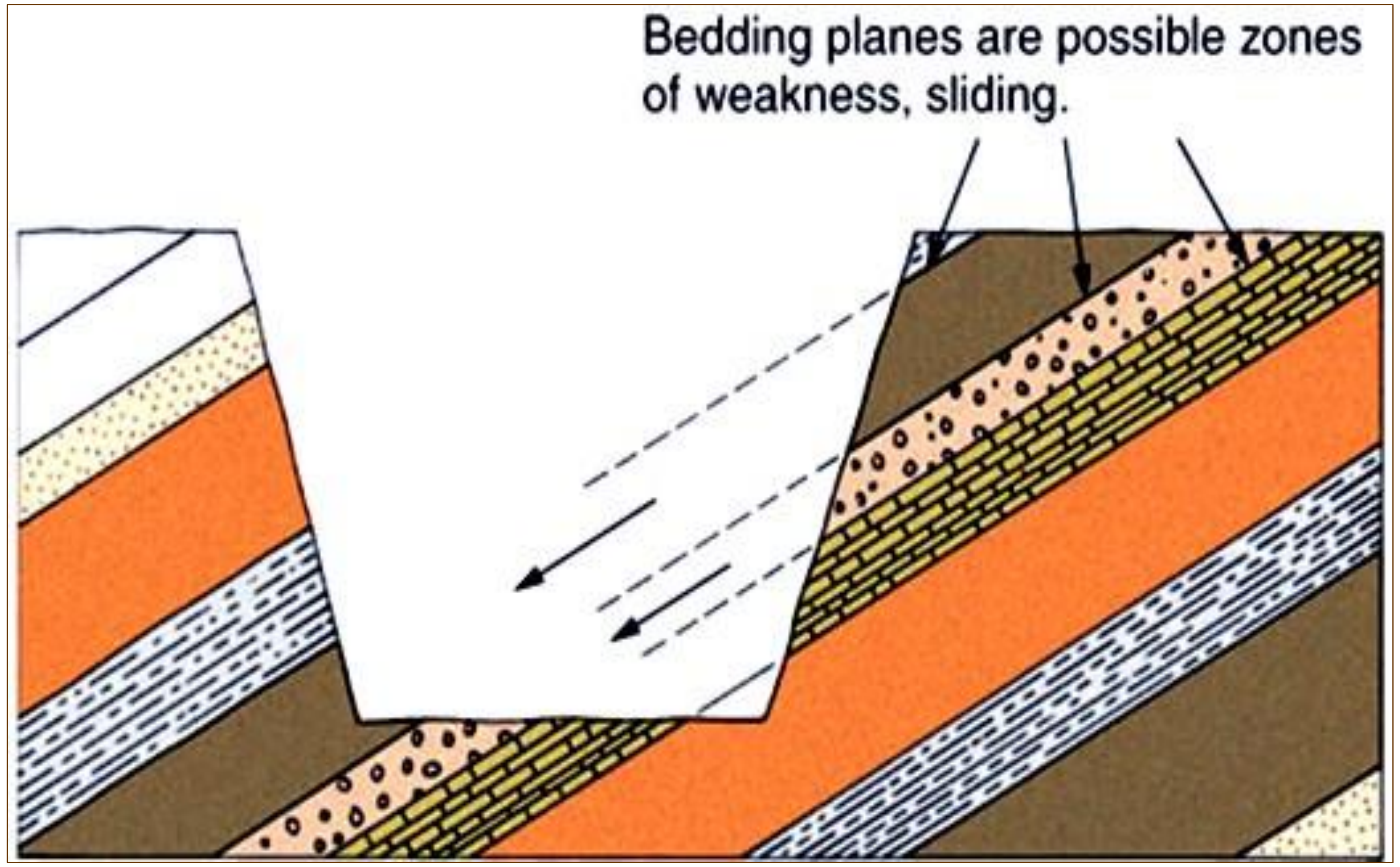
Discontinuities in Surface Excavations

Introduction

- *If support to the ground is withdrawn by surface excavation – e.g. by opening up of a quarry for* ***construction materials,*** *a slope results.*
- *Surface excavations can result from processes undertaken by:*

✓**Natural agencies – e.g.** *river or coastal erosion*

✓**Man-made processes –** *excavation for railways, roads, canals etc*



- **Factors that Influence stability of Slopes**

Factors that Influence stability of Slopes

Surface excavations *leave slopes whose* ***stability*** *is related to:*

1. *Slope angle*

2. *Strength of materials and discontinuities in the slope*

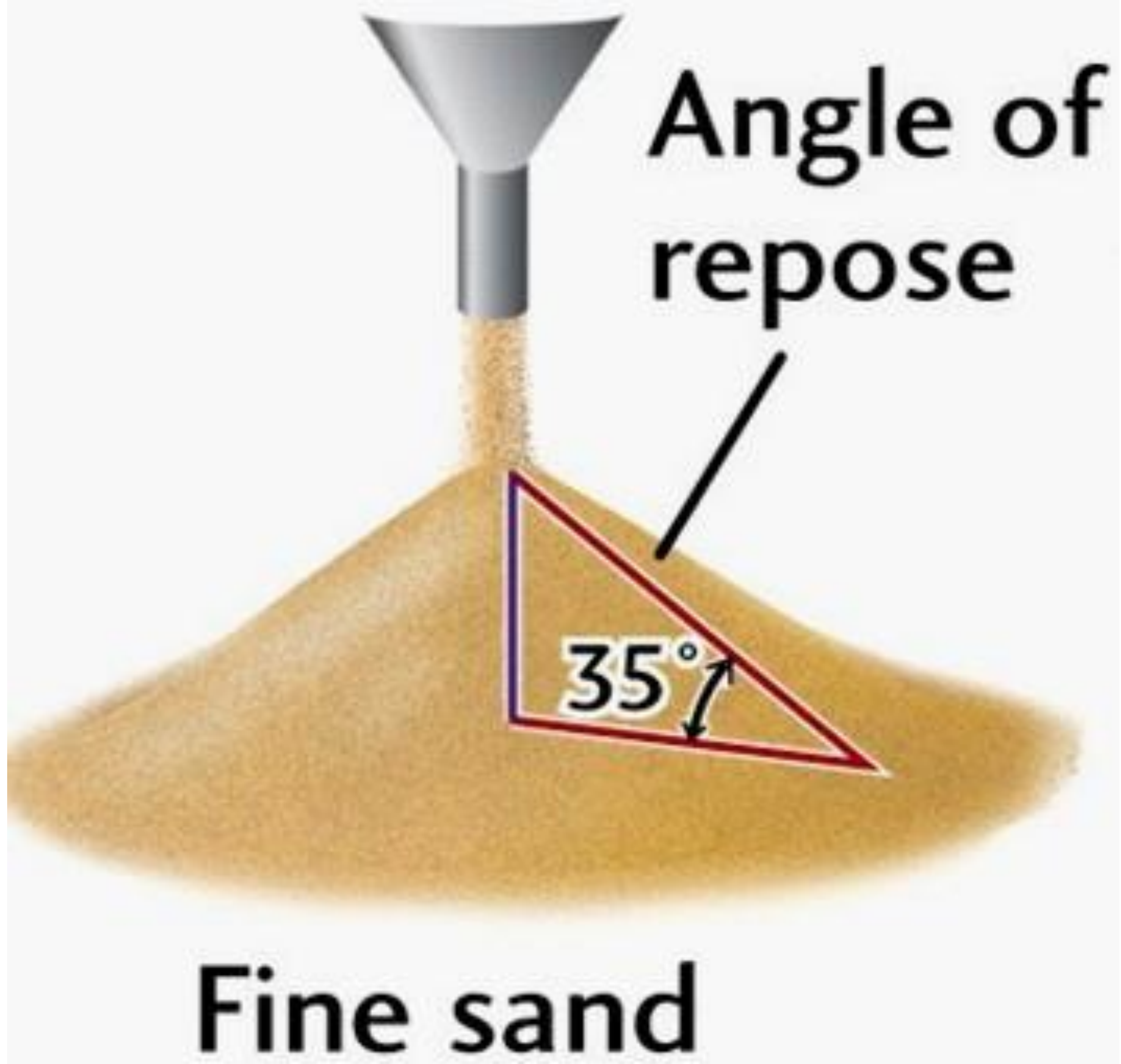
3. *Groundwater situation*

If the ***formed slope*** *is* ***too steep*** *to be supported by the ground in the sides of excavation, then slope will fail.*

Factors that Influence stability of Slope…..contd.

1. Slope angle of material

- The steepness of a slope influences stability of its **rock/soil masses** in the slope:
  - ✓ *steepness of a pile of loose material such as sand has a **distinct limit –** **angle of repose***
  - ✓ *Once the angle of repose is reached, addition of more sand will make the pile **broader** but **not taller***

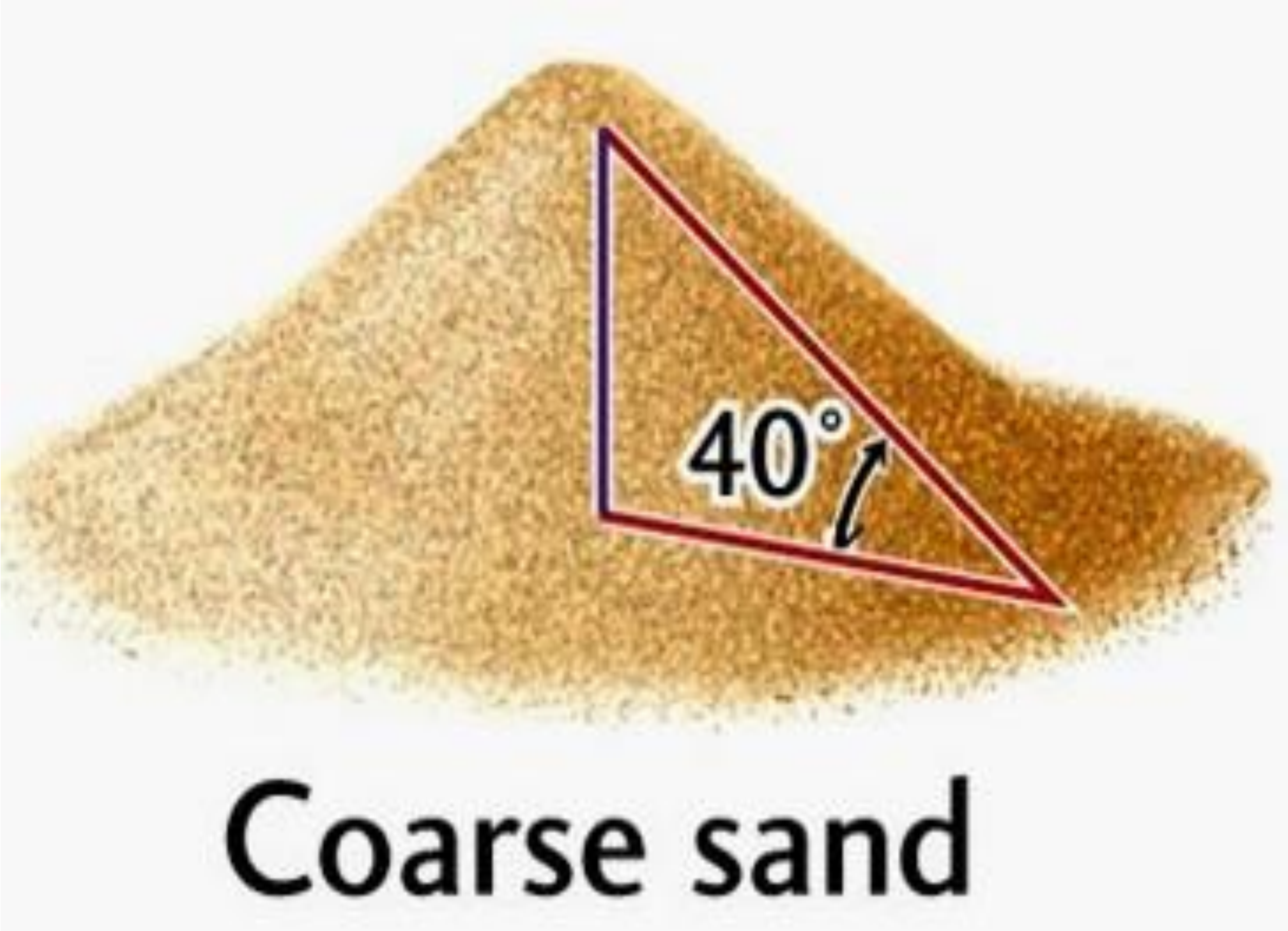


Factors that Influence stability of Slope.....contd.

Stability of the slope also depends upon:

2) **Nature of material in the slope** & **its water content**

   ✓ **and thus, its steepness.**



Factors that Influence stability of Slope…..contd.

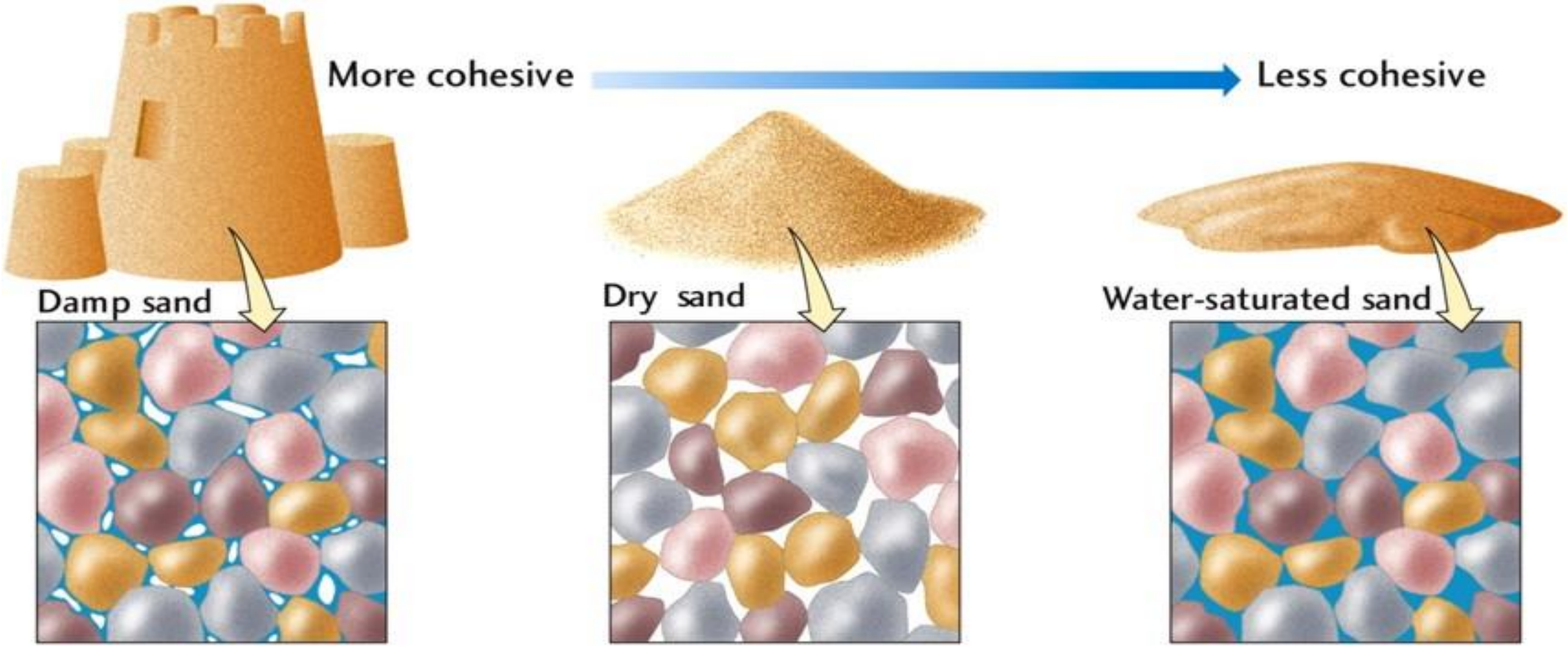
3. **Material's internal friction** – *i.e*. total resistance to movement:

- **Consolidated dry materials** are held together by;
- ✓ cohesion (**attraction of like particles**),
- ✓ adhesion (**attraction of unlike particles**) and
- ✓ Cementation **(gluing together of particles by a binding material)**

Factors that Influence stability of Slope.....contd.

4. Material's moisture content

- too little limits vegetation growth and diversity
- too much can push grains apart, add weight, or provide lubrication.



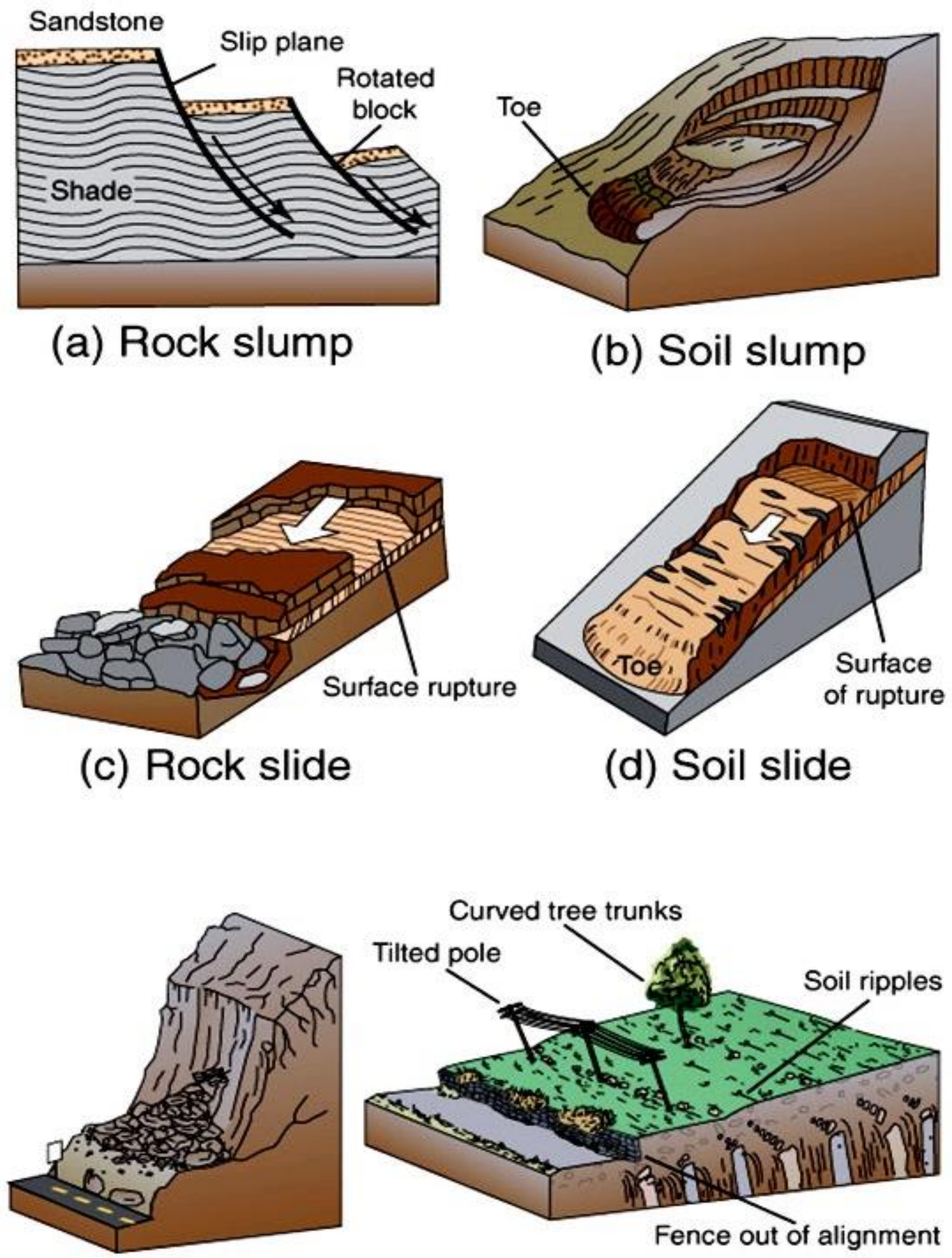
Types of Slope Failures

Classification of **slope failures** is based upon:

- ✓**Nature of the material** (un/consolidated)
- ✓**Speed of movement**
- ✓**Nature of movement** (sliding, falling, or flowing)

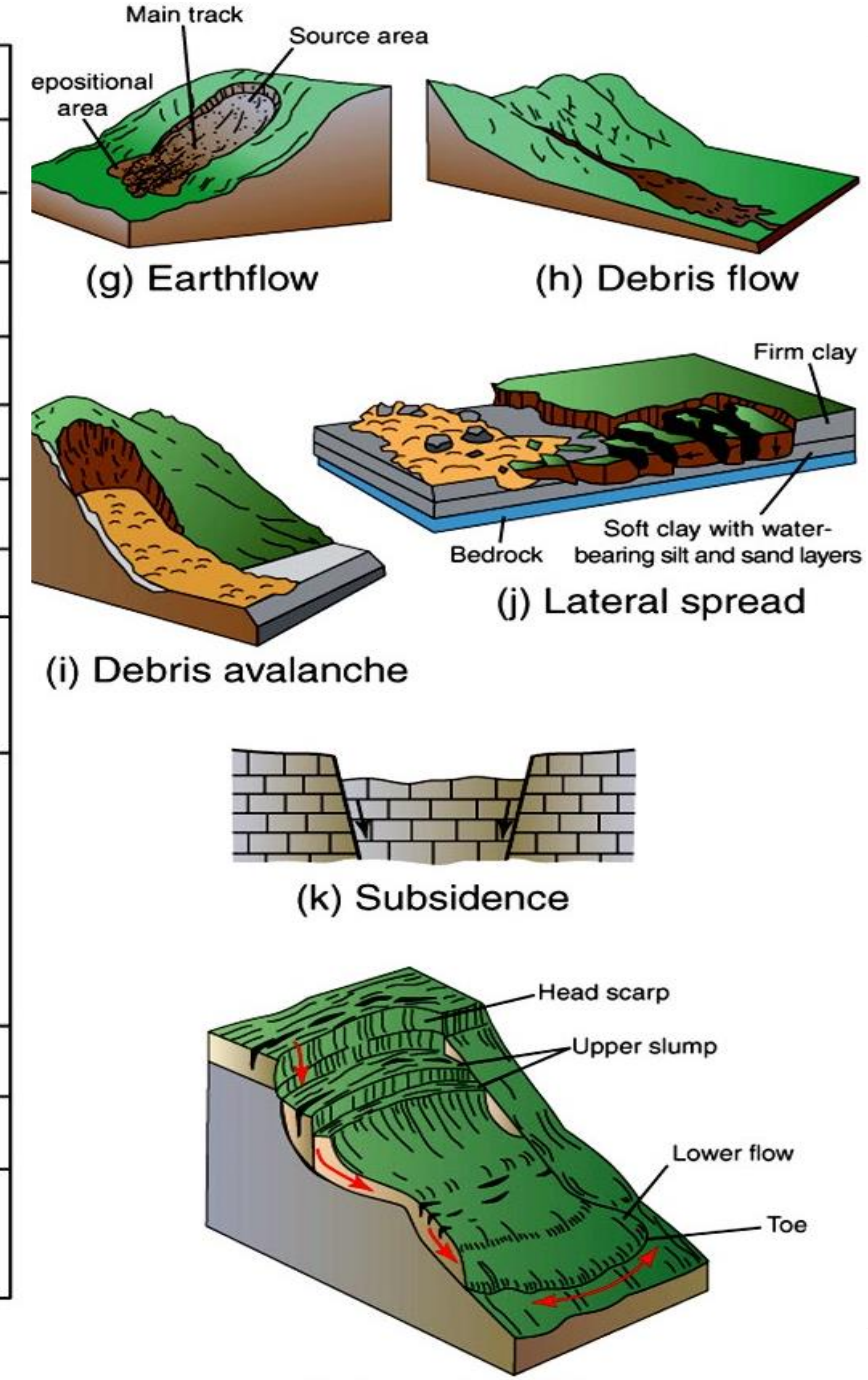
Types of Slope Failures

Types of Slope Failures…..contd.



(a) Rock slump (b) Soil slump (c) Rock slide (d) Soil slide (e) Rockfall (f) Soil creep

Type of Movement	Materials	
	Rock	Soil
Landslides with variable water content and rate of movement	Rotational	
	Slump(a)	Slump(b)
	Translational	
	Rock slide(c)	Soil slide (slip)(d)
Falls	Rock fall(e)	Soil fall
Flows: Slow	Rock creep	Soil creep(f)
↓	Unconsolidated rock and soil (saturated)	
Rapid	Earth flow(g)	
	Debris flow / mud flow(h)	
↓ Very rapid	Debris avalanche(i)	
Lateral spread	Rock(j)	Soil
Subsidence	Rock(k)	Soil
Complex	Combination of slides, slumps, and flows(l)	

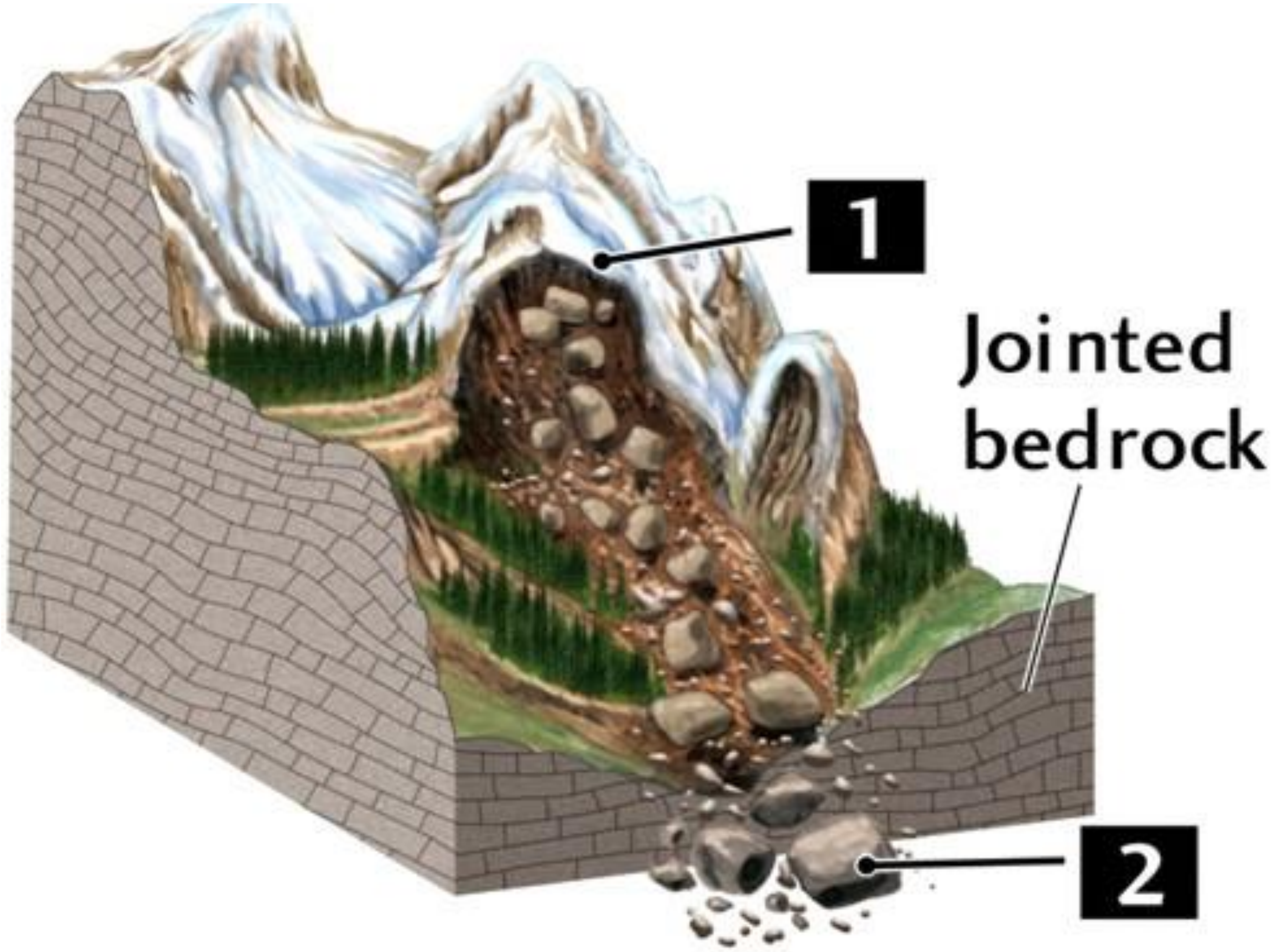


(g) Earthflow (h) Debris flow (i) Debris avalanche (j) Lateral spread (k) Subsidence (l) Complex slide

Types of Slope Failures…..contd.

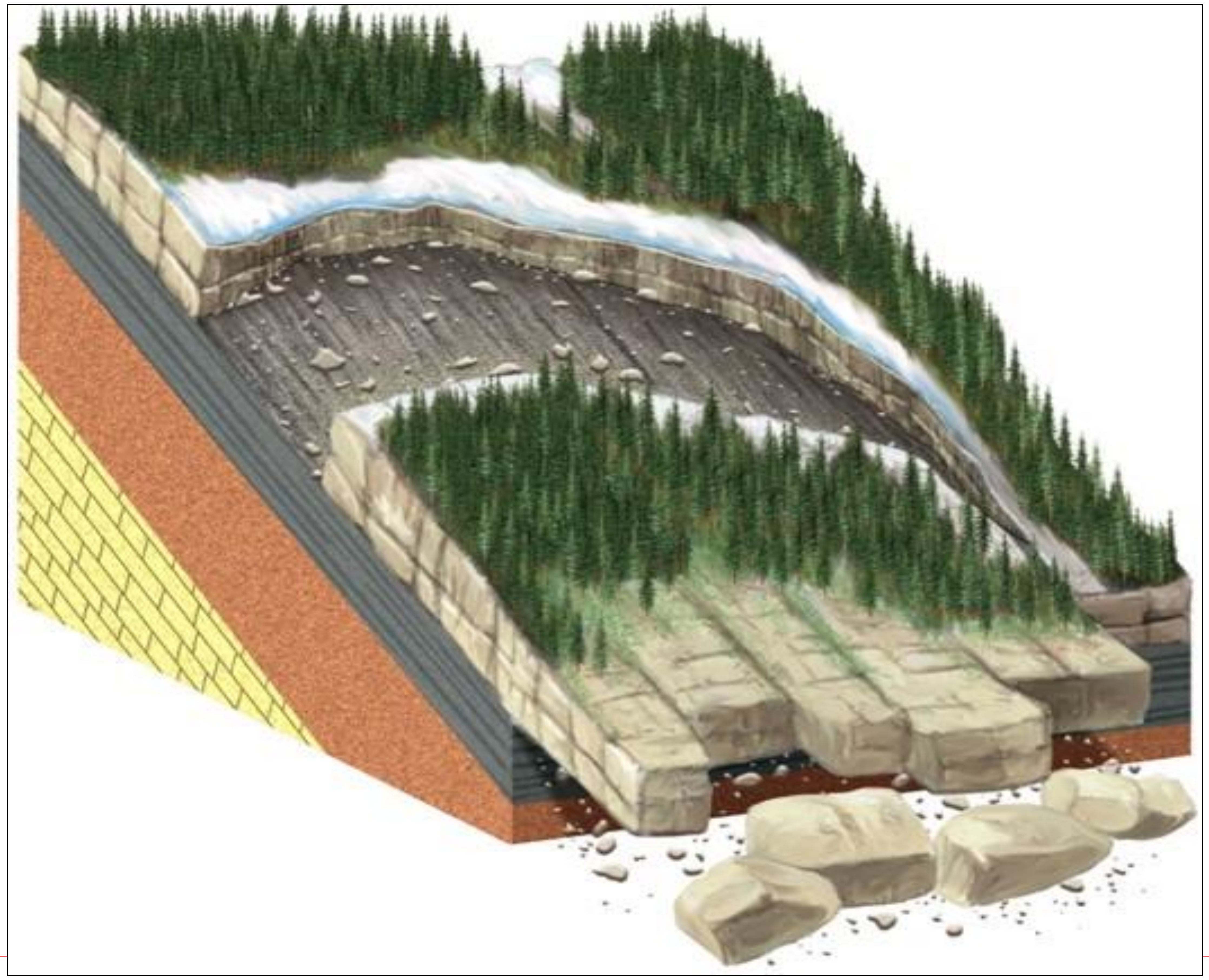
1. Nature of Material – Failure in CONSOLIDATED (Rock) Masses

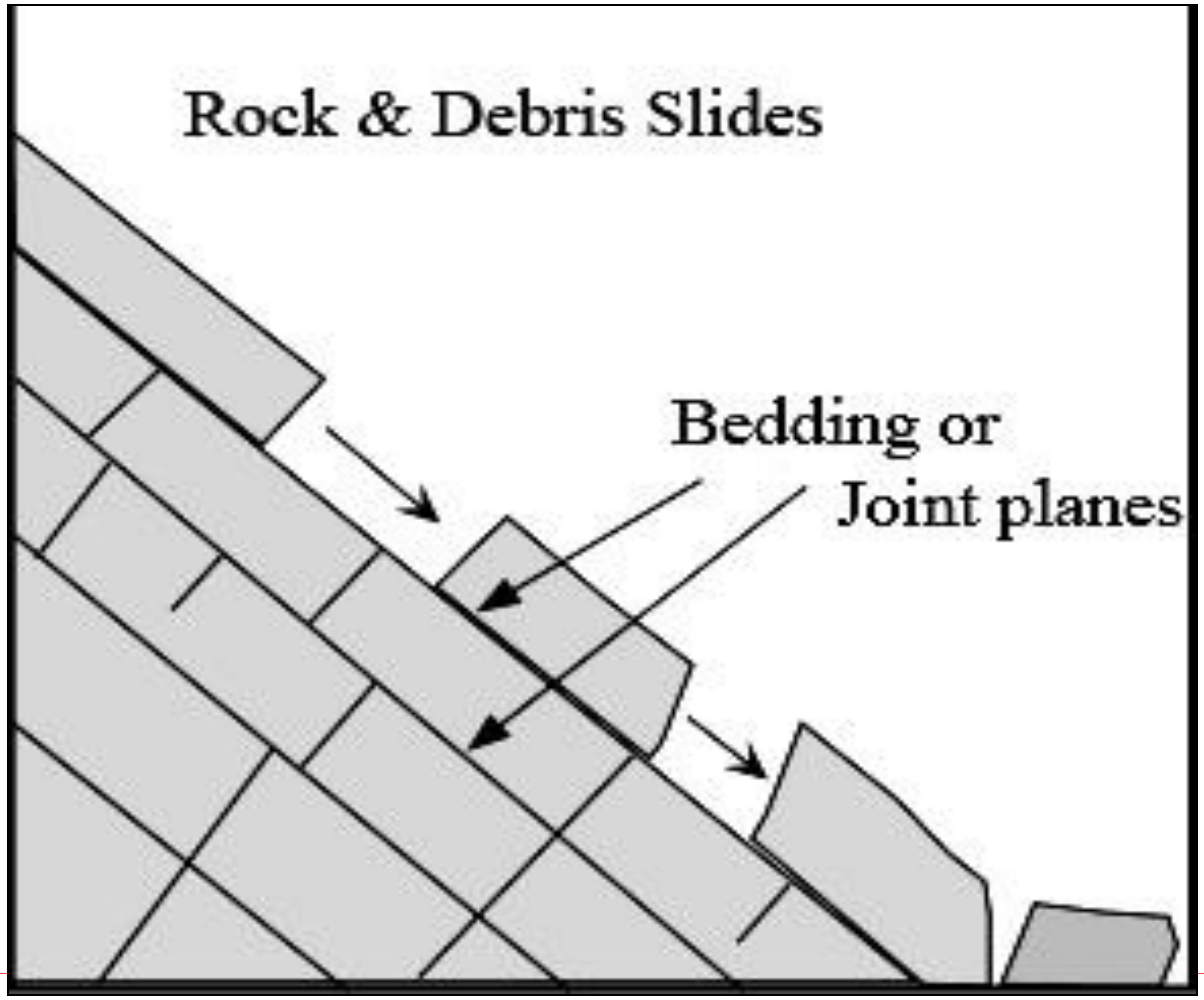
a) **Rockfall –** *free fall of boulders from a cliff*



Types of Slope Failures…..contd.

b) **Rockslides** – sliding of rock down an incline usually due to rock breaking from its host material along bedding plane, joint, or other structural weakness.

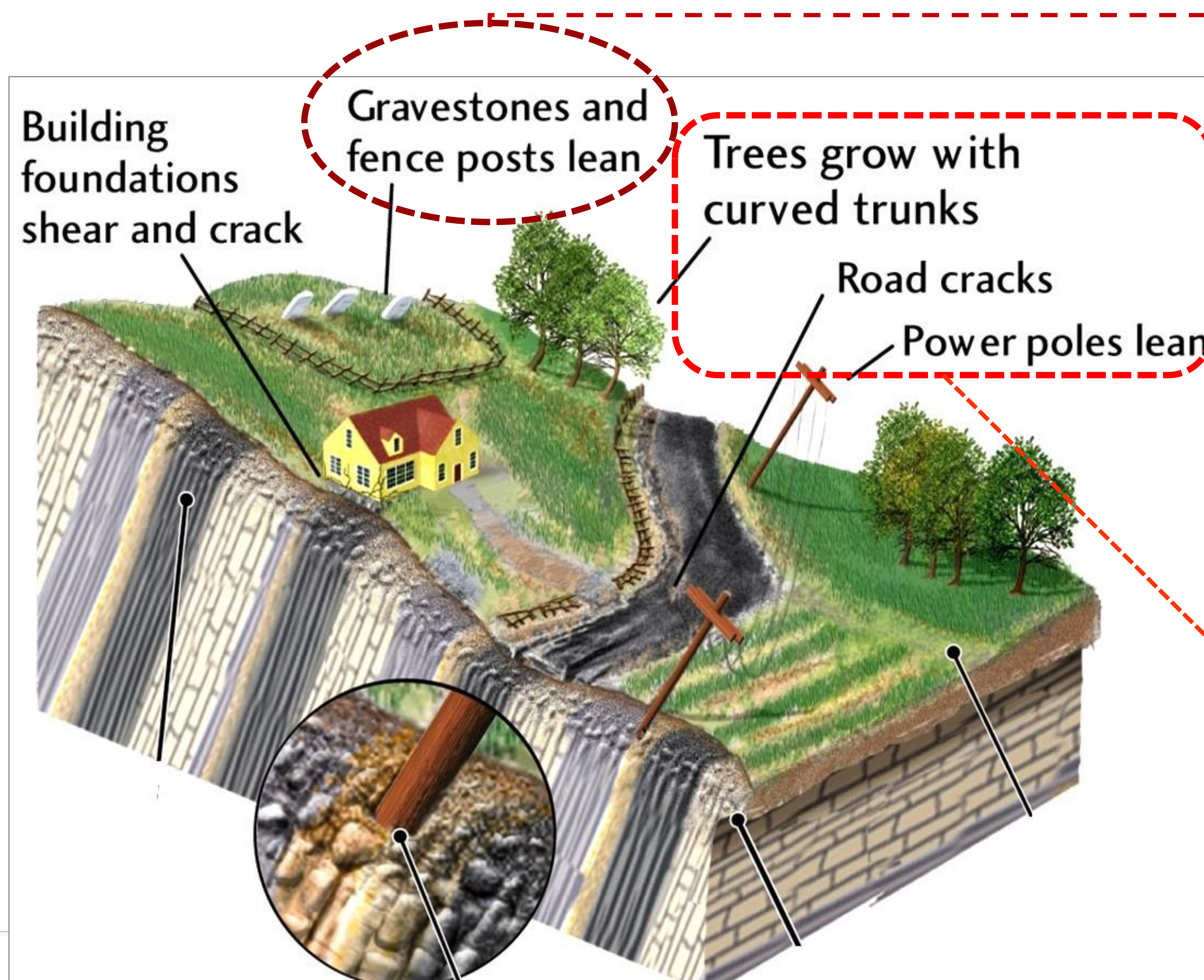




Types of Slope Failures…..contd.

2. Failure in UNCONSOLIDATED ('Soil') Masses

a) Creep – *extremely slow, almost imperceptible downslope movement of soil and rock debris.*



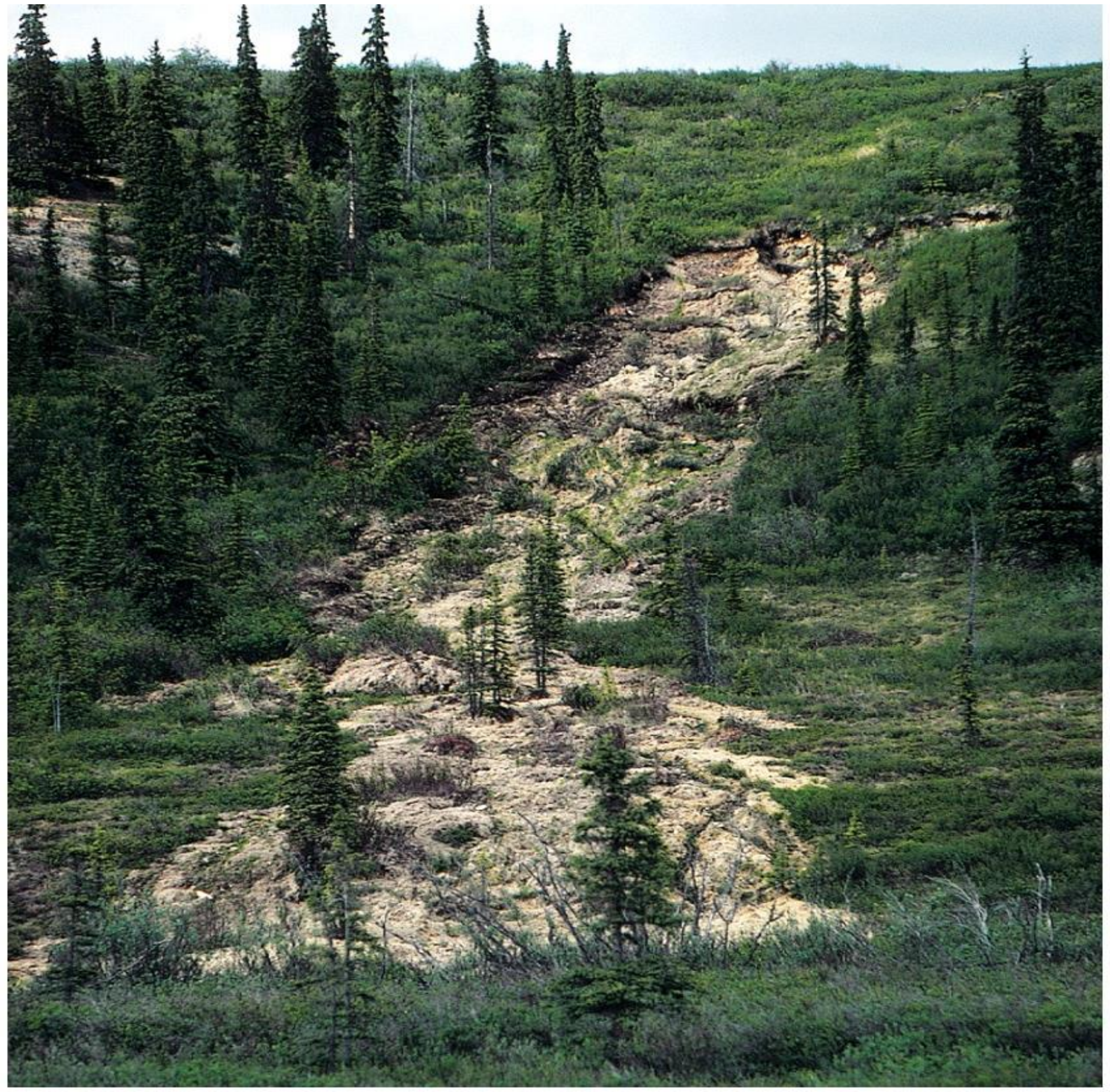
Tilting of tombstone

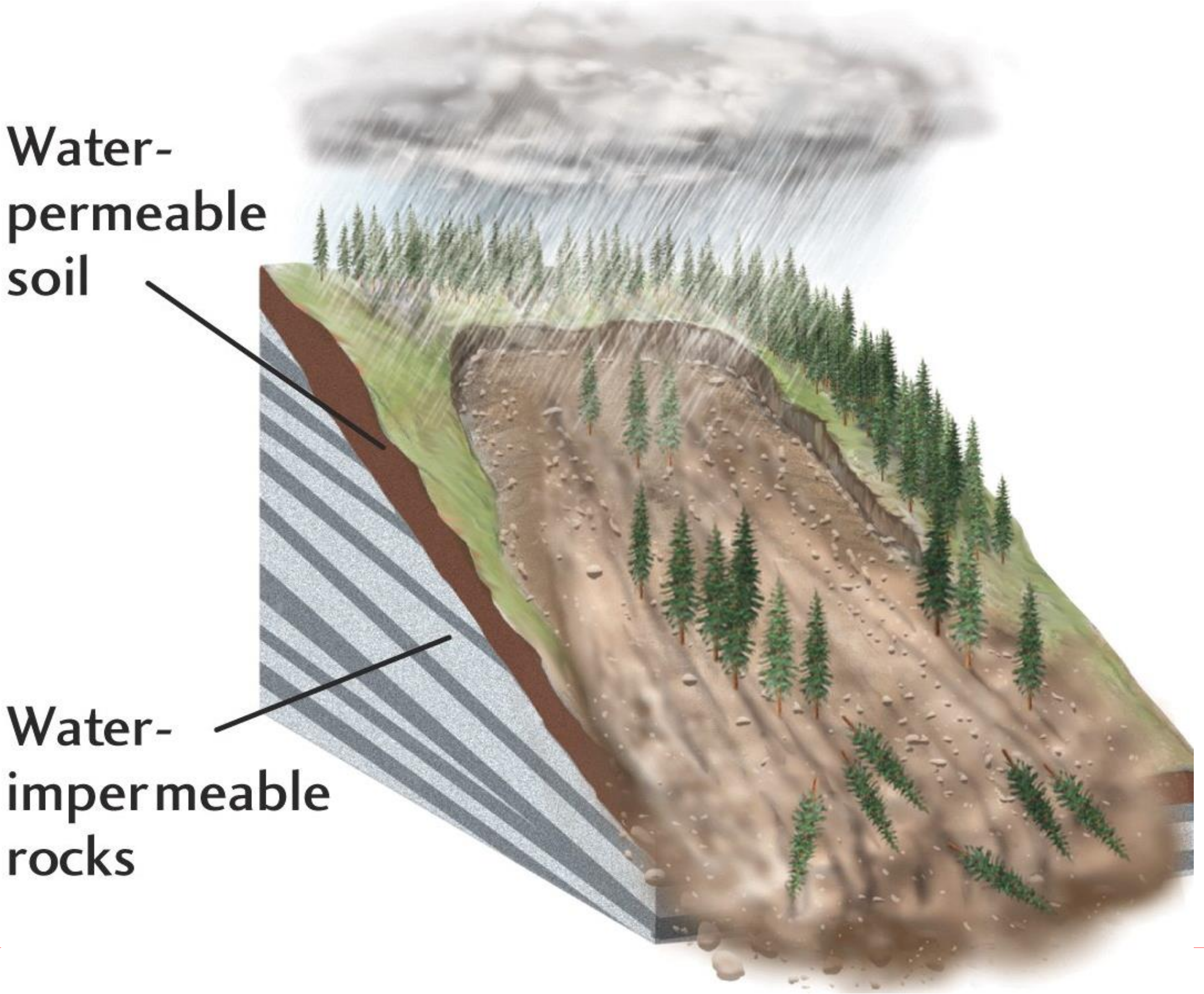
Trees on slopes develop pistol-butt shape

Types of Slope Failures.....contd.

b) Earth flows and Debris flows – consist of mixtures of **rock fragments**, **mud** & **water** that **flow downslope** as **viscous fluids**;

✓**avalanches** are the fastest **unconsolidated failure** on steep slopes in humid areas

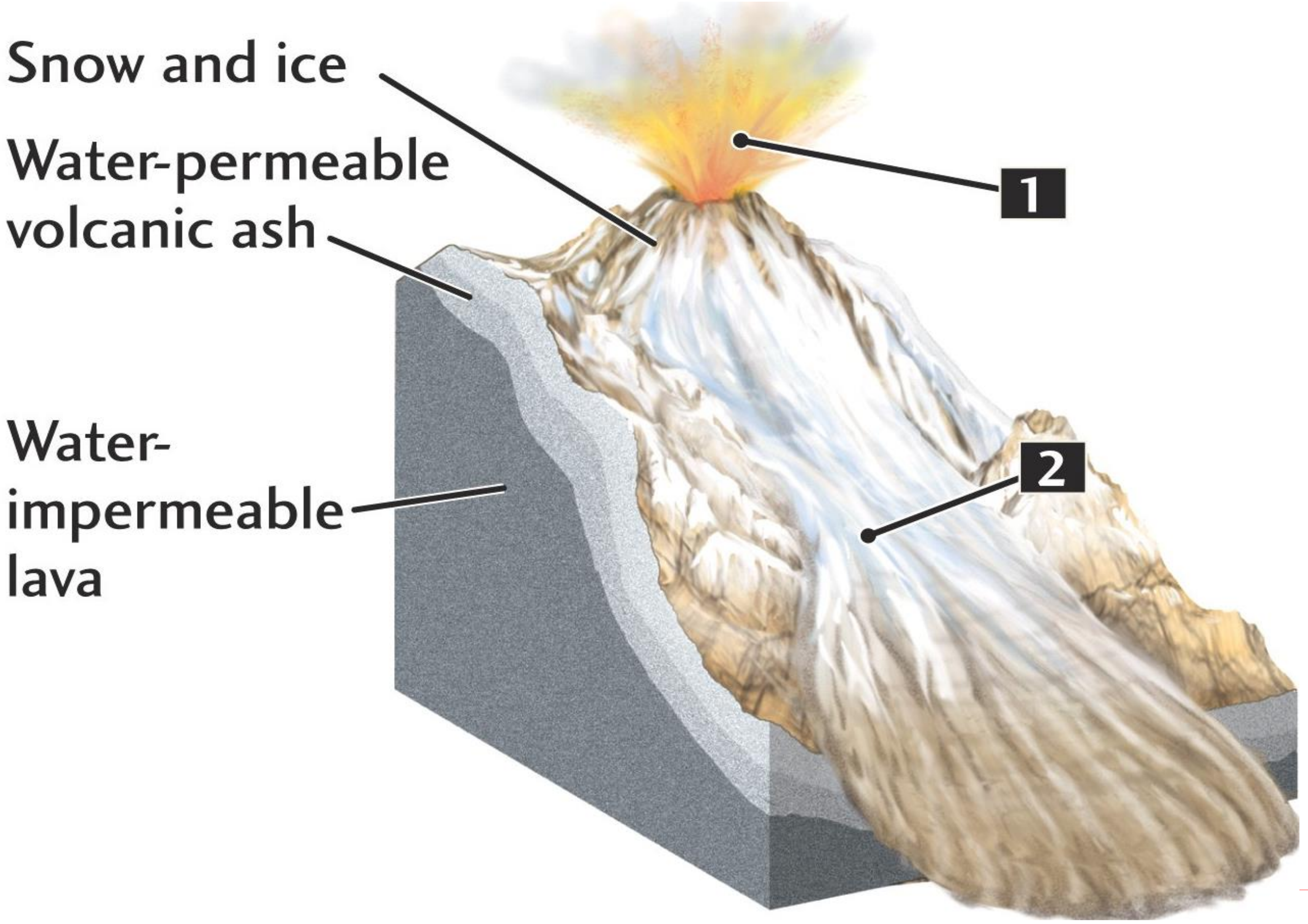




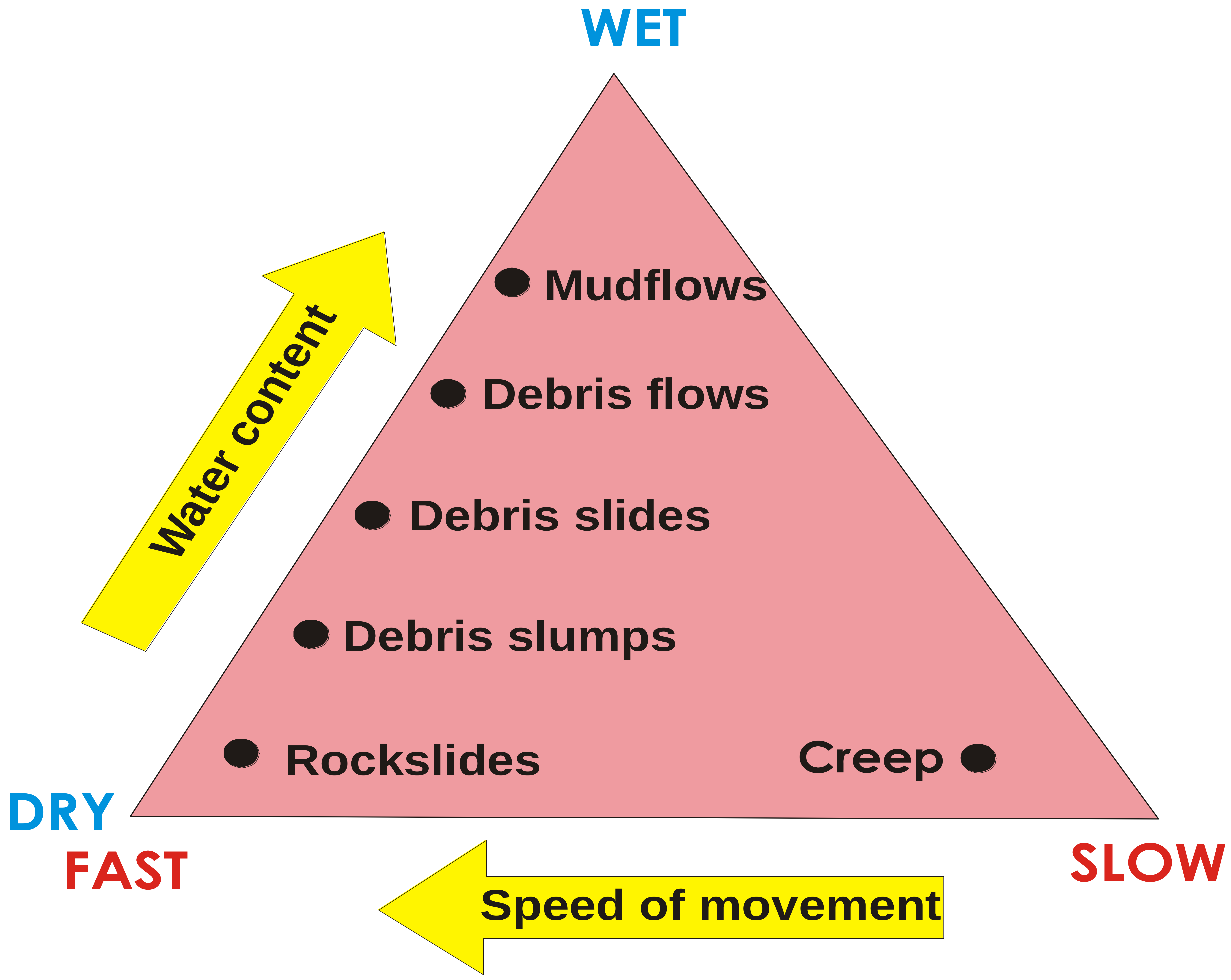
Types of Slope Failures…..contd.

c) **Mudflows** – a variety of debris flow that consist mostly of **small silt** and **clay-sized** particles

- ✓ Usually occur after **heavy rain**
- ✓ Have as much as **30% water content**



Types of Slope Failures – Summary



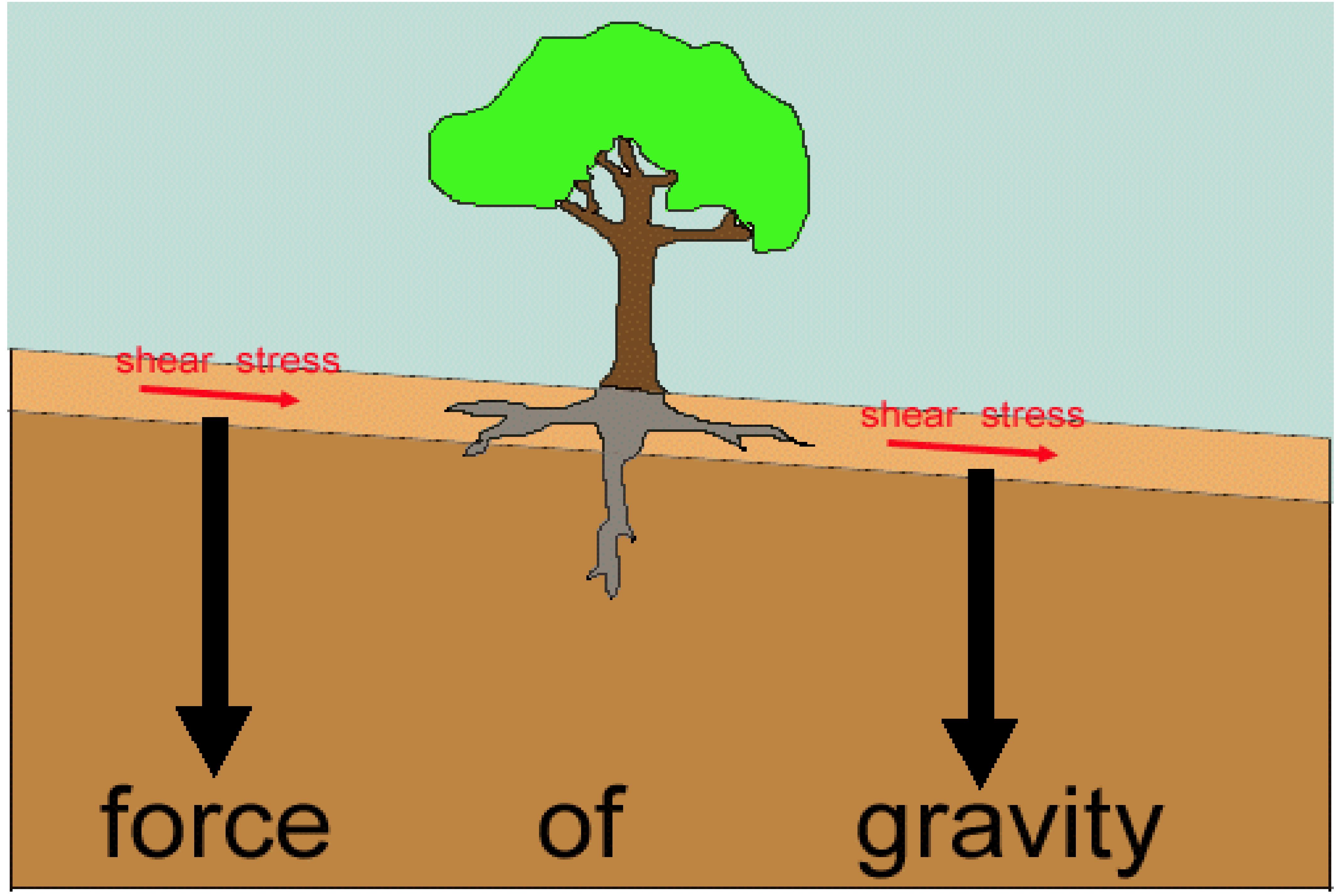
Sliding due to Gravitational Loading

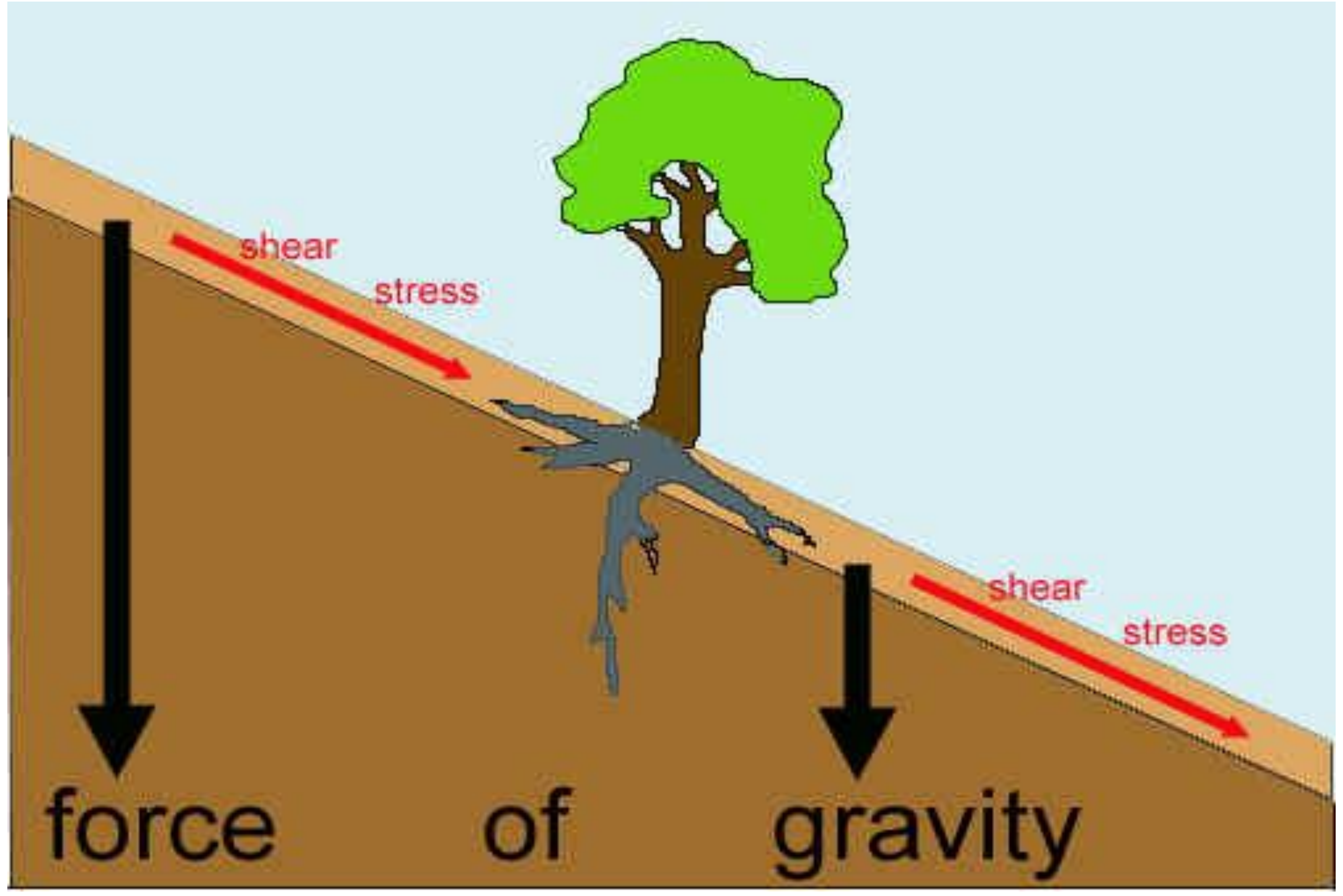
1. GRAVITATIONAL FORCE

Sliding due to Gravitational Loading

1. GRAVITATIONAL FORCE

Force that acts everywhere on the Earth's surface, pulling everything in a direction toward the centre of the Earth.





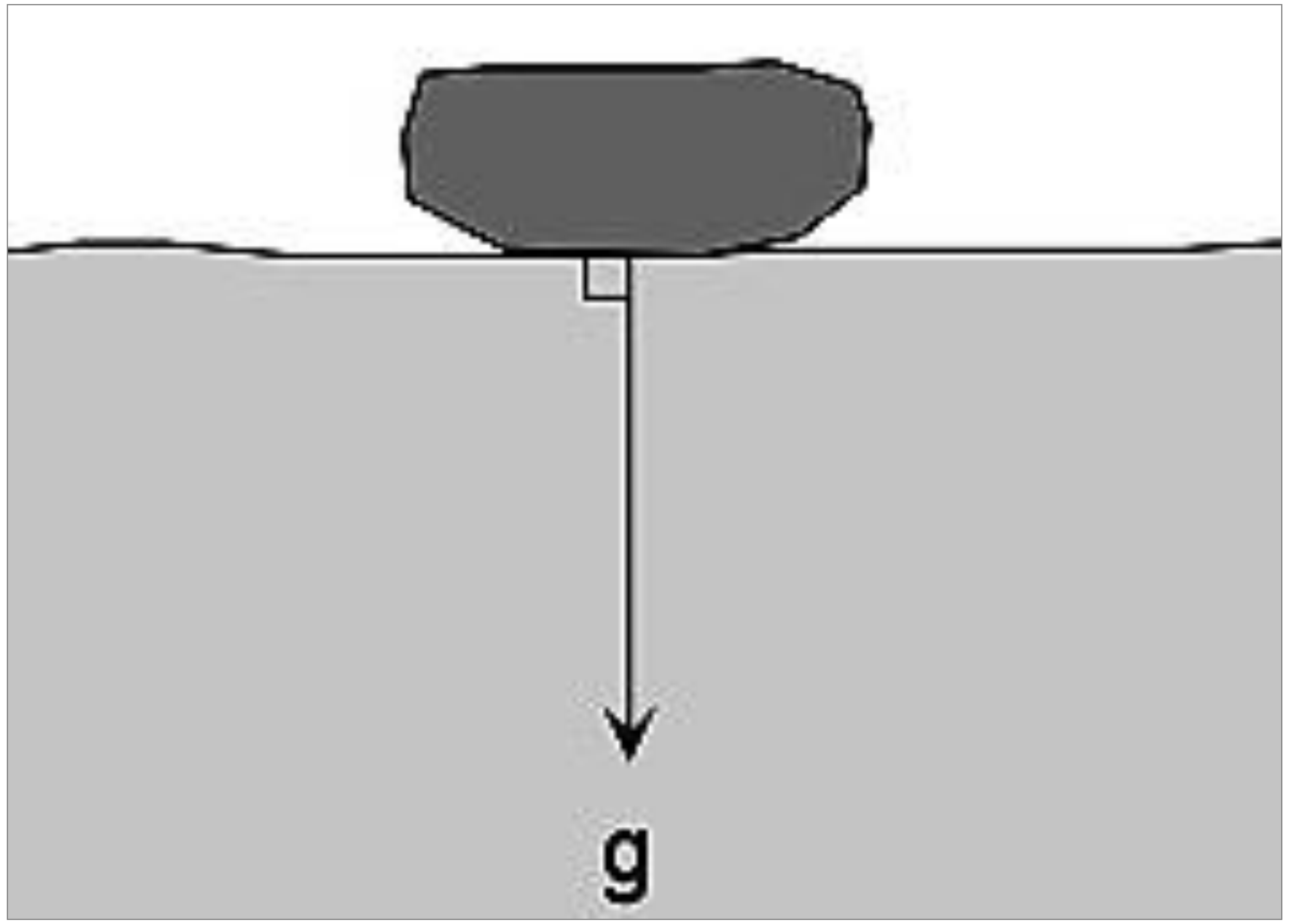
Mass-wasting is unlikely on this slope because ***little shear stress*** *is being produced by gravity.*

Mass-wasting is much more likely on the slope because ***more shear stress*** *is being produced*

Sliding due to Gravitational Loading…..contd.

2. CONCEPT OF SLIDING DUE TO GRAVITATIONAL LOADING

Gravity *– Is a force that acts everywhere on the Earth's surface, pulling everything in a direction toward the centre of the Earth.*



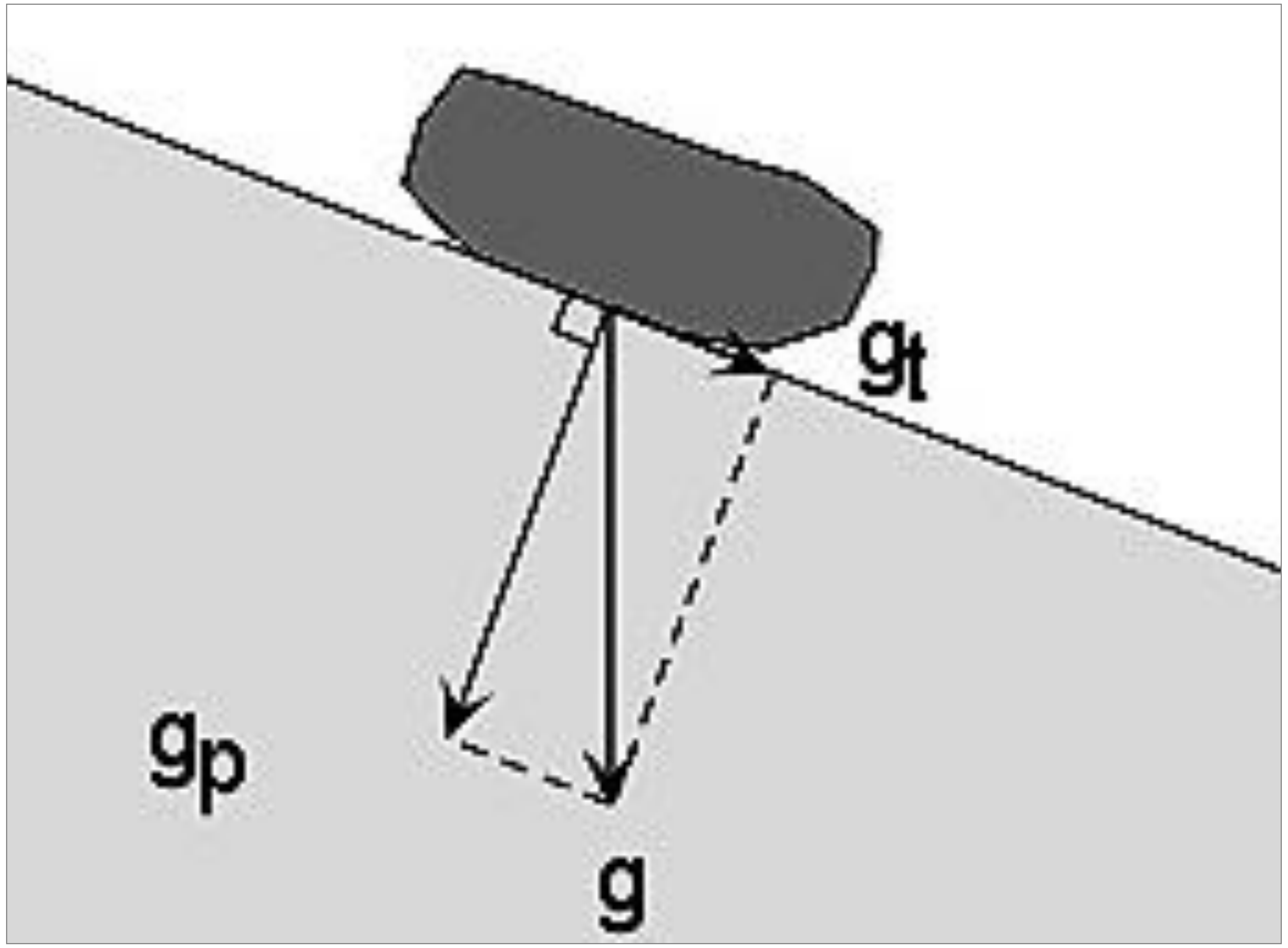
On a flat surface, parallel to the Earth's surface, the force of gravity acts downward.

So, long as material remains on flat surface, it will 'generally' NOT move under force of gravity.

Sliding due to Gravitational Loading.....contd.

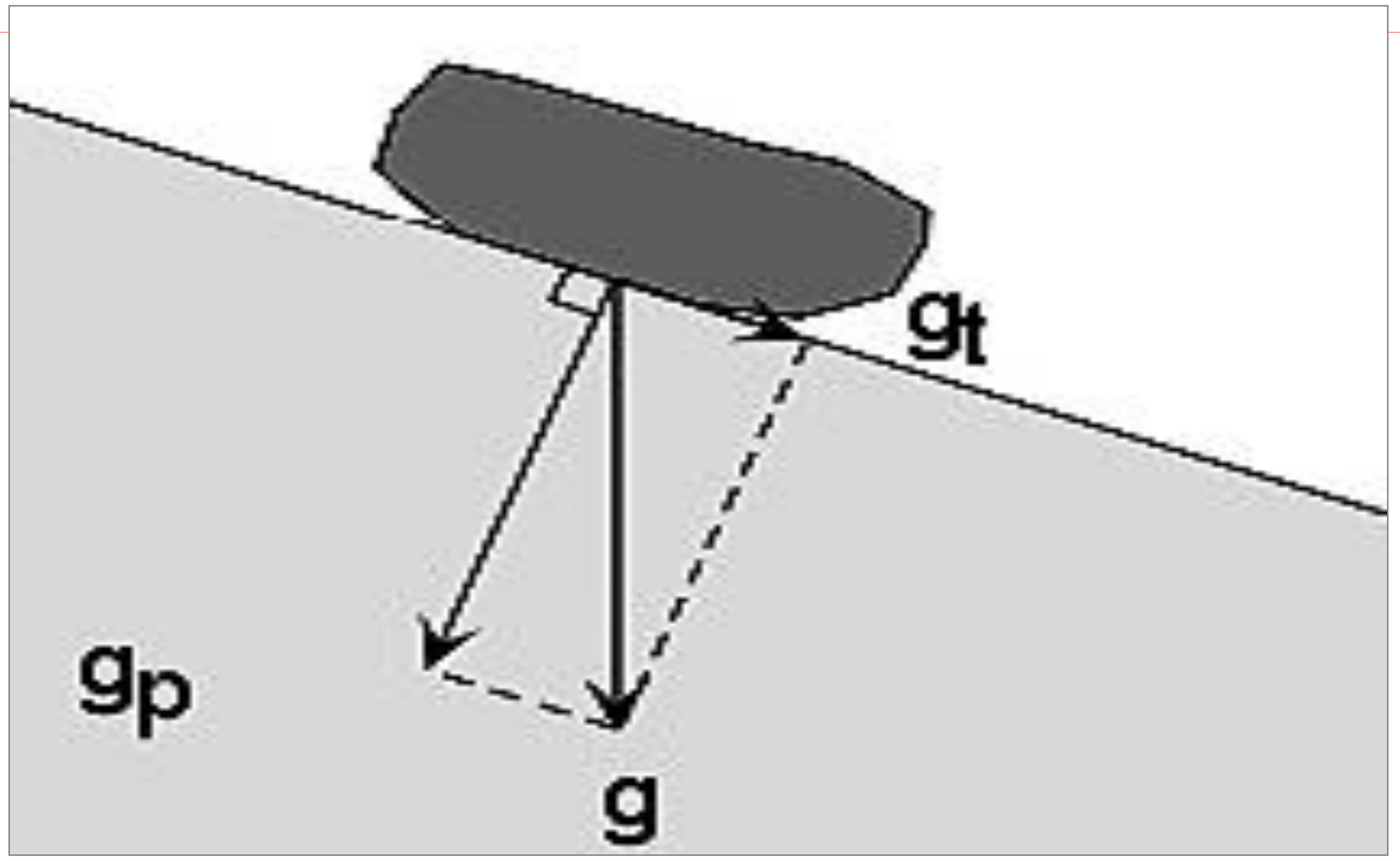
On a slope, the force of gravity can be resolved into two components:

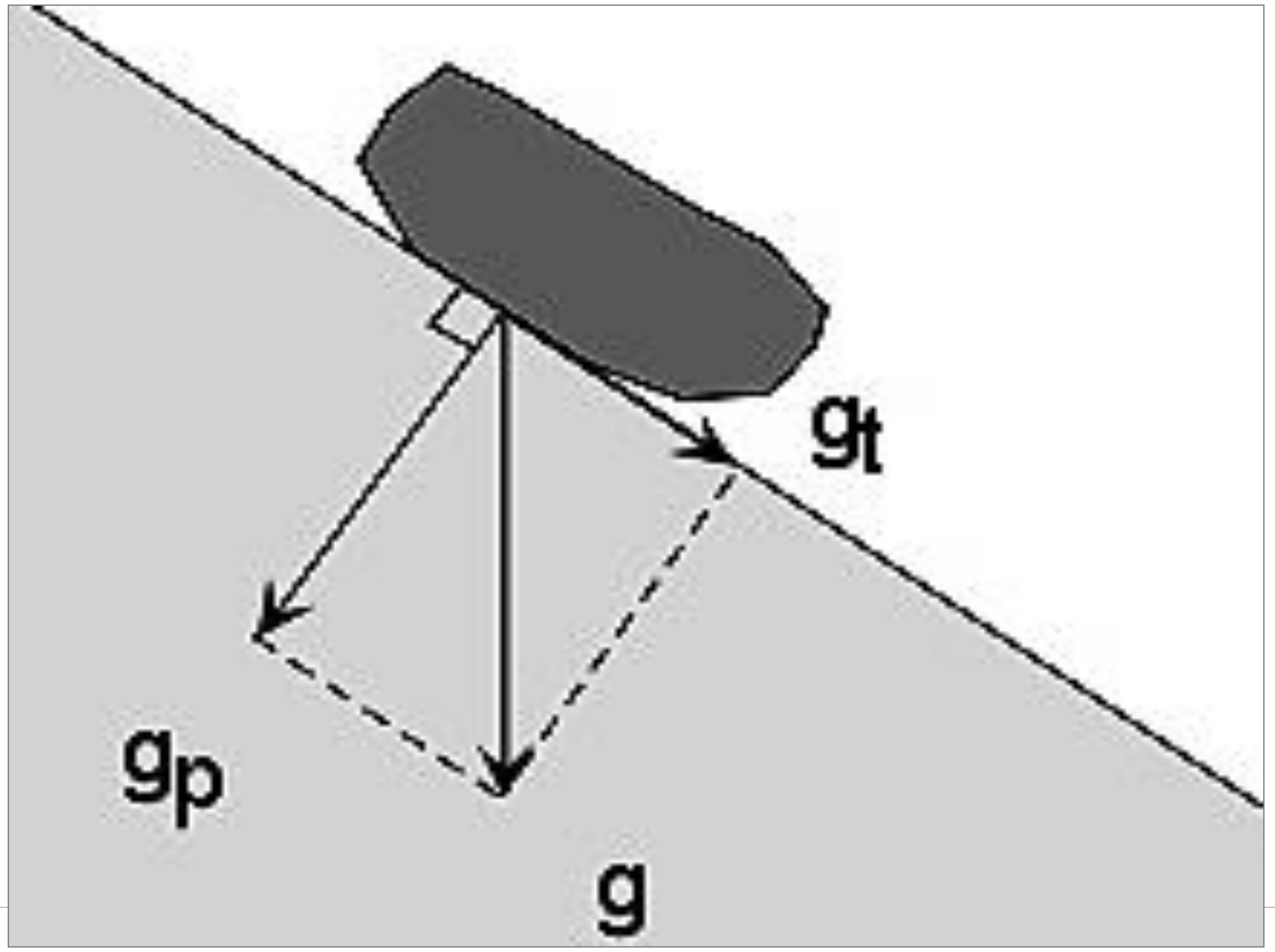
- ✓ *A component acting* ***perpendicular*** *to slope, and*
- ✓ *A component acting* ***tangential*** *to slope.*



Sliding due to Gravitational Loading…..contd.

- *The Perpendicular component of gravity, **g_p**, helps to hold objects in place on the slope.*
- *Tangential component of gravity, **g_t**, causes shear stress parallel to slope & helps to move objects in downslope direction.*
  - ✓ *When **shear forces become > forces holding object** on slope, the object will move down-slope,*
  - ✓ ***Steep slope angles** increase shear stress, & result in reduction of COHESION among particles & lowering of FRICTIONAL resistance.*





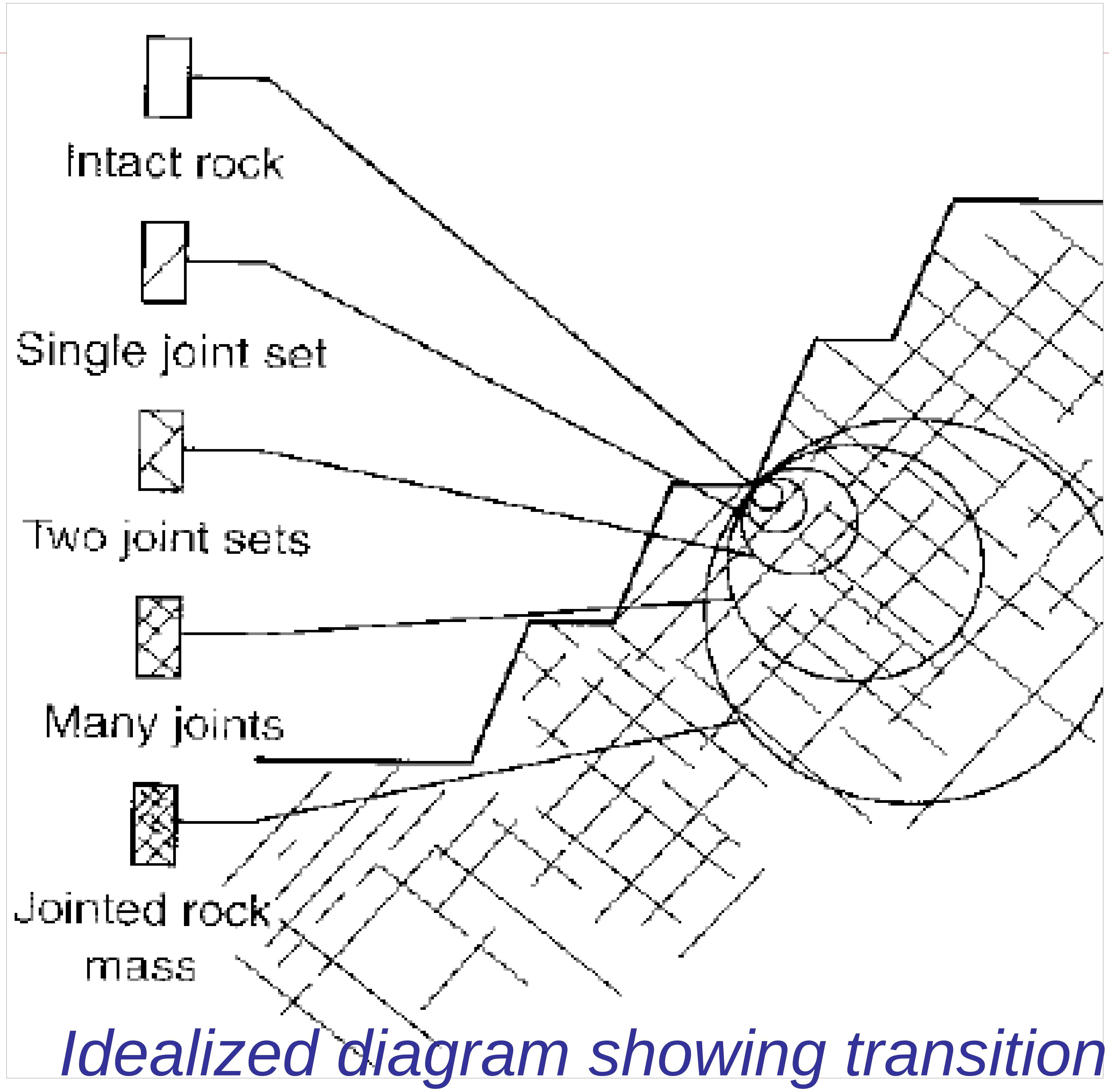
Factors Influencing Slope Stability

Factors Influencing Slope Stability

a) Geologic Discontinuities in Rock Masses

These include:

- *Joints*
- *Bedding*
- *Faults, including their*
  - *Spacing, and*
  - *Altitude*



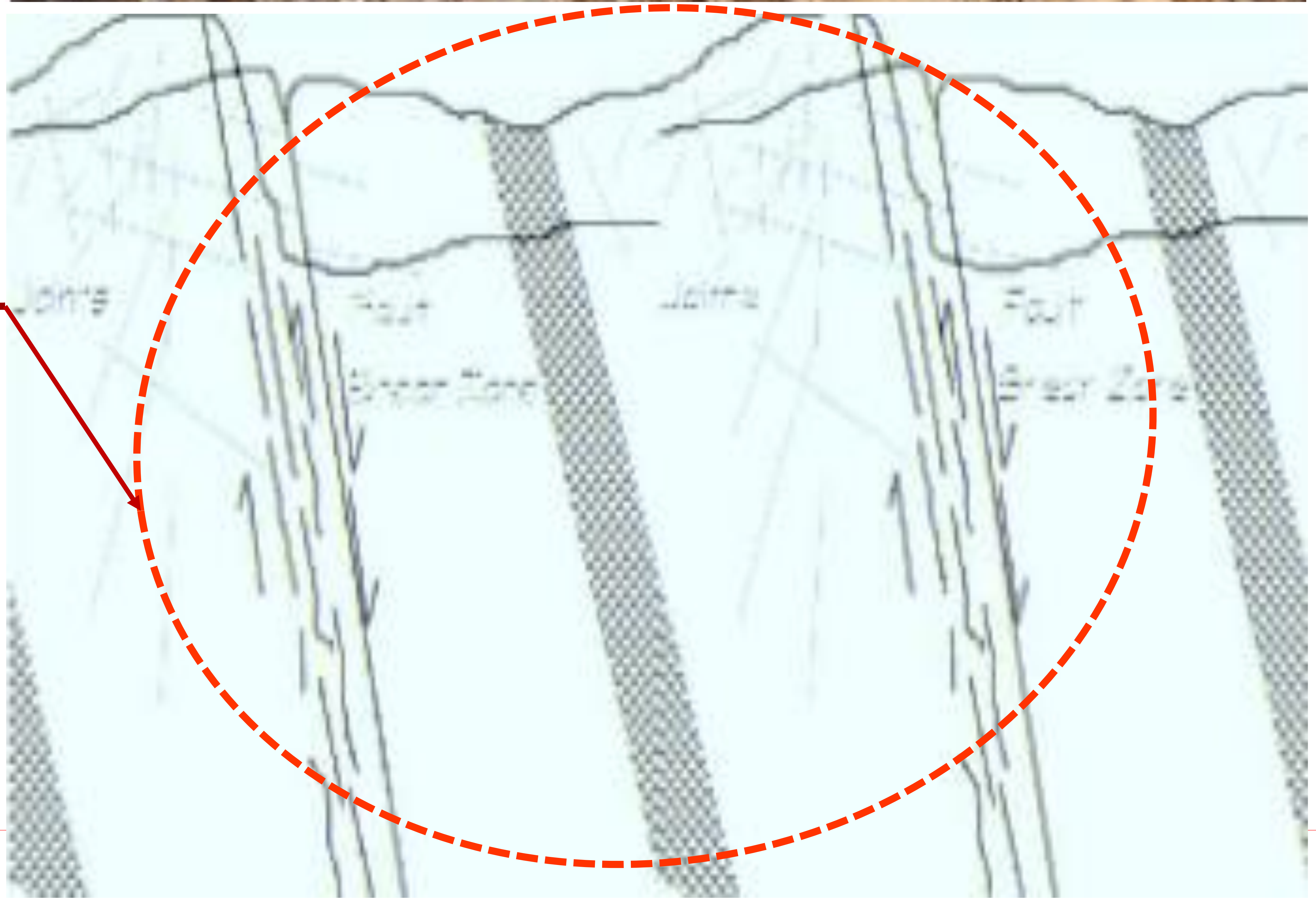
*Idealized diagram showing transition from **intact rock** to jointed **rock mass** with increasing sample size*

Factors Influencing Slope Stability.....contd.

b) Geologic Structure

In open pits, this includes:

- amount & dip direction of critical planes.
- faults that act as groundwater conduits & influence weathering & alternation
- intra-formational shear zones that;
    - ✓ reduce shear strength
    - ✓ change permeability & act as sub surface drain
    - ✓ act as planes of failure



Factors Influencing Slope Stability…..contd.

c) Geotechnical Properties

These include:

- ✓ **Shear strength of rock mass**
- ✓ **Cohesion (c)** – characteristic property of a **rock or soil** that measures how well material **resists being deformed** or **broken** by forces.
- ✓ **Angle of Internal friction (φ)** – measured between normal stress (σ_n) and shearing stress (τ) attained **at the point of failure**…

Factors Influencing Slope Stability…..contd.

c) Geotechnical Properties (contd.)

- Permeability/groundwater situation;
  - ✓ ***alters*** *cohesion and frictional parameters*
  - ✓ *increases up-thrust and driving water forces with adverse effect on stability of slopes;*
  - ✓ *alter cohesion & friction of discontinuity surface….*
  - ✓ *Alters **moisture content** of geologic masses*
- Particle size distribution

3. COMPUTATION OF FORCES / STRESSES

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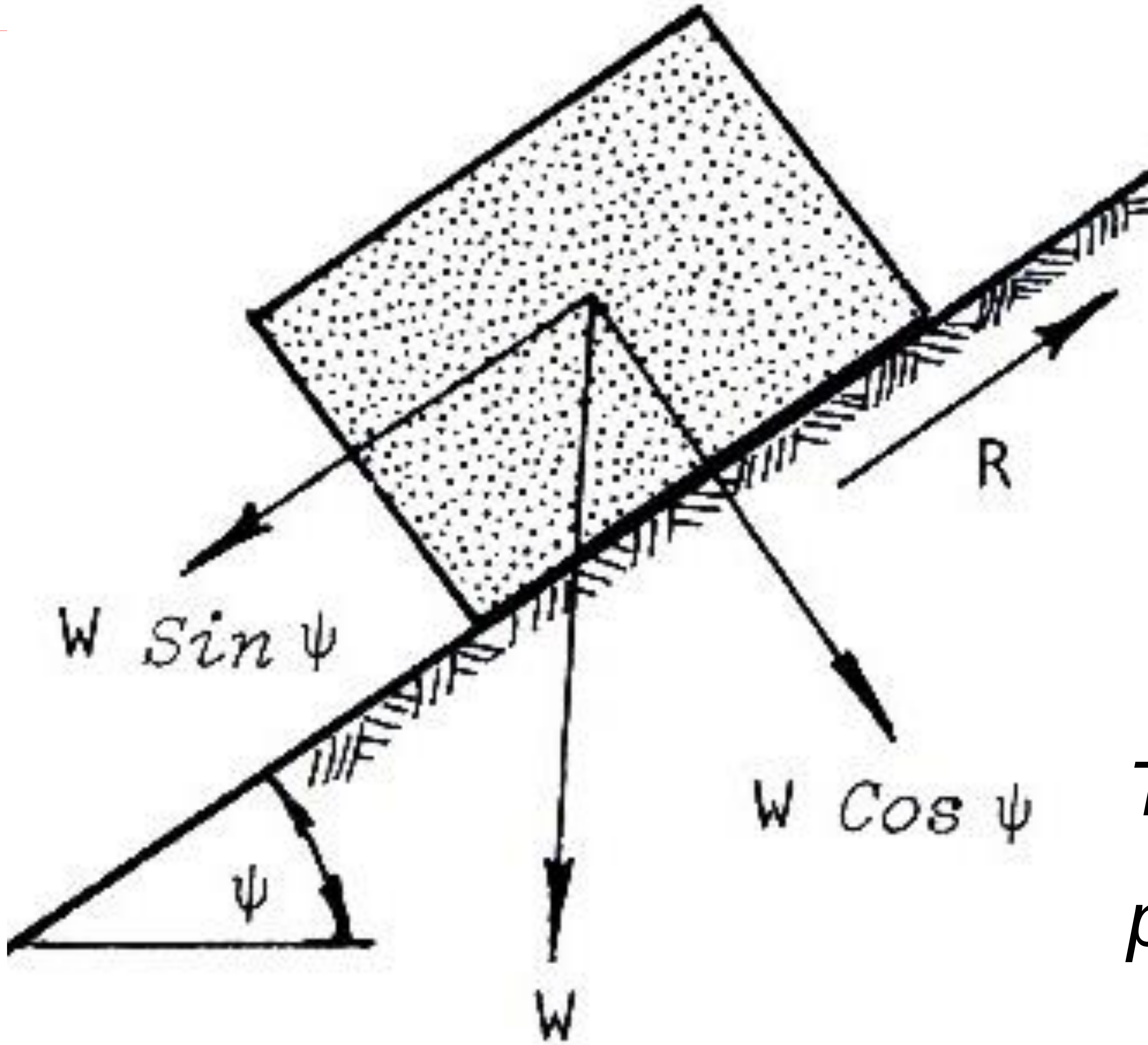


*From previous e.gs., component of **W** acting across plane & which tends to **stabilise slope is**:*

W Cos ψ

*The **NORMAL** stress, **σ,** acting across potential sliding surface is:*

$$\sigma = \frac{(W \ Cos \ \psi)}{A} \quad \text{.........} \rightarrow \textbf{(1)}$$

*Where **A** is base area of block*

3. Computation of Forces / Stresses.....contd.

Recall that:

$$\tau = c + \sigma \tan \phi \qquad \text{.......................... (2)}$$

Substituting for ***NORMAL*** *stress in equation 2, gives:*

$$\tau = c + \frac{(W \cos \psi)}{A} \tan \phi \qquad \text{.......................... (3)}$$

or

$$R = cA + (W \cos \psi) \tan \phi \qquad \text{.......................... (4)}$$

Where ***R = τA*** *is* ***SHEAR FORCE*** *resisting sliding down plane*

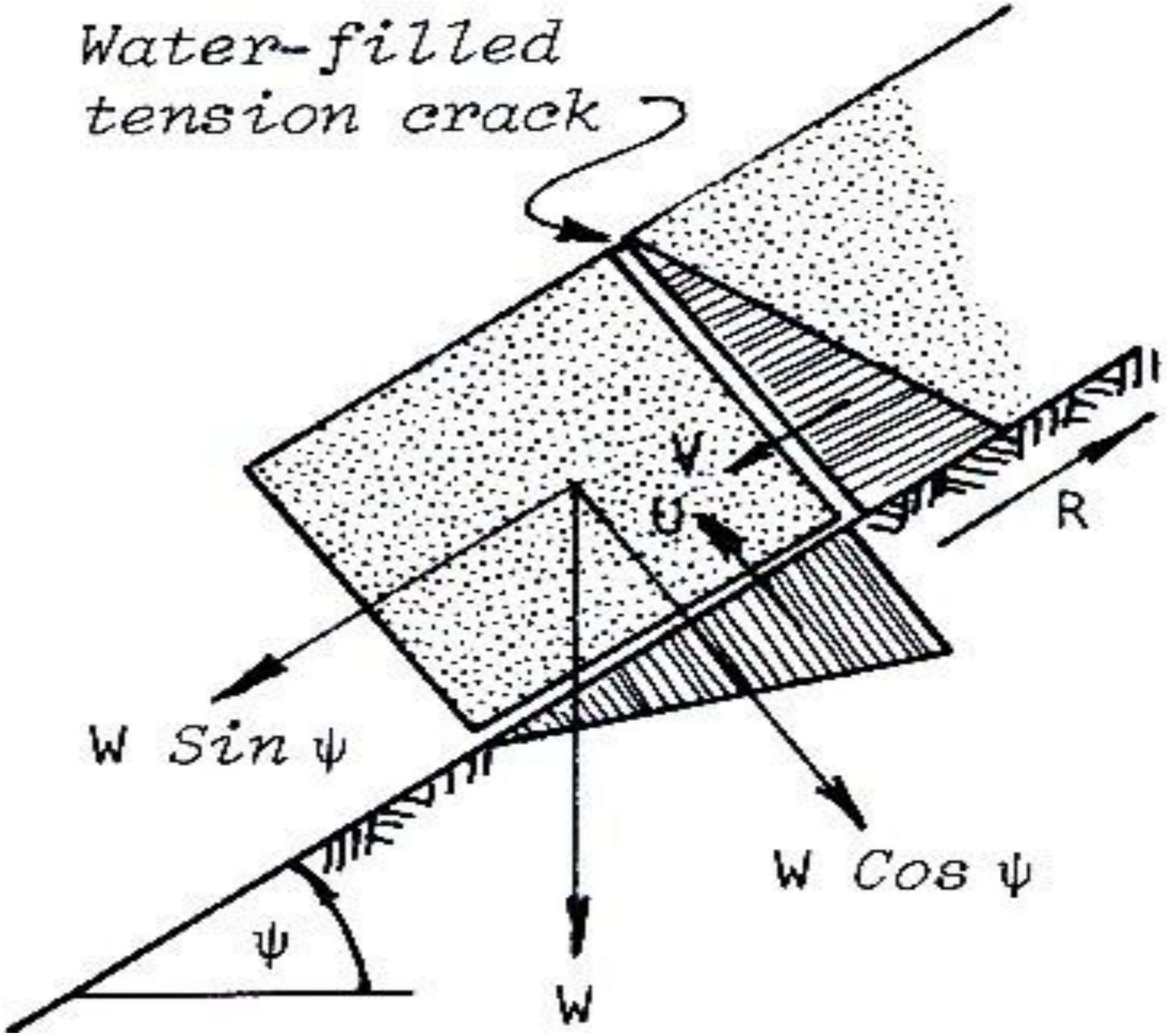
3. Computation of Forces / Stresses…..contd.

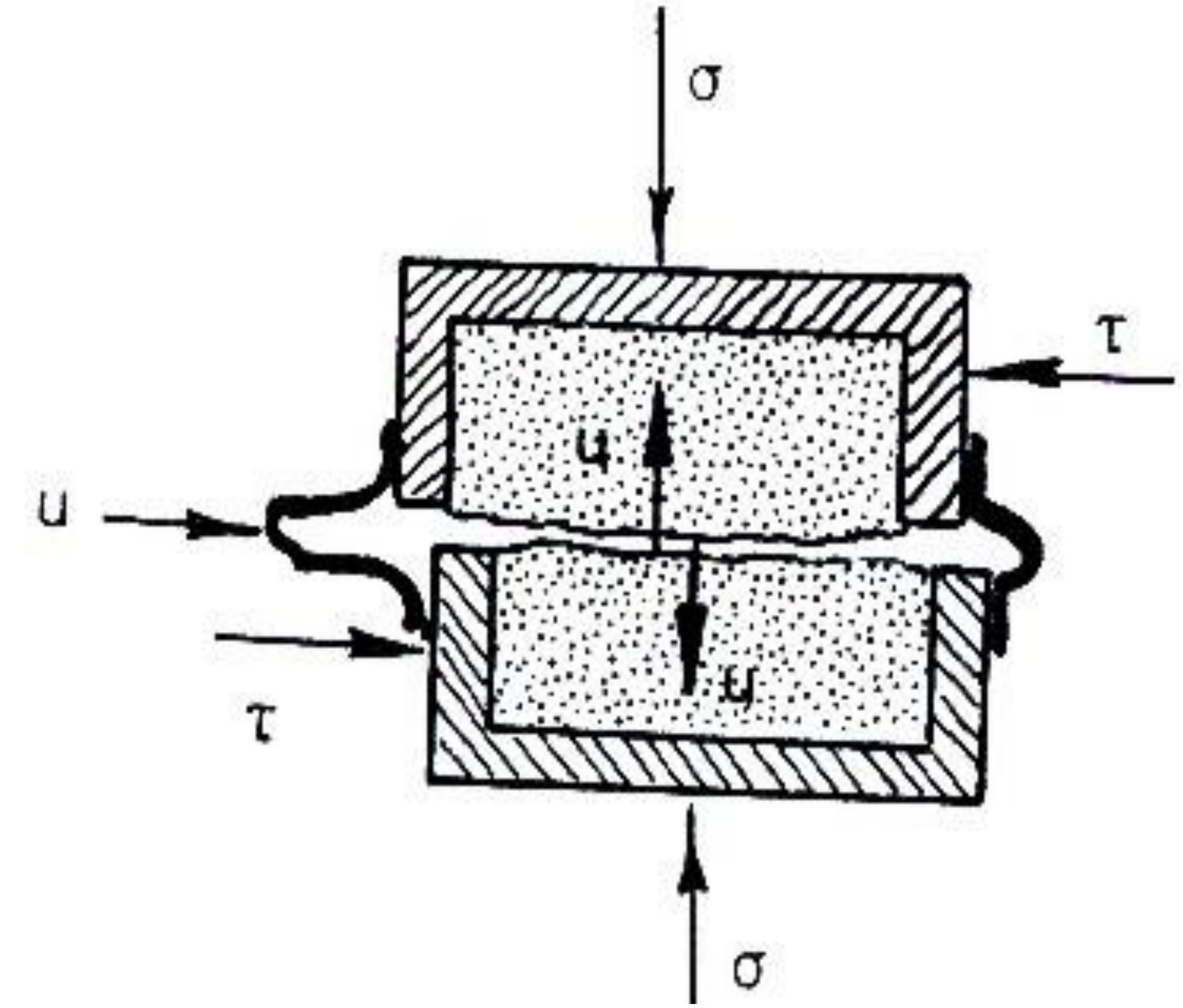
The Block will be ***just on point*** *of sliding or condition of* ***LIMITING EQUILIBRIUM****, when:*

Disturbing Force *acting down plane is* ***EXACTLY EQUAL*** *to* ***Resisting Force***

$$W \sin \psi = c A + W \cos \psi \tan \phi \qquad (5)$$

3.1 Effect of water pressure on Discontinuity Shear strength





Condition of ***LIMITING EQUILIBRIUM***

for this case is defined by:

$$W \sin \psi + v = c A + (W \cos \psi - u) \tan \phi \quad (6)$$

3.1 Effect of water pressure on Shear strength.....contd.

$$W \sin \psi + v = c A + (W \cos \psi - u) \tan \phi$$

From this equation, it can be seen that:

✓The **Force promoting sliding** is **INCREASED** by **v**

✓The **Frictional force resisting sliding** is **DECREASED** by **u**

✓Both **u** & **v** result in **DECREASES** in stability of the slope

✓Although water pressures involved may be small, **they act over large areas and hence, very large water forces** may be involved.

FACTOR OF SAFETY OF SLOPE

All equations defining stability of any slope have been presented for the ***CONDITION OF LIMITING EQUILIBRIUM****, i.e.:*

- *The Condition @ which Forces tending to* ***induce sliding*** *are* ***EXACTLY BALANCED*** *by those* ***resisting sliding***

FACTOR OF SAFETY OF SLOPE.....contd.

To compare stability of slopes under conditions other than those of limiting equilibrium, some form of ***index*** *is required – the* ***FACTOR OF SAFETY (FS), as follows:***

$$FS = \frac{\text{TOTAL FORCE resisting sliding}}{\text{TOTAL FORCE promoting sliding}}$$

FACTOR OF SAFETY OF SLOPE.....contd.

Considering the case of a block acted upon by water forces [equation (6) above], ***FACTOR OF SAFETY*** *is given by:*

$$F = \frac{cA + (W \cos\psi - u)\tan\phi}{W \sin\psi + v} \quad \text{......(7)}$$

- ✓At limiting equilibrium, **RESISTING** & **DISTURBING** forces are **EQUAL**, and **FS = 1**.
- ✓When slope is stable, **RESISTING FORCES > DISTURBING FORCES** & value of **FS** will usually be **greater than unity** (1).

FACTOR OF SAFETY OF SLOPE.....contd.

Practical experience suggests that:

- ☑ A **FS of 1.0 to 1.3** is adequate for mine slopes that are **not required to remain stable for long periods.**
- ☑ For **critical slopes adjacent to roads** (or important installations), **FS of 1.5** is usually preferred.

Reinforcement to Prevent Sliding

Reinforcement to Prevent Sliding

One of the most effective means of stabilising rock blocks is:

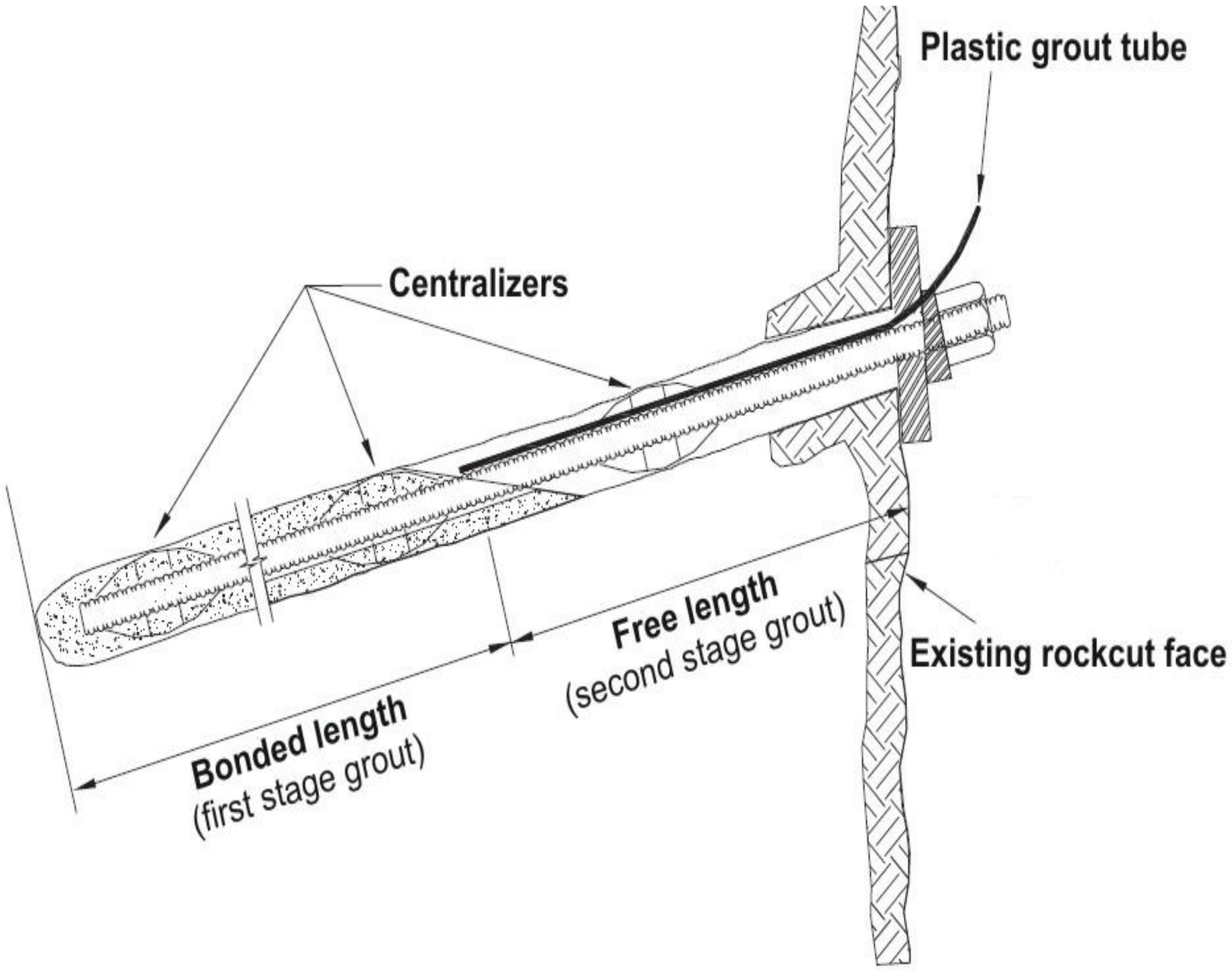
- ✓ *To install **tensioned rock-bolts** or **cables**.*

*Consider a block resting on inclined plane & acted upon by uplift force, **u,** and force **v**, due to water pressure in **tension crack.***

Stabilization of Slopes

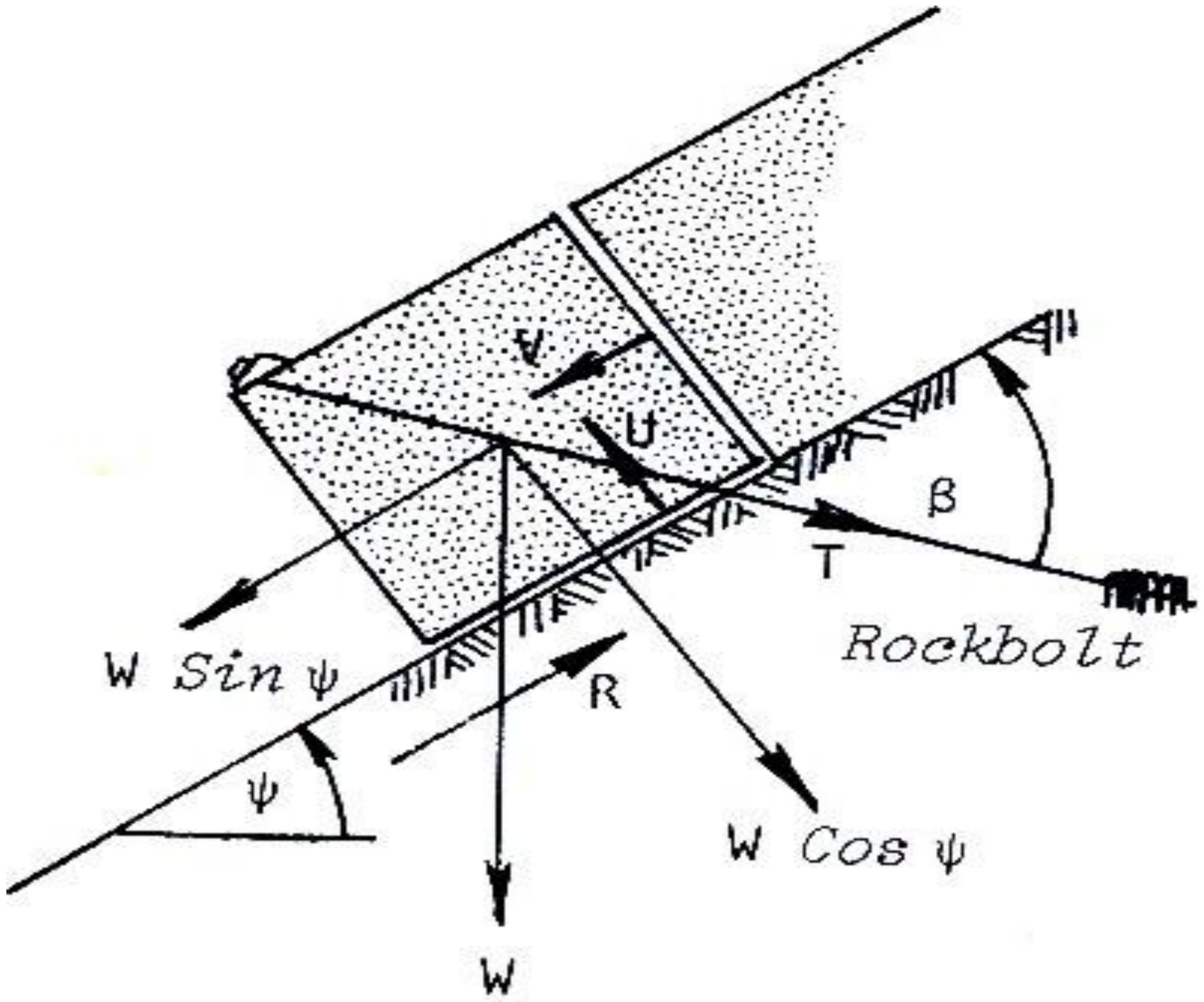
Tensioned rock-bolts:

- ✓ *Used on rock masses that show signs of instability or on newly cut rock slopes to **prevent movement along fractures***
- ✓ *Are considered a type of **active reinforcement** due to the **post-tensioning they provide***
- ✓ *Are used to **add compressive stress to joints** within a rock mass, which **increases friction along fracture planes** and helps to **reduce block movement**.*
- ✓ ***Require more time to install**….because installation involves drilling, grouting bonded length and inserting bar/cable, then tensioning anchor and grouting free length.*



Stabilization of Slopes.....contd.

*Consider **a block** resting on **inclined plane** & acted upon by uplift force, **u,** and force **v**, due to water pressure in tension crack.*



*Rock-bolt, tensioned to load **T** is installed @ angle **β** to plane....*

Resolved component acting along surface, upon which block resists is

T Cos β

Stabilization of Slopes.....contd.

Condition of limiting equilibrium for this case is defined by:

$$W \sin \psi + v - T \cos\beta = c A + (W \cos \psi - u + T \sin\beta) \tan \phi \quad (7)$$

Equation shows that bolt tension:

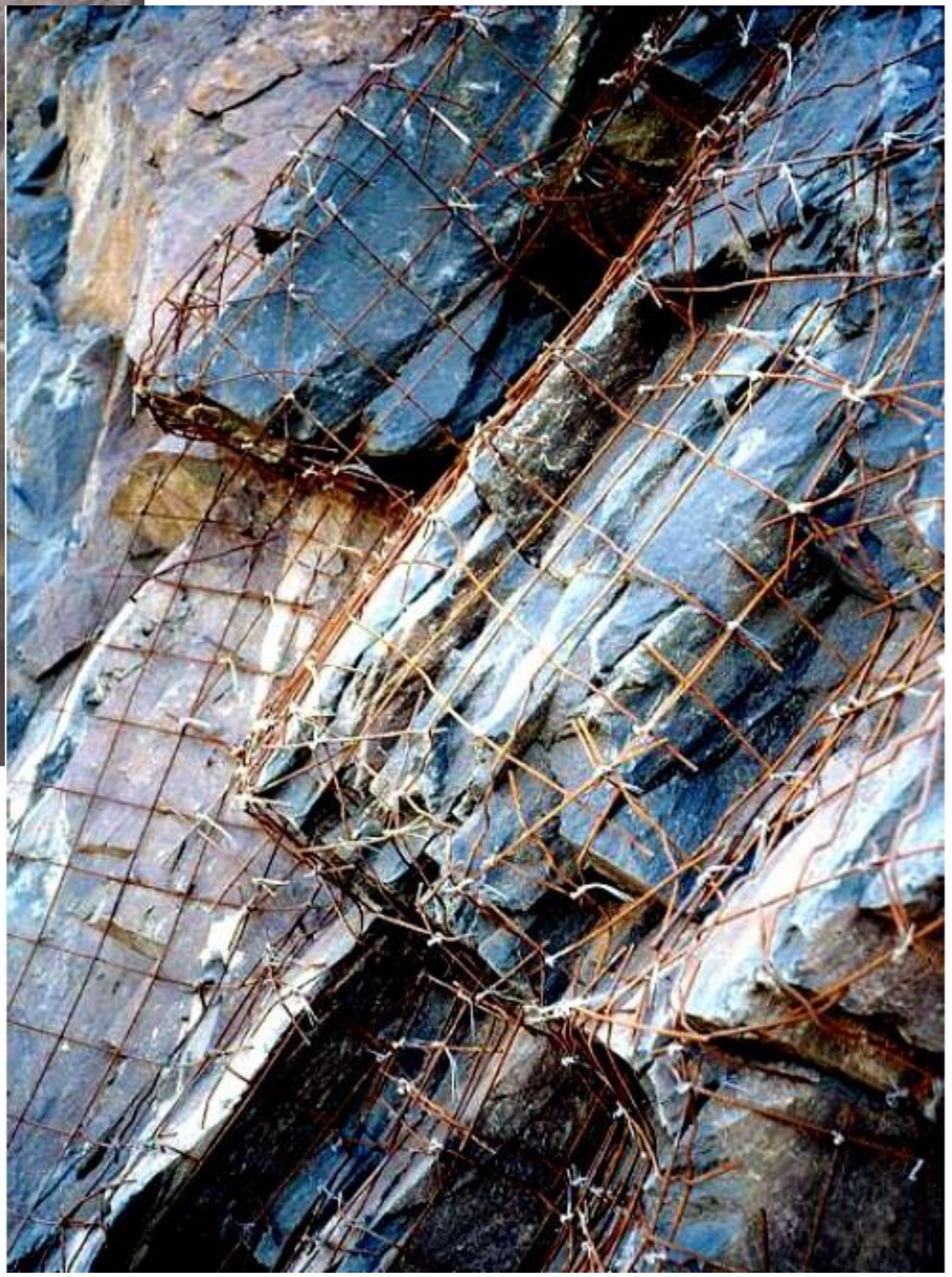
- **Reduces DISTURBING FORCE** acting down plane
- **Increases NORMAL FORCE** and hence **FRICTIONAL RESISTANCE** between base of block & plane.

Stabilization of Slopes.....contd.

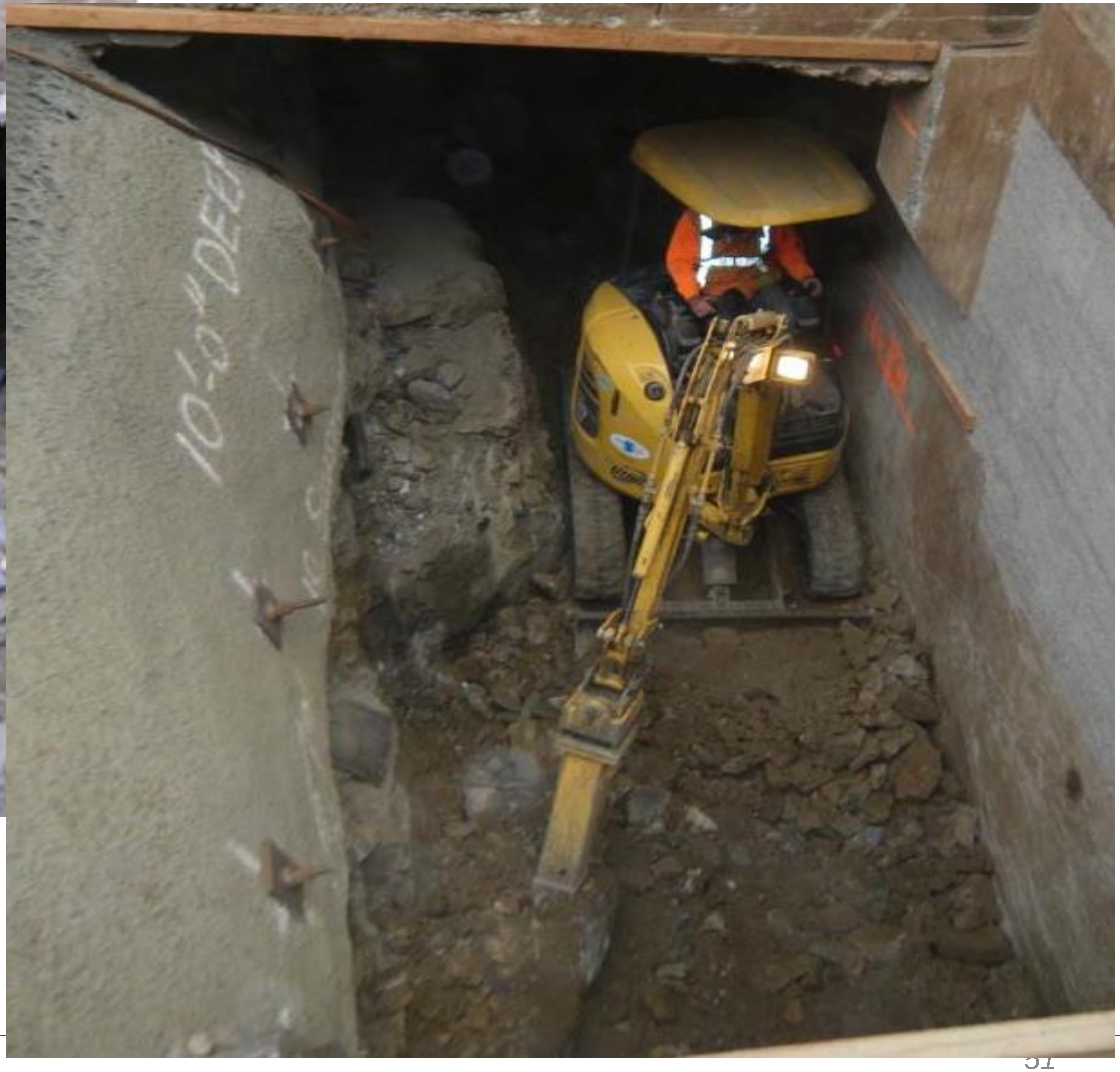
*To assess, whether or not this block is now stable is by determination of **FACTOR OF SAFETY.** Considering the case of the block acted upon by water forces [equation (6) above], **FACTOR OF SAFETY** is given by:*

$$F = \frac{cA + (W \quad Cos\ \alpha - u + T\ Sin\ \beta)\ Tan\ \varphi}{W\ Sin\ \alpha + v - T\ Cos\ \beta}$$

Stabilization of Slopes.....contd.

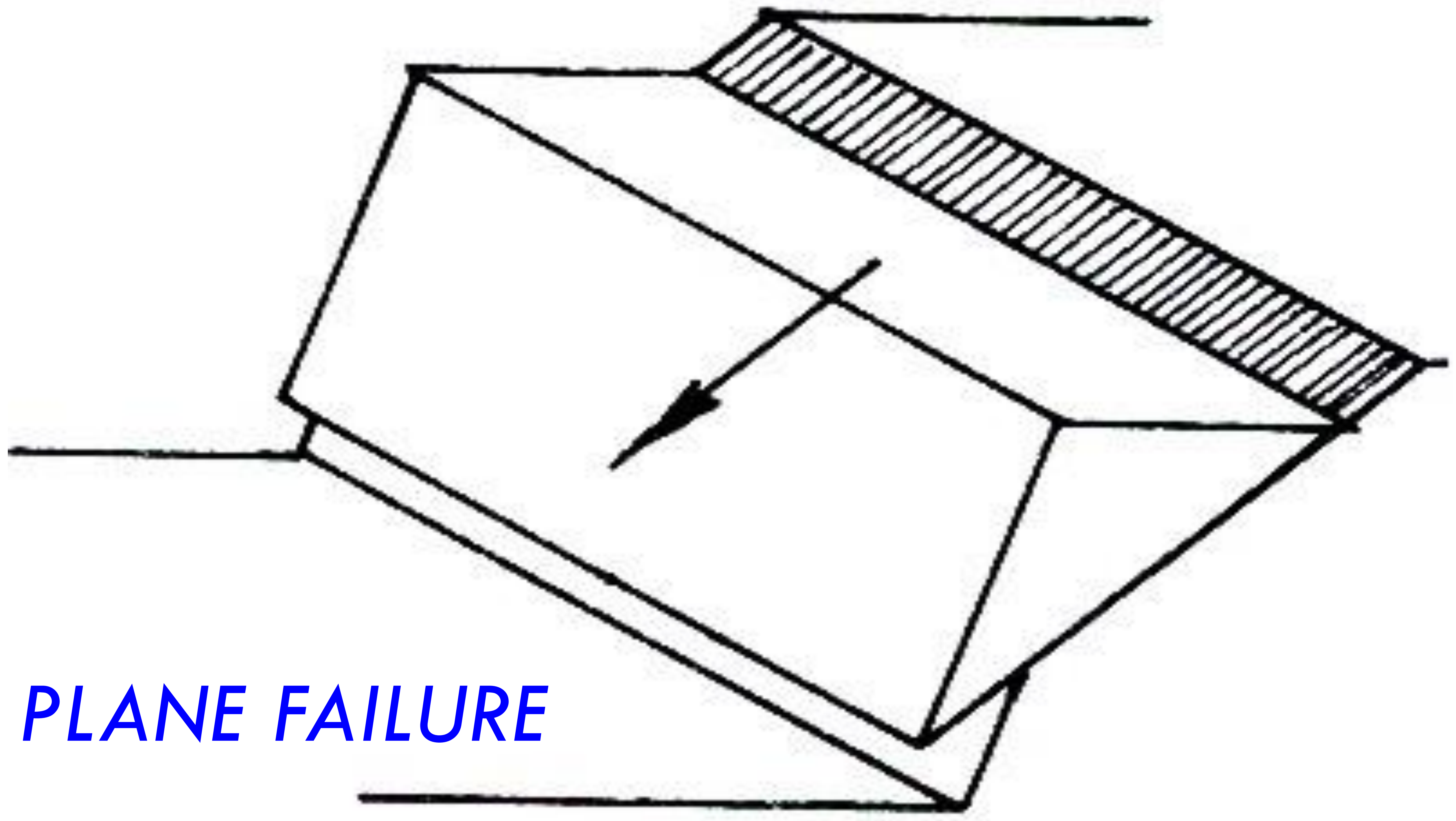


Stabilization of Slopes…..contd.



Slope Failures for which Factors of Safety can be calculated

1. ***Translational*** *– encompasses* ***plane*** *and* ***wedge*** *failures*

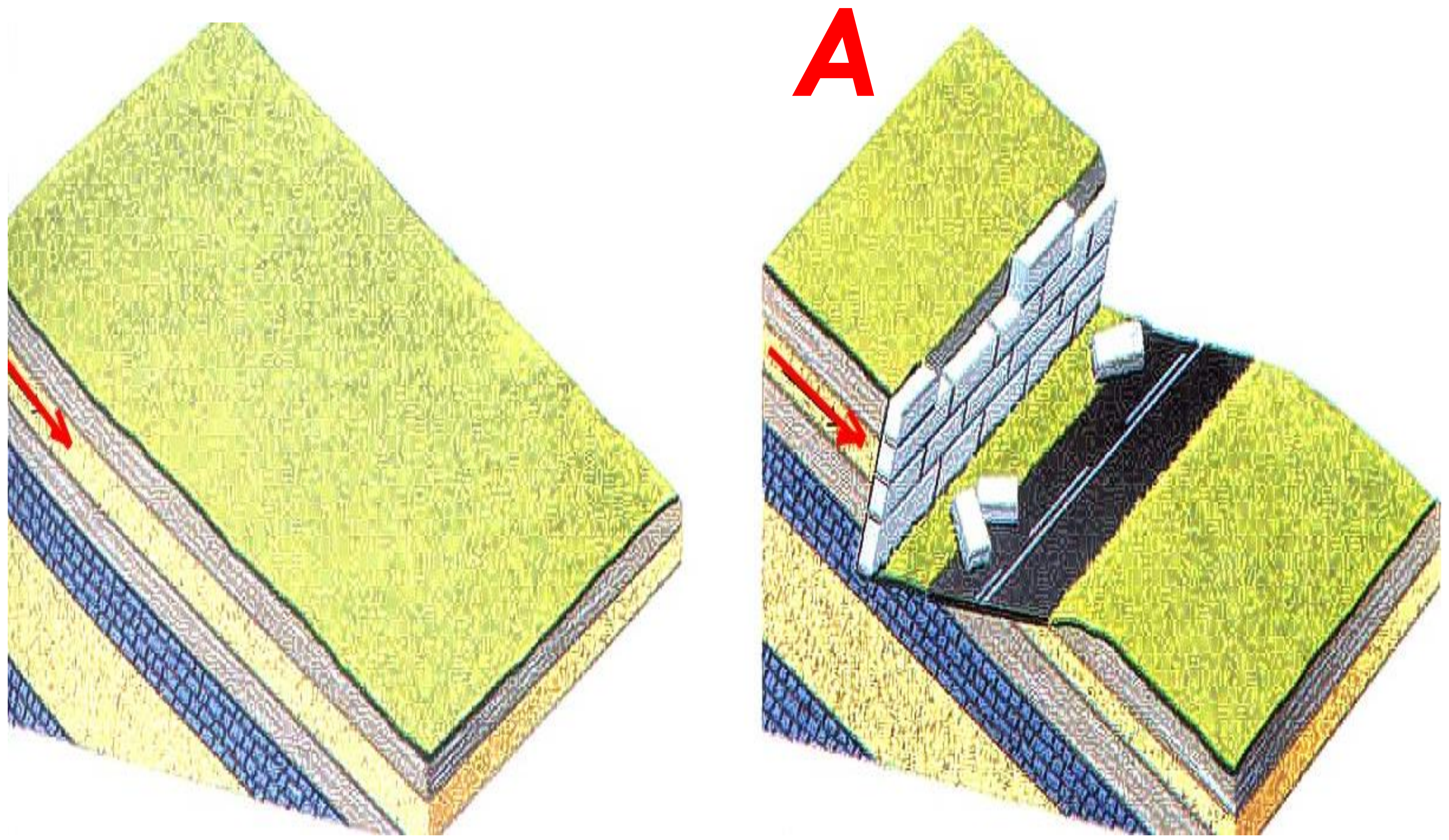


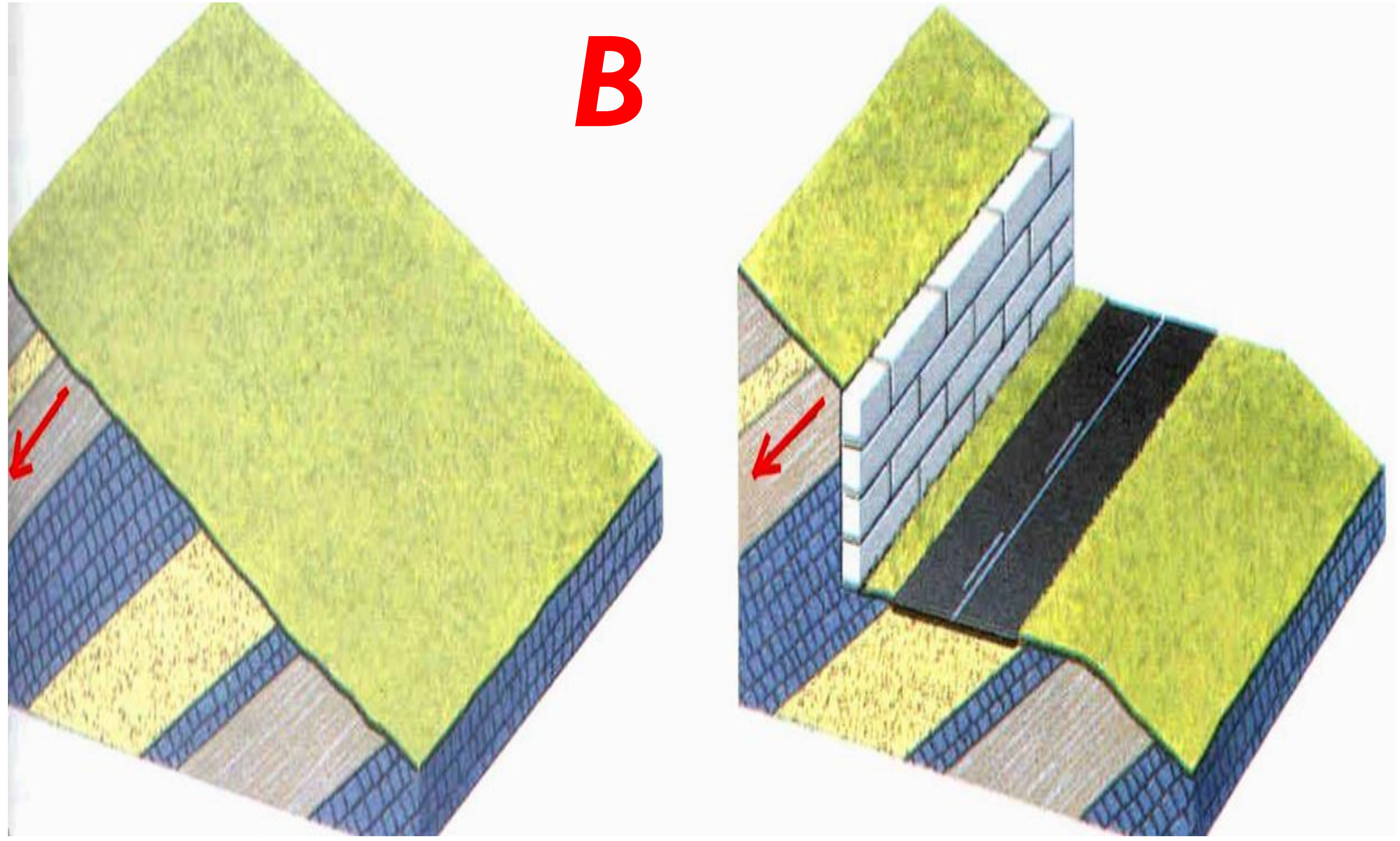
a) ***Plane failure*** *– occurs when discontinuities – joints, bedding – strike parallel to the slope face and dip into the excavation at an angle* **>** *angle of friction.*

Slope Failures for which Factors of Safety can be calculated…..contd.

For example:

If sedimentary rock layers dip in the same direction as slope, upper layers may slide over the lower ones.





(A) If road cut undermines slope, where rocks dip parallel to slope, dipping rock provides good sliding surface.

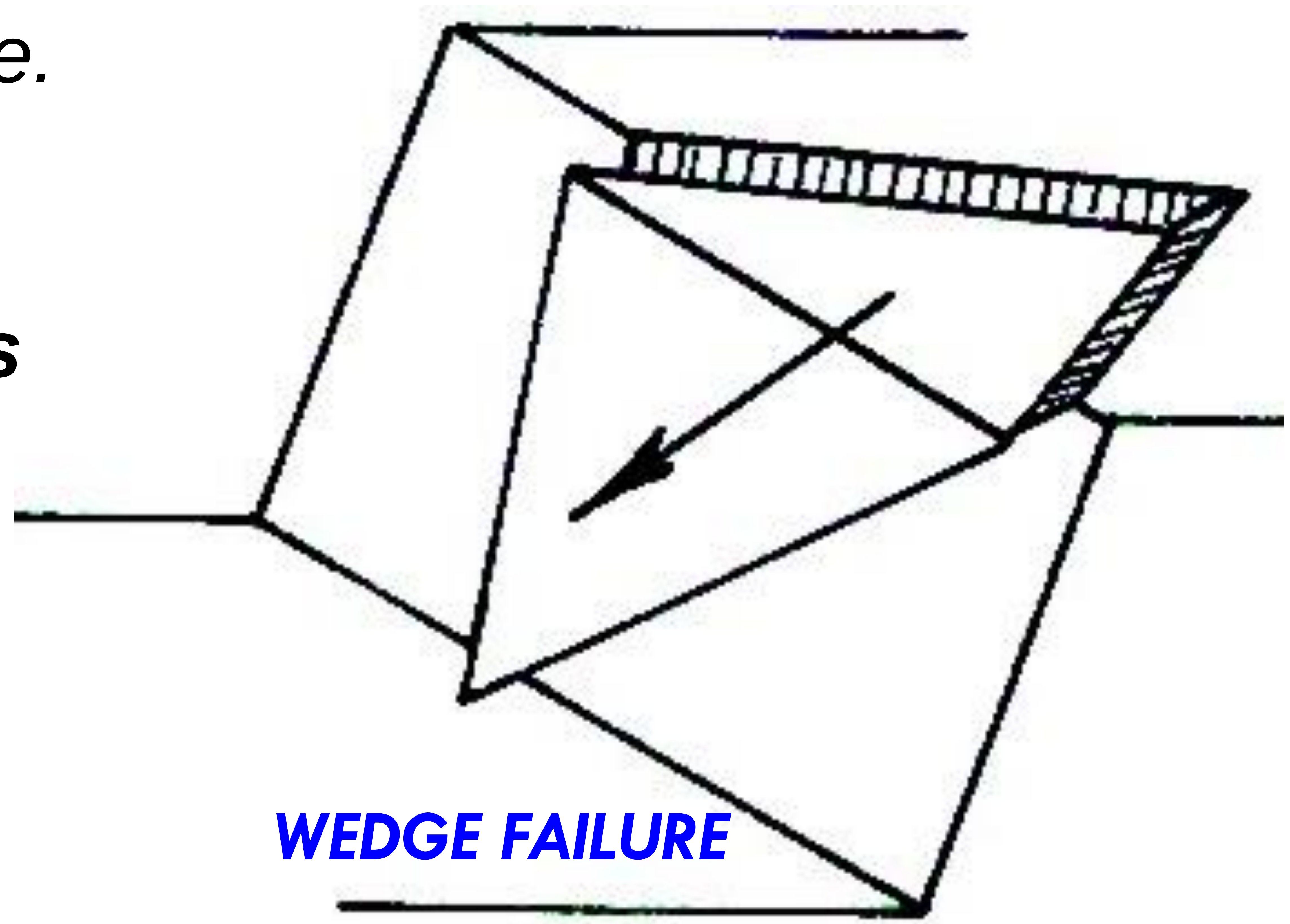
(B) Slope will remain stable even when undermined if rock layers dip away from cut.

Slope Failures for which Factors of Safety can be calculated.....contd.

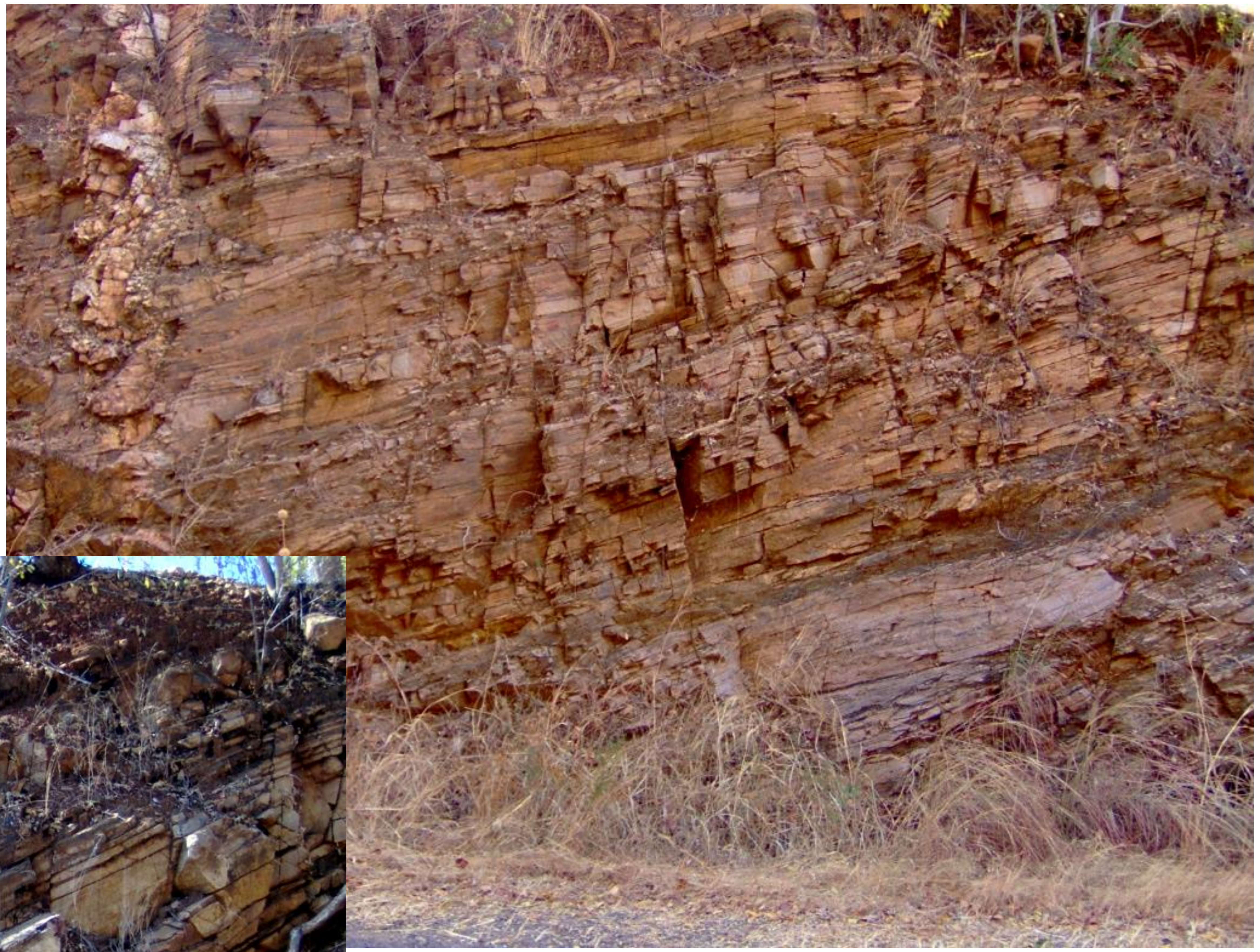
b) Wedge failure *occurs when*

- ✓ *line of intersection of* ***two discontinuities striking obliquely*** *daylights into slope face.*

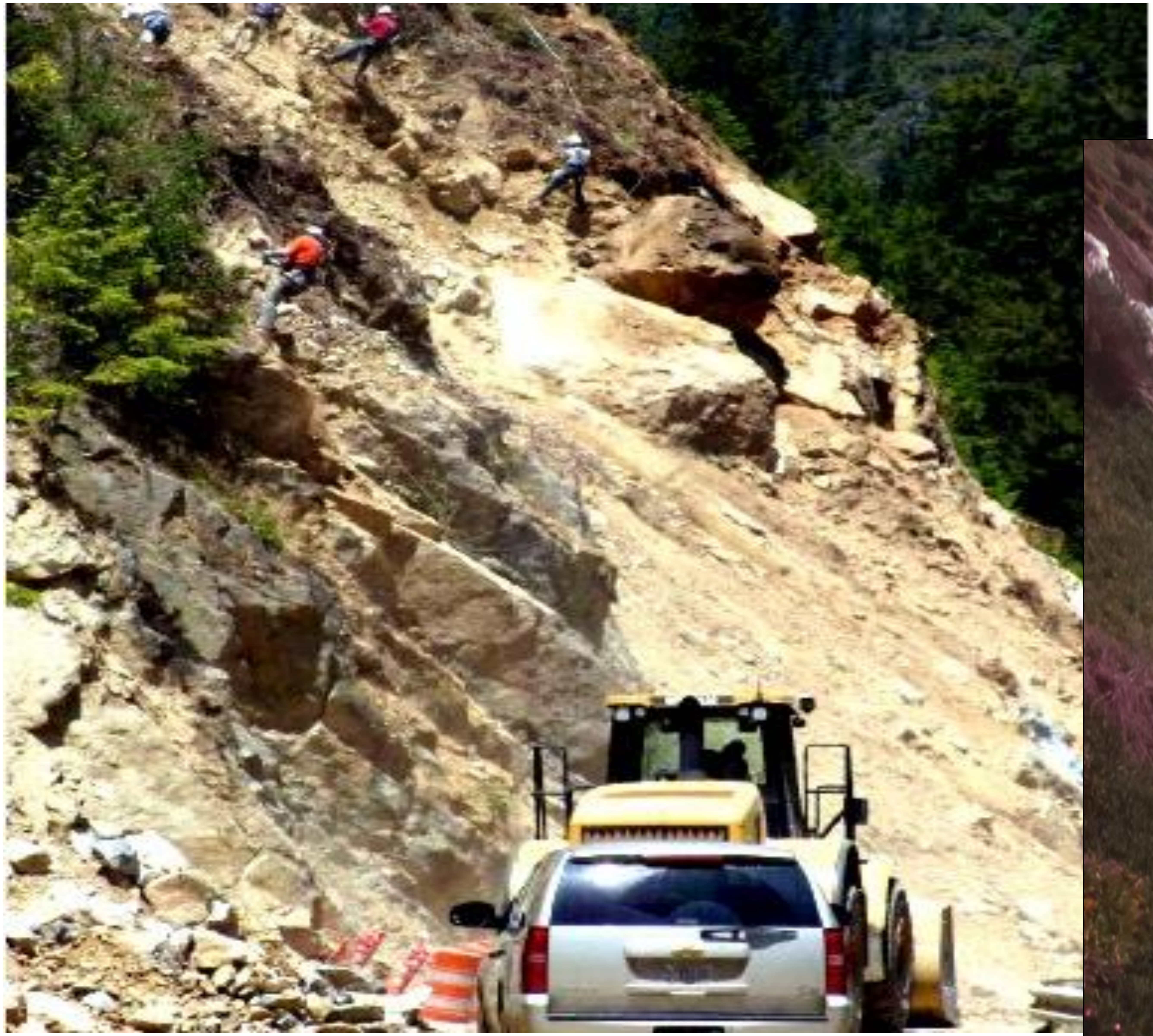
- ✓ *Wedge of* ***rock resting on discontinuities*** *slides down line of intersection* ***provided inclination of the latter is significantly greater than the angle of friction.***



Orientation of Engineering works to Discontinuity Orientations…..contd.



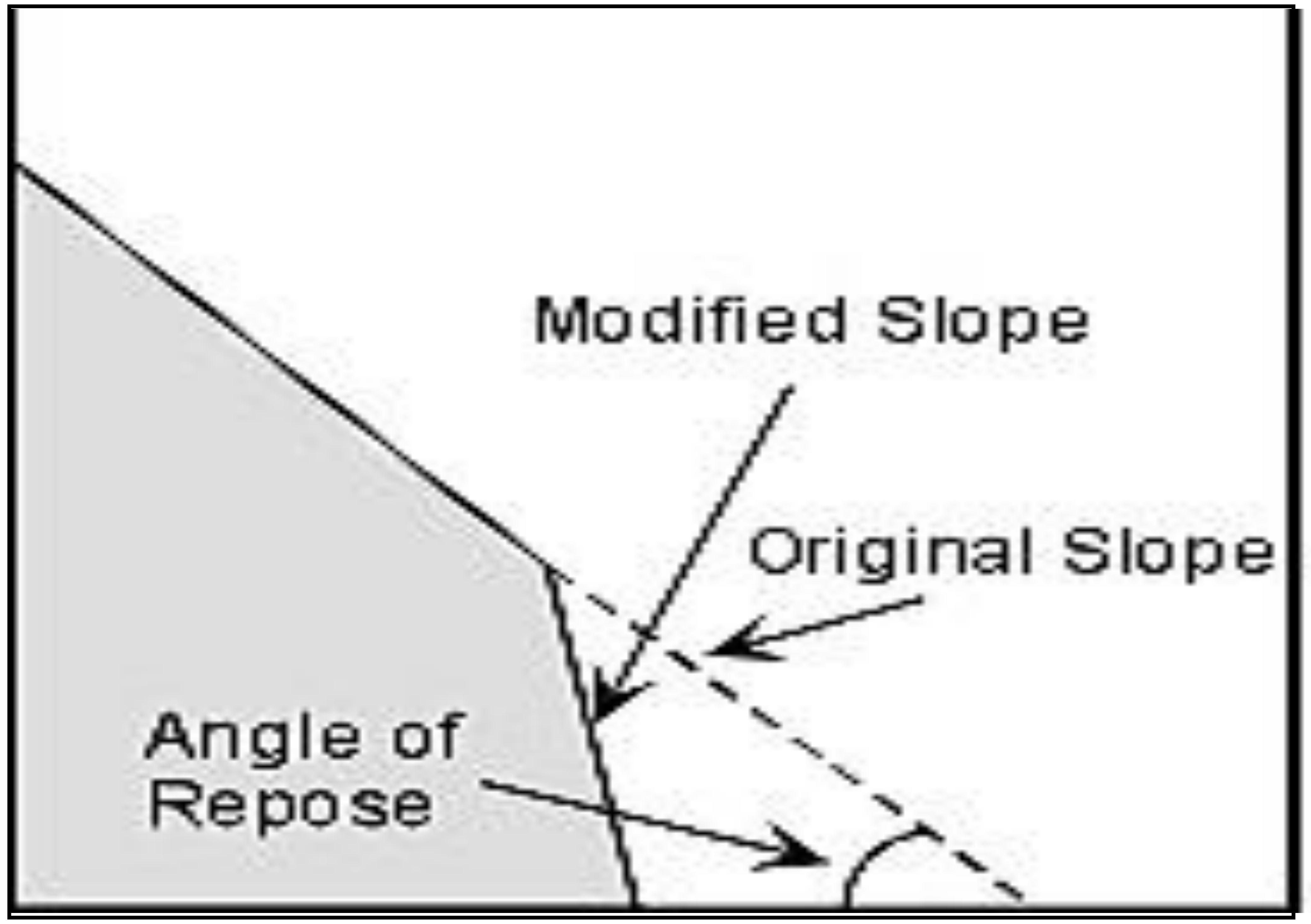
Orientation of Engineering works to Discontinuity Orientations.....contd.

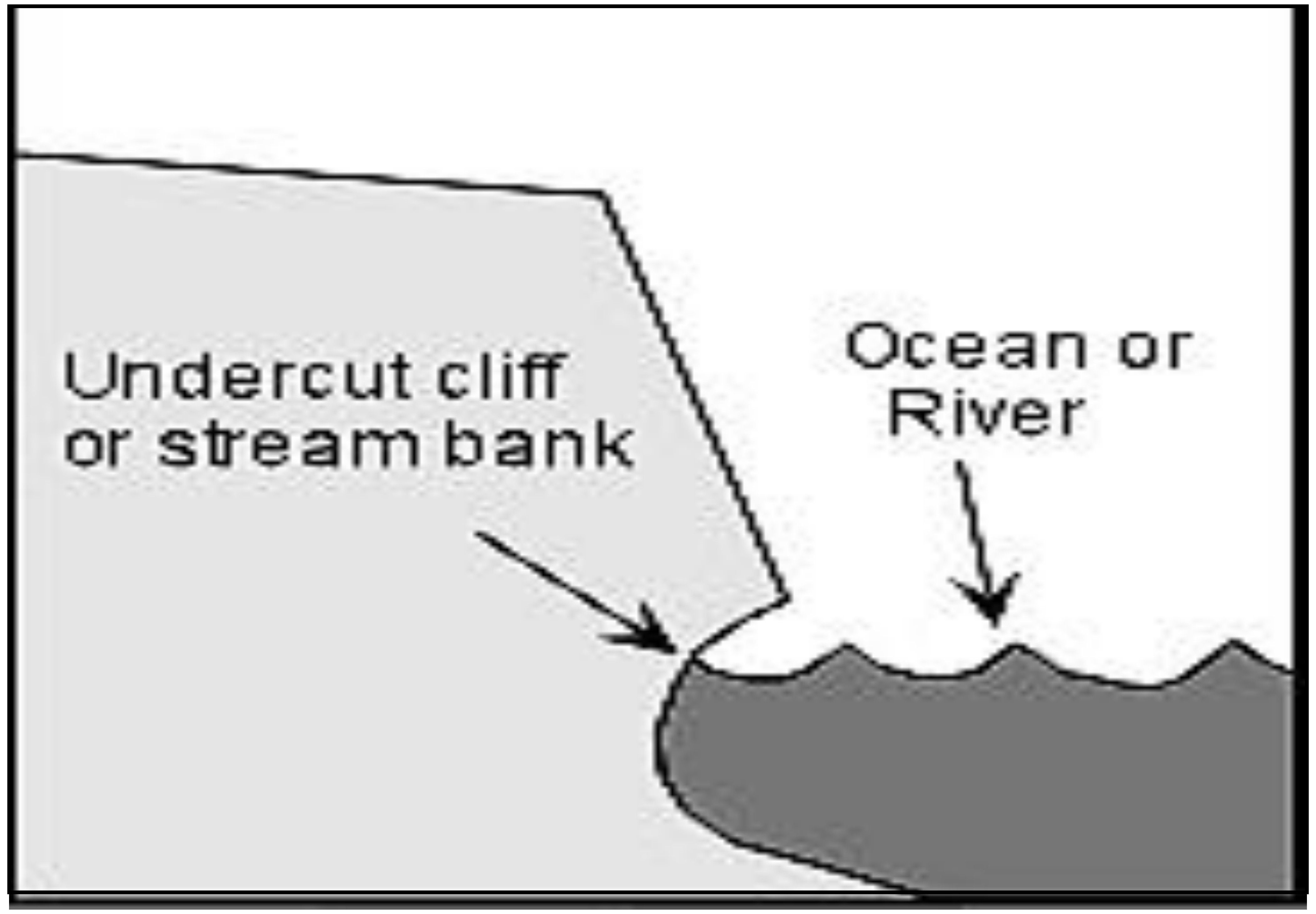


Triggering Mechanisms for slope failure

Slope failure can occur <u>any time a slope becomes unstable</u>. For example:

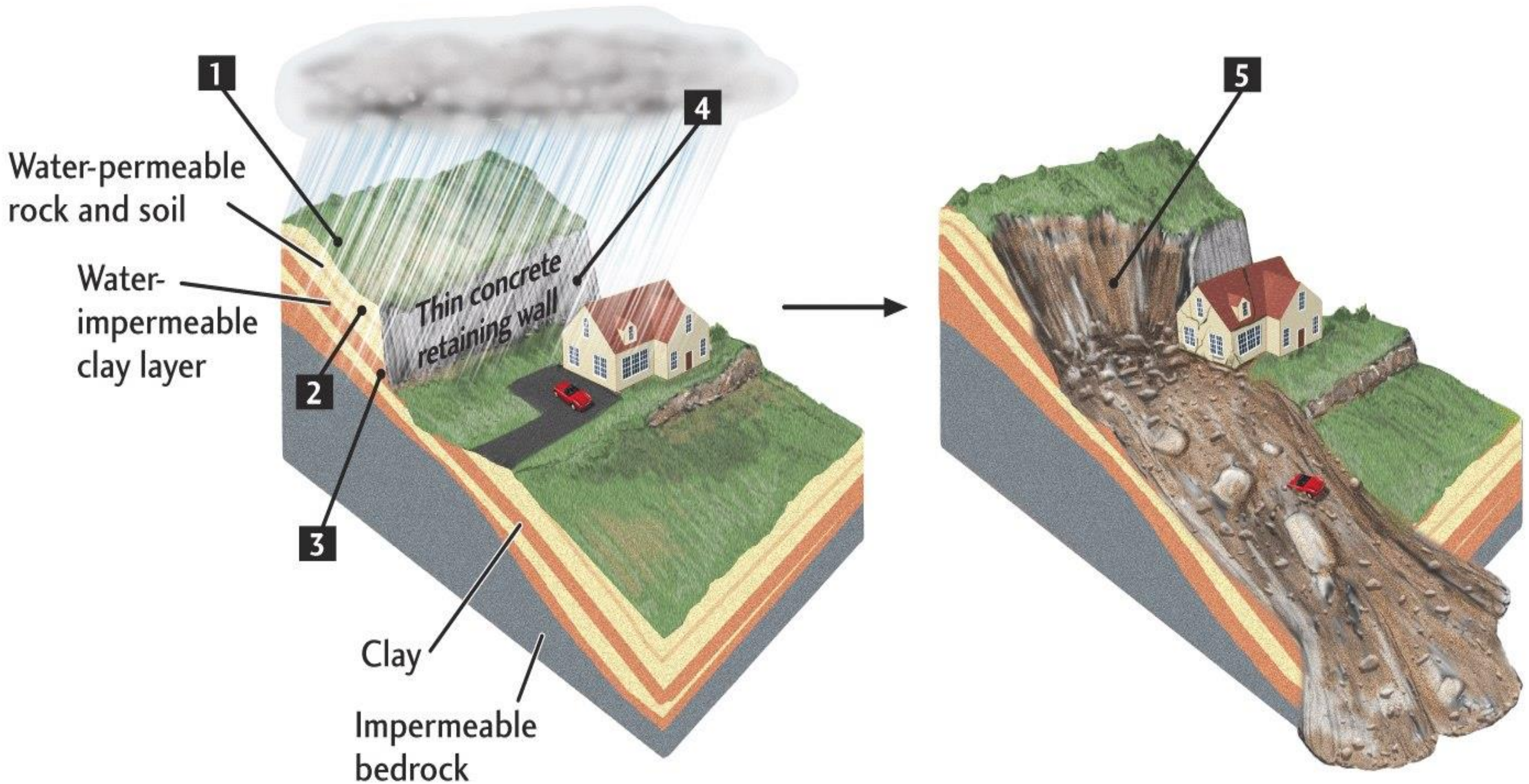
a) *Modification of slope either by **humans or by natural causes** can change the **slope angles**, e.g. by **Undercutting***





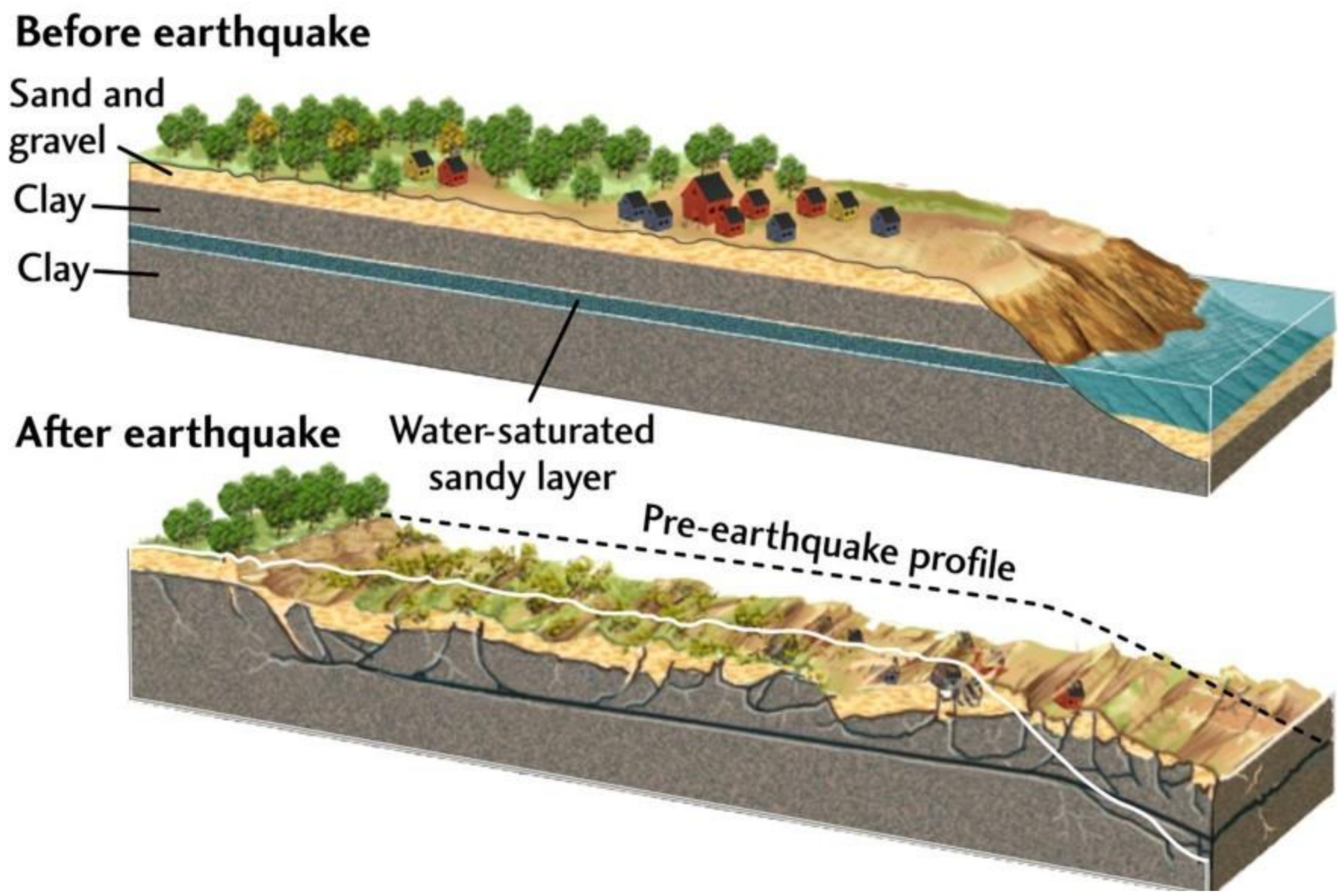
Triggering Mechanisms for slope failure.....contd.

*b) **Sudden addition of moisture** to rock/soil mass.*



Triggering Mechanisms for slope failure.....contd.

c) Shocks – A sudden shock/shake of ground by, e.g. an earthquake, may trigger a slope instability thru **Liquefaction**



Triggering Mechanisms for slope failure.....contd.

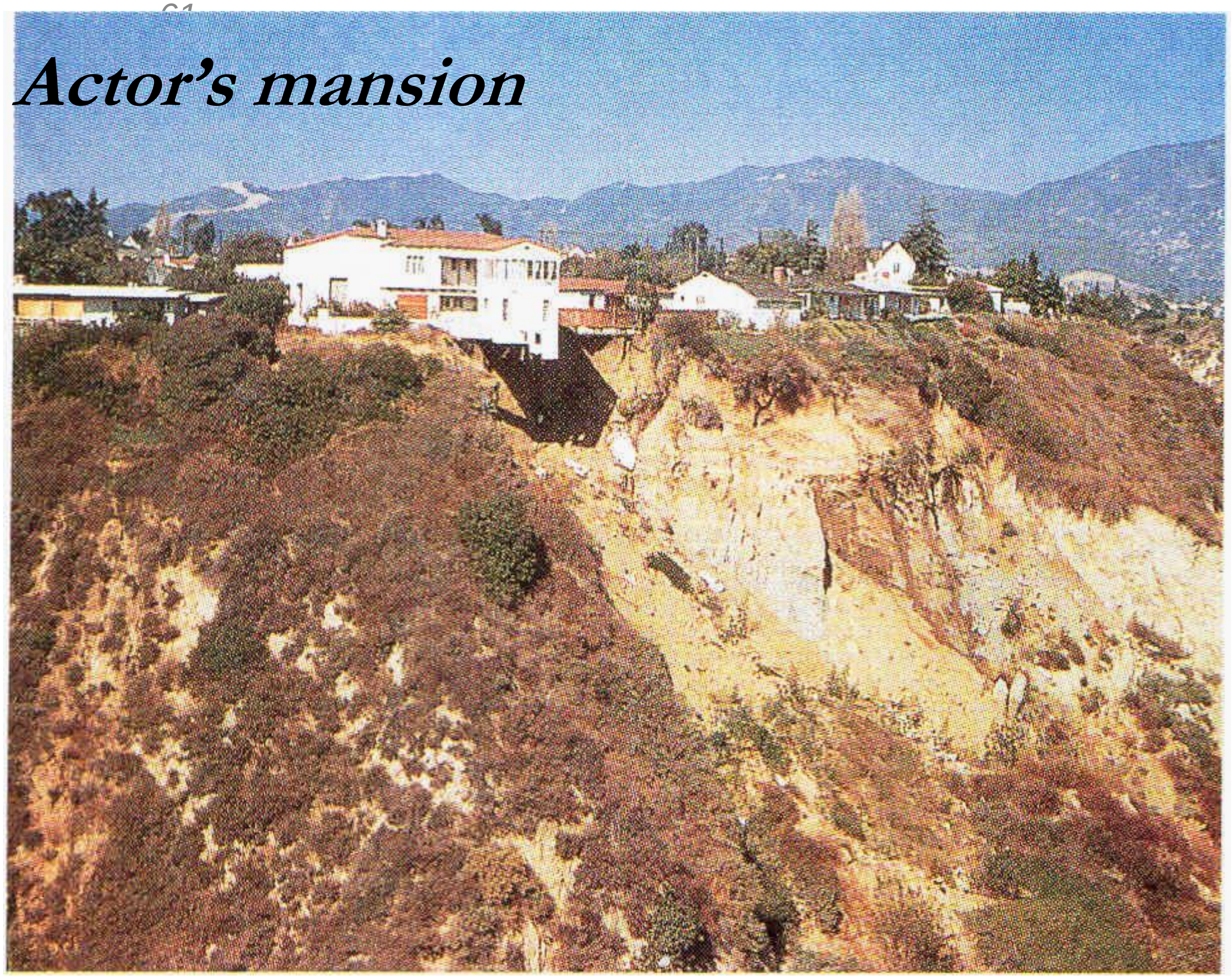
d) Undercutting phenomena

In diagram 1, the residents of the house have a fine ocean view, with stable rocks below them

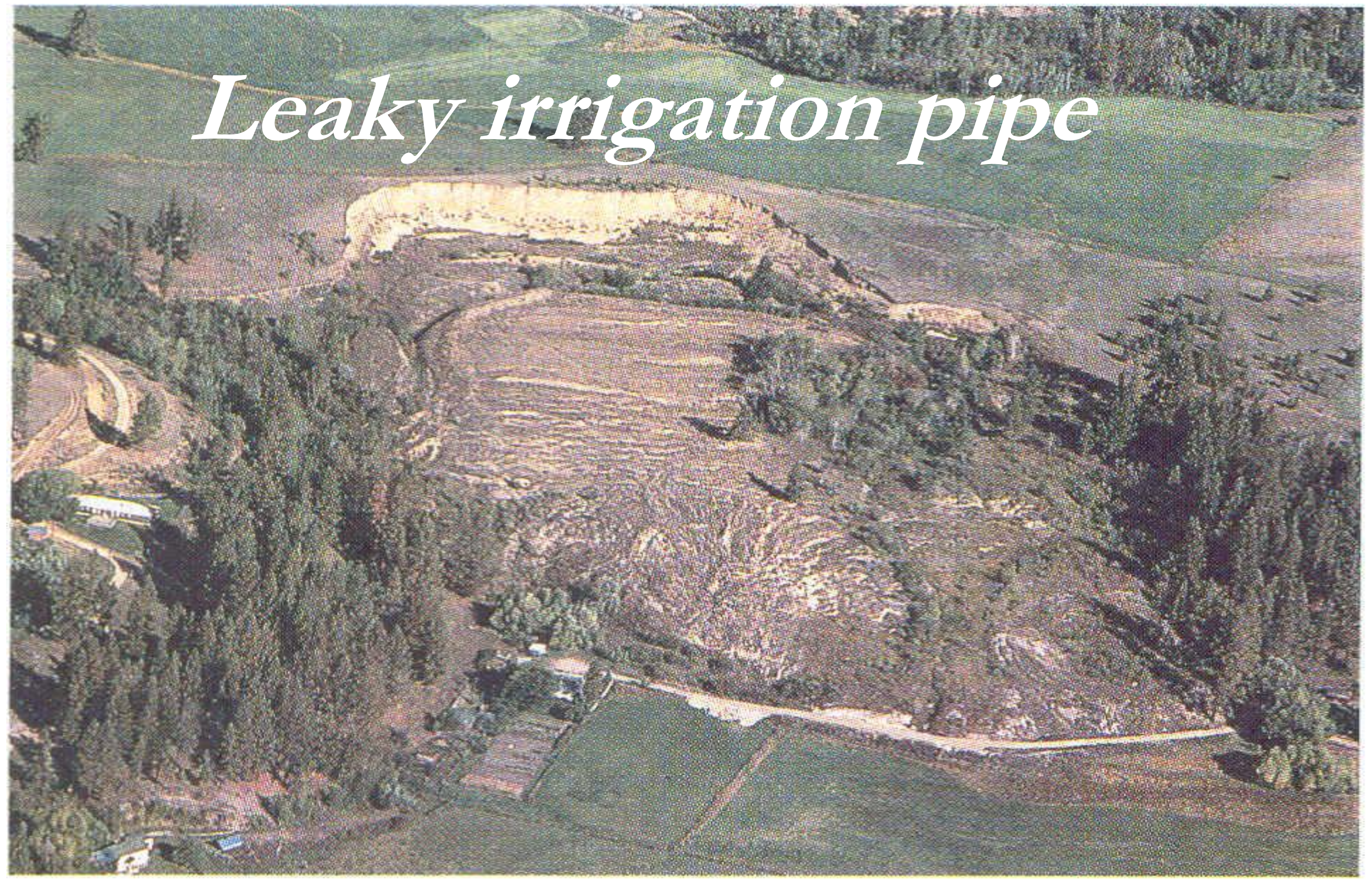
In diagram 2, ocean waves have removed the base of the slope beneath the house. Removal of support will result in formation of a fracture.. Residents will see a widening crack cutting across their lawn…

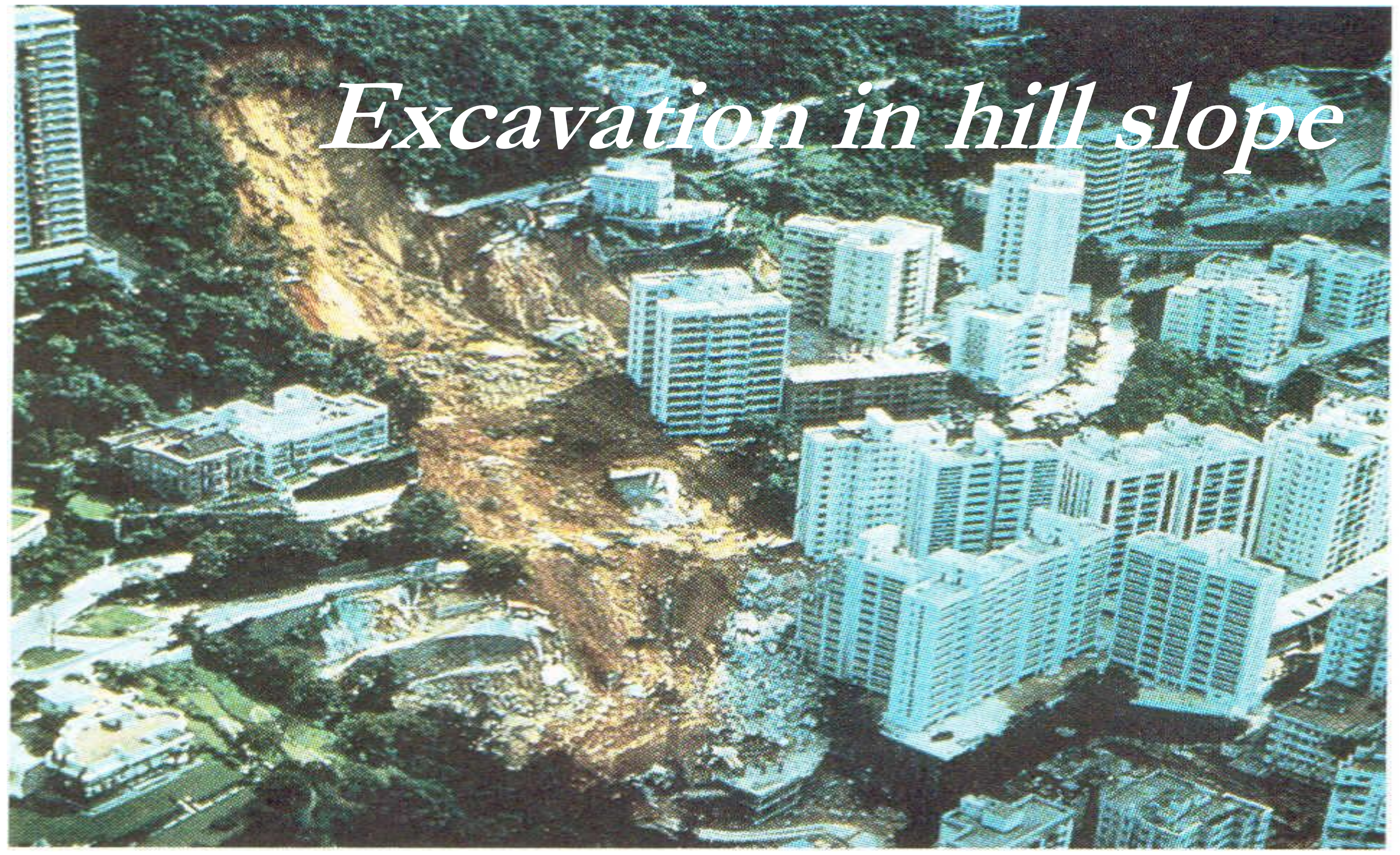
Diagram 3 shows that the slump block has slid downward along the surface of rupture,

Examples of Some Slope Failure Mechanisms



House fell a few days after this photo was taken

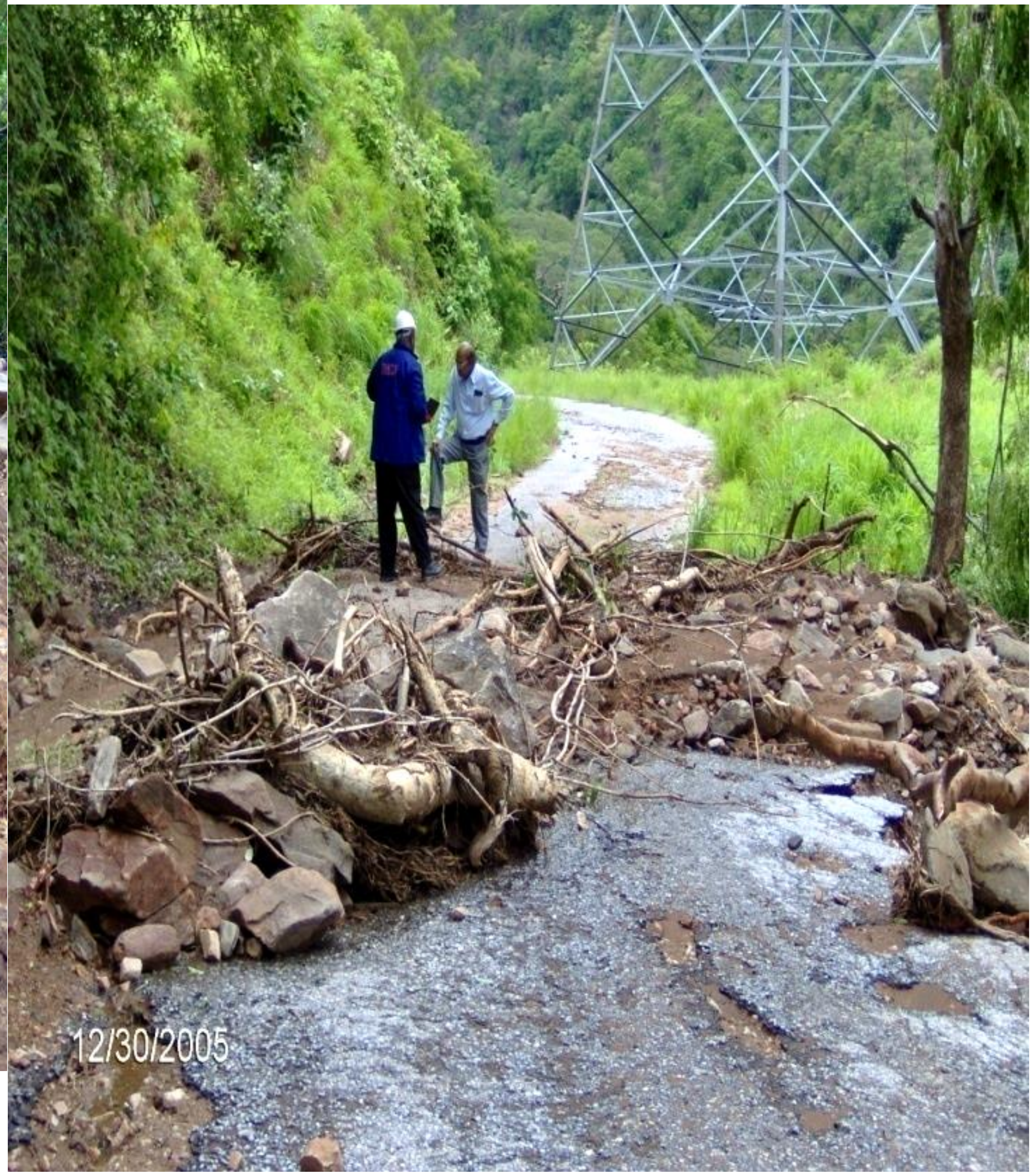




Examples of Some Slope Failure Mechanisms.....contd.

Bending of tree-trunks – indicative of gradual movement of the slope in ***creep***

Examples of Some Slope Failure Mechanisms.....contd.



Flow failures in pictures

Examples of Some Slope Failure Mechanisms.....contd.

PREDICTING AND AVOIDING SLOPE FAILURES

- ***Landslides*** *commonly occur on same slopes as earlier ones bcoz geologic conditions that cause mass wasting tend to:*
  - ⇨ *Be constant over a large area*
  - ⇨ *Remain constant for long periods of time.*
  - ⇨ *If a hillside has slumped, nearby hills may also be vulnerable to mass wasting.*
  - ⇨ *landslides and mudflows commonly follow paths of previous slides and flows.*

Predicting and Avoiding Slope Failures.....contd.

- If an old mudflow lies in a stream valley, future flows may follow the same valley.

- Awareness and avoidance are the *most* effective defences against mass wasting.