SENIOR SIX TERM 2

TOPIC 1/3: Slope Development

Competency: The learner analyses spatial and temporal variations of slope processes by examining their nature, factors influencing their occurrence and impact to devise strategies for managing slope-related hazards.

A **slope** refers to the rise or fall of the land surface, essentially describing how steep or gentle the terrain is.

Evolution of a slope

The evolution of a slope in geography refers to how the shape and steepness of land surfaces change over time due to processes like weathering, erosion, and mass movement.

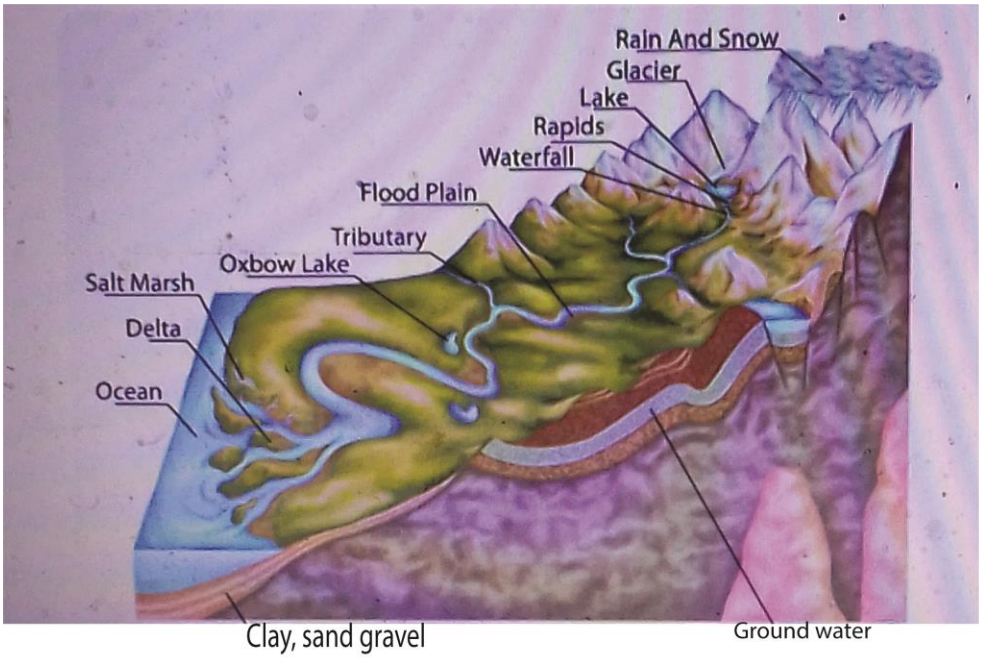


Fig. 1: Evolution of a slope

Figure 1 provides a channel overview of land scape evolution from steep mountain to flat plain near the ocean. It shows how land changes from high steep relief with water falls and rapids near the top representing an early stage of the river. The middle section the slope become gentler with meanders and flood plain developing in mature stage. Finally, at the bottom near the ocean, the land is nearly flat forming peneplain in the old stage.

Factors Driving Slope Evolution

(i) **Weathering**: Breaks down rock, producing regolith.
(ii) **Erosion**: Removes weathered materials material via water, wind, or ice.
(iii) **Mass movement**: Landslides, soil creep, and rockfalls reshape slopes.
(iv) **Climate**: Rainfall, temperature, and vegetation cover influence slope stability.
(v) **Human activity**: Farming, construction, and deforestation accelerate slope changes.

The theories of slope development

These are proposed explanation or models used to how slopes change over time due to erosion, weathering, and tectonic forces.

1. Slope Decline Theory (W.M. Davis)

Proposed by William Morris Davis in 1899, this theory is linked to his "Cycle of Erosion".

- **Main Idea:** Slopes gradually lose height and steepness over time, a process called **downwearing**.
- **Evolution:** Slopes pass through youthful (steep), mature (moderate), and old (very gentle) stages.
- **Result:** Upper parts weather faster than they can be removed, leading to an eventual flattening into a featureless plain called a **peneplain**.

2. Slope Replacement Theory (Walther Penck)

Walther Penck proposed this as a dynamic alternative to Davis, focusing on the relationship between tectonic uplift and erosion.

- **Main Idea:** A steeper slope is replaced from below by gentler slopes as denudation occurs.
- **Slope Forms:** Slope shape reflects the rate of uplift: **convex** (increasing uplift), **straight** (constant uplift), and **concave** (decreasing uplift).

- **Result:** The cycle ends in a low-relief surface called an **endrumpf**.

3. Parallel Retreat Theory (L.C. King)

Lester Charles King developed this theory based on observations of arid and semi-arid landscapes, such as the African savanna.

- **Main Idea:** Slopes retreat backward while maintaining their original gradient and angle.
- **Slope Elements:** King identified four essential parts: **waxing slope** (top convexity), **free face** (bare rock cliff), **debris slope** (talus), and **waning slope** (basal concavity/pediment).
- **Result:** The merging of expanding pediments creates a broad, gently sloping surface called a **pediplain**.

4. Wood's Theory of Slope Evolution (Alan Wood, 1942)

Wood proposed a composite model that combined elements of retreat and decline.

- **Process:** He suggested that a cliff (free face) retreats parallel to itself while weathered material (scree) accumulates at the base, protecting it and gradually burying it.
- **Standard Profile:** A fully developed slope consists of four elements similar to King's model.
- **Flexibility:** He argued that climate and local rock structure determine whether a slope will primarily retreat or decline.

5. Statistical Equilibrium Theory (A.N. Strahler)

Strahler applied statistical methods to measure slope angles in different regions.

- **Main Idea:** Slopes maintain an **equilibrium angle** proportional to the channel gradient of the local drainage system.
- **Function:** This angle adjusts to allow for the steady and efficient removal of debris under prevailing climate and soil conditions.

Applicability of various slope development theories in different environments (e.g., humid vs. arid) and their limitations

Slope development theories (Davis, Penck, King, Strahler, etc.) were designed to explain how slopes evolve, but their **applicability varies depending on environmental conditions** like climate, geology, and human activity. Each theory has strengths and limitations.

Applicability in Different Environments

(i) **Humid Environments (e.g., tropical or temperate regions)**
  - **Davis' Slope Decline Model**: Works best here because heavy rainfall and chemical weathering gradually reduce slope steepness, leading to gentler landscapes.
  - **Limitations**: Oversimplifies; assumes uniform erosion and ignores tectonic activity.

(ii) **Arid Environments (e.g., deserts, semi-arid regions)**
  - **King's Parallel Retreat Model**: More applicable, as resistant rock escarpments retreat backward while maintaining steepness due to mechanical weathering and sparse vegetation.
  - **Limitations**: Doesn't account for variations in rock resistance or episodic flash floods.

(iii) **Regions with Active Tectonics (mountainous zones)**
  - **Penck's Slope Replacement Model**: Useful because it considers uplift and erosion simultaneously, explaining why slopes can remain steep while retreating.
  - **Limitations**: Assumes continuous uplift and uniform erosion, which rarely occurs.

(iv) **Complex Environments (mixed climates, varied geology)**
  - **Strahler's Complex Model**: Most realistic, as it integrates multiple processes (weathering, erosion, tectonics, vegetation, human activity).
  - **Limitations**: Too broad; lacks predictive precision compared to simpler models.

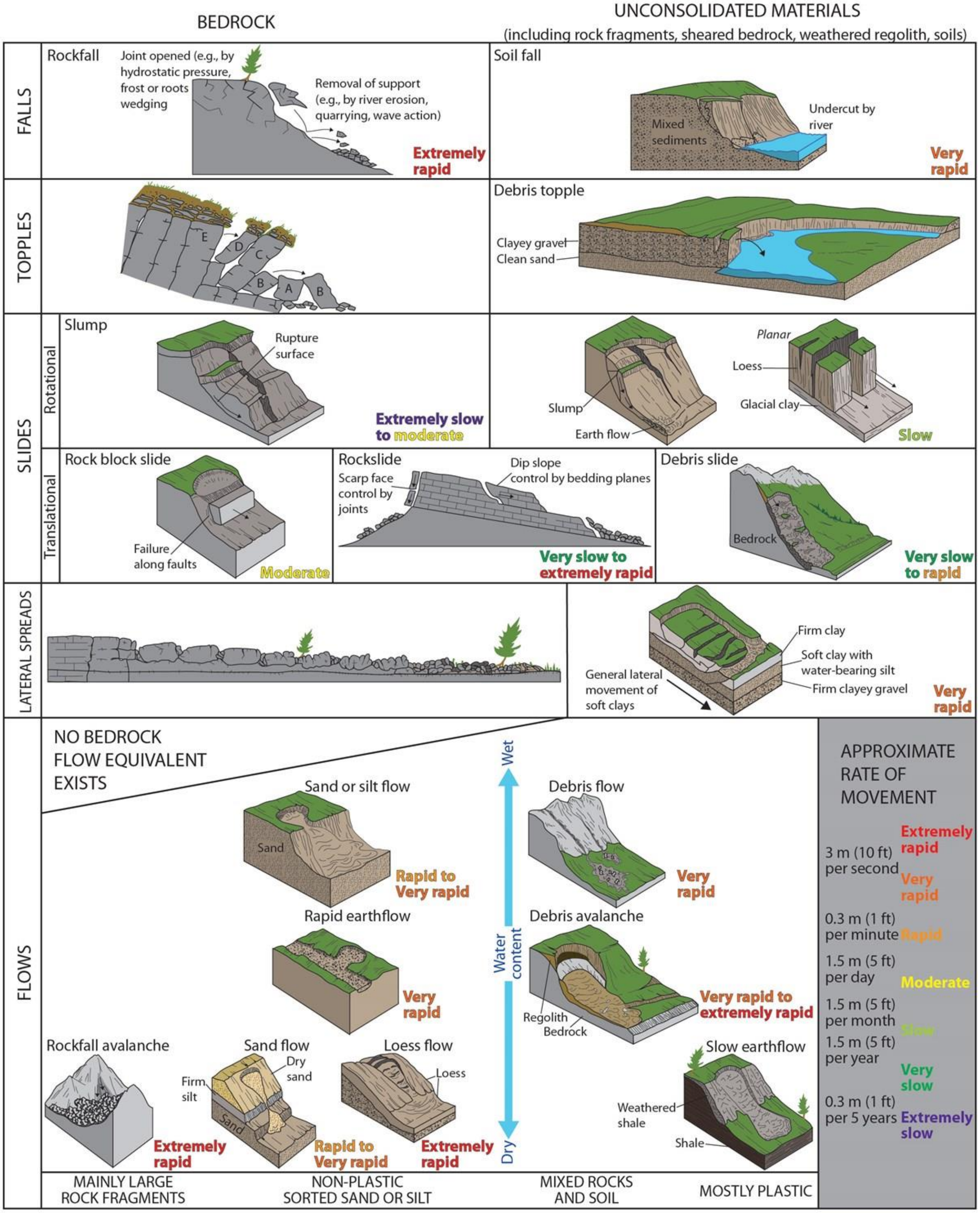
Summary Table

Theory	Best Environment	Applicability	Limitations
Davis' slope decline	Humid regions	Explains gentle slope evolution	Ignores tectonics, oversimplifies
Penck's slope replacement	Tectonically active areas	Considers uplift + erosion	Assumes uniform processes
King's parallel retreat	Arid regions	Explains scarp retreat	Neglects climatic variability
Strahler's complex model	Mixed/varied environments	Accounts for multiple factors	Too general, less predictive

Key Takeaway

- **Humid climates** → Davis' model fits better (gentle slope decline).
- **Arid climates** → King's model explains parallel retreat of scarps.
- **Tectonic regions** → Penck's model highlights uplift-erosion balance.
- **Mixed/complex settings** → Strahler's model is most realistic but less precise.

Types of Mass Wasting



Mass wasting is the downslope movement of soil, rock, and debris under the direct influence of gravity. It differs from erosion because the material is not carried by water, wind, or ice—it simply moves downslope due to gravity, often triggered by factors like water saturation, earthquakes, or human activity.

(i) **Creep:** Very slow, gradual downslope movement of soil and regolith, often caused by freeze-thaw or wet-dry cycles.
(ii) **Slump:** Rotational movement of material along a curved surface, leaving a crescent-shaped scar.
(iii) **Rockfall:** Sudden detachment of rock fragments from steep slopes or cliffs.
(iv) **Debris flow:** Rapid downslope movement of water-saturated soil, rock, and organic matter, common in mountainous regions.
(v) **Earthflow:** Viscous flow of fine-grained, water-saturated material, slower than debris flows.
(vi) **Mudflow:** Fast-moving slurry of mud and water, often occurring in arid or semi-arid regions after heavy rain.
(vii) **Avalanche:** Rapid flow of snow, ice, and debris downslope.
(viii) **Solifluction:** Slow downslope flow of water-saturated soil in periglacial environments.

Summary Table

Type	Speed	Material	Trigger
Creep	Very slow	Soil/regolith	Freeze-thaw, wet-dry cycles
Slump	Moderate	Soil/rock	Water saturation, gravity
Rockfall	Fast	Rock fragments	Weathering, earthquakes
Debris flow	Very fast	Soil, rock, water	Heavy rainfall
Earthflow	Moderate	Fine-grained soil	Water saturation
Mudflow	Fast	Mud + water	Intense rainfall
Avalanche	Very fast	Snow, ice, debris	Gravity, melting, earthquakes
Solifluction	Slow	Saturated soil	Periglacial thawing

Key Takeaway

Mass wasting processes range from **slow soil creep** to **catastrophic landslides and debris flows**, shaped by gravity, water, and environmental triggers. Understanding these processes is vital for hazard management, especially in mountainous and unstable regions.

Processes Driving Mass Wasting

(i) **Gravity:** The fundamental force pulling material downslope.
(ii) **Water saturation:** Adds weight and reduces cohesion, making slopes unstable.
(iii) **Weathering:** Weakens rock and soil, preparing material for movement.
(iv) **Earthquakes:** Shake slopes, triggering landslides and rockfalls.
(v) **Human activity:** Deforestation, mining, and construction destabilize slopes.
(vi) **Freeze-thaw cycles:** Expand cracks in rocks, loosening material for movement.

Impact of mass wasting on environment

(i) **Landscape modification**: It creates new landforms such as scarps, hummocky terrain, and depositional fans. And Alters slope profiles, valleys, and river courses.
(ii) **Soil erosion and loss of fertile land**: Removes topsoil, reducing agricultural productivity. And Leads to desertification in extreme cases.
(iii) **Deforestation and vegetation loss:** Uproots trees and plants, destroying habitats, thereby reducing biodiversity and disrupts ecosystems.
(iv) **Water systems disruption**: Landslides can block rivers, forming temporary lakes. Sediment loads increase in rivers, affecting aquatic life and water quality.
(v) **Hazards to human settlements:** Damages infrastructure such as roads, bridges, and buildings. It causes displacement of communities and economic losses.
(vi) **Climate and microclimate effects**: Exposed bare soil increases surface runoff and reduces infiltration. It also changes local hydrology and slope stability.

Impact of mass wasting on human activities

(i) **Damage to infrastructure**: Roads, bridges, railways, and pipelines can be destroyed or blocked by landslides which Increases maintenance costs for transportation networks in mountainous regions.
(ii) **Loss of property and settlements:** Houses and entire villages may be buried or displaced. Relocation of communities becomes necessary in high-risk zones.
(iii) **Agricultural disruption**: Loss of fertile topsoil reduces crop yields. Terraced farming areas can collapse, leading to food insecurity.
(iv) **Economic consequences:** High costs of reconstruction and disaster relief. Tourism in mountainous areas may decline after major landslides.
(v) **Human casualties and displacement**: Landslides and mudflows often cause fatalities. While survivors may face long-term displacement and psychological trauma.
(vi) **Water supply and hydropower impacts**: Landslides can block rivers, forming temporary lakes that later burst, causing floods. Sediment loads reduce dam efficiency and water quality.
(vii) **Transportation delays and isolation**: Mountainous communities may be cut off for weeks after slope failures. Emergency response becomes difficult in remote areas.

Case studies of deadly mass wasting events in history

The Oso landslide (USA, 2014) and the Sierra Leone mudslides (2017) are two of the deadliest mass wasting events in recent history. Both highlight how natural factors (rainfall, geology) and human activity (deforestation, settlement patterns) combine to create disasters. Their responses reveal strengths and weaknesses in disaster management.

Case Study 1: Oso Landslide, Washington, USA (2014)

Causes

- Heavy rainfall led to soil saturation and slope instability.
- The hill had a history of smaller landslides, showing long-term geological vulnerability.
- Weak glacial sediments amplified slope collapse.

Effects

- 43 people killed, 49 homes destroyed, $60 million in property damage.
- A rural neighborhood was buried under debris covering 1 square mile.
- Highway 530 was blocked, isolating communities.

Response Measures

- Immediate search and rescue by local, state, and federal agencies.
- Federal disaster declaration enabled funding and support.
- Long-term hazard mapping and stricter land-use planning introduced.

Critical Evaluation

- Rescue efforts were rapid but hampered by the scale and mobility of debris.
- Hazard warnings existed but were underestimated; residents were not fully informed of risks.
- Post-disaster reforms improved monitoring, but prevention was reactive rather than proactive.

Case Study 2: Sierra Leone Mudslides, Freetown (2017)

Causes

- Three days of torrential rainfall triggered slope failure.
- Deforestation and unregulated urban expansion on steep hillsides worsened vulnerability.
- Soil erosion and poor drainage systems contributed.

Effects

- Over 1,100 people killed, 3,000 displaced.
- Hundreds of buildings destroyed, leaving thousands homeless.
- Severe contamination of water sources and spread of disease.

Response Measures

- Emergency rescue and recovery coordinated by Sierra Leone government, UN agencies, and NGOs.
- UNICEF used digital platforms (U-Report) to engage affected communities.
- International aid provided relief supplies, medical care, and temporary shelters.

Critical Evaluation

- Response was swift but limited by poor infrastructure and lack of preparedness.
- Community engagement via digital tools was innovative but reached only part of the population.
- Long-term measures (reforestation, urban planning reforms) remain weak, leaving recurrence risks high.

Comparative Analysis

Event	Causes	Effects	Response	Effectiveness
Oso, USA (2014)	Heavy rainfall, weak glacial sediments, history of slides	43 deaths, $60M damage, homes destroyed	Federal aid, hazard mapping, stricter planning	Effective long-term reforms, but risk underestimated
Sierra Leone (2017)	Torrential rain, deforestation, poor urban planning	1,100+ deaths, 3,000 displaced, water contamination	Govt + UN rescue, UNICEF digital engagement, aid	Swift but limited; long-term prevention weak

Key Takeaway

- **Oso landslide** shows the importance of *scientific hazard mapping and proactive land-use planning*.
- **Sierra Leone mudslides** highlight how *deforestation and poor urban governance* amplify natural hazards.
- Both cases reveal that while emergency responses save lives, **long-term prevention and community awareness are critical** to reducing future risks.

Warning signs to mass wasting accidents

(i) **Steep slopes:** Slopes with high angles are more vulnerable because gravity exerts stronger downslope force.
(ii) **Weak or unconsolidated materials:** Loose soils, weathered rock, or volcanic ash are easily mobilized.
(iii) **Water saturation:** Areas with heavy rainfall, poor drainage, or high groundwater levels are prone to slope failure.
(iv) **Sparse vegetation:** Lack of plant roots reduces soil cohesion, common in deforested or arid regions.
(v) **Evidence of past landslides:** Scarps, hummocky terrain, or displaced blocks indicate previous slope failures.
(vi) **Seismic activity:** Earthquake-prone regions often experience landslides due to ground shaking.
(vii) **Human activity:** Road cuts, mining, terracing, and construction destabilize slopes.
(viii) **Displaced Infrastructure:** Tilted utility poles, sagging lines, cracked road pavements, or sticking doors and windows in nearby buildings are early warning signs of ground movement.
(ix) **Drainage Patterns:** Landscapes with high drainage density or locations near first- and second-order streams are prone to undercutting, which removes support from the base of the slope.
(x) **Using Modern Detection Technologies (2025) such as remote sensing and Satellite Radar.**

Measures to Control Mass Wasting

Mass wasting cannot be completely prevented because it is a natural geomorphic process, but its **impacts can be minimized** through engineering, environmental management, and planning. The goal is to stabilize slopes, reduce triggers, and protect human activities.

Engineering Measures

- **Retaining walls:** Built at slope bases to hold back soil and rock.
- **Terracing:** Converts steep slopes into stepped levels to reduce runoff and erosion.
- **Drainage control:** Channels, culverts, and pipes remove excess water that weakens slopes.
- **Rock bolts and netting:** Secure loose rock fragments on cliffs to prevent rockfalls.
- **Slope grading:** Reduces slope angle to lower gravitational stress.

Environmental & Biological Measures

- **Afforestation:** Planting trees and vegetation to bind soil with roots.
- **Controlled grazing:** Prevents overgrazing that exposes soil to erosion.

- **Revegetation projects:** Restores vegetation cover on disturbed slopes.

Planning & Policy Measures

- **Hazard mapping:** Identifies high-risk zones to restrict settlement and construction.
- **Land-use regulations:** Prevents building on unstable slopes.
- **Early warning systems:** Rainfall thresholds, sensors, and monitoring to alert communities.
- **Community awareness:** Education on slope risks and safe practices.

Thank You

Dr. Bbosa Science