MANAGEMENT OF NATURAL HAZARDS
IN MOUNTAIN BASINS

Introduction to geomorphology

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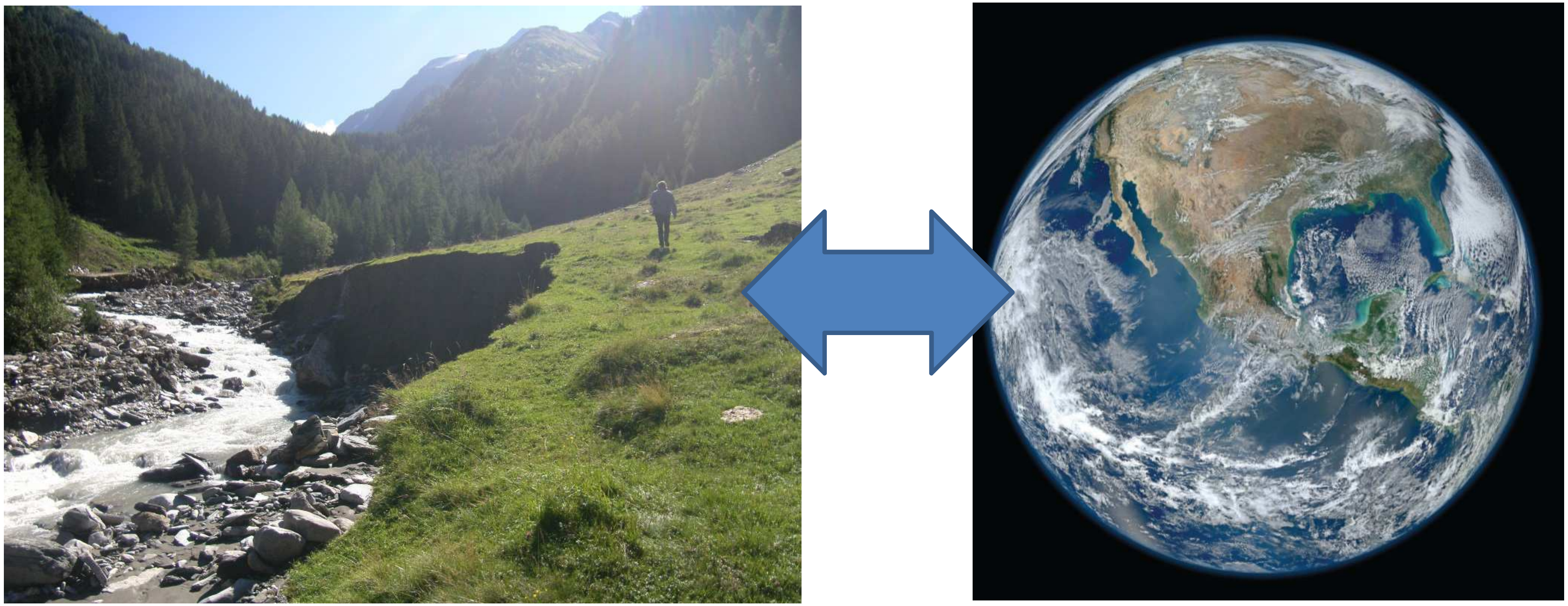
Credits to: P.R. Bierman, D.R. Montgomery (2014)
Key concept in Geomorphology. Freeman Pubs.

Definition of geomorphology

- Study of the processes shaping Earth’s surface and the landforms they produce, at all spatial scales



- Synthetic discipline drawing on geology, physics, hydrology, chemistry and biology

Relevance of geomorphology

- Geomorphology has fundamental societal relevance as humans live on Earth's surface !

  - ✓ Spatial distribution of soil types (arable lands)
  - ✓ Location, frequency and dynamics of floods and landslides (natural hazards)
  - ✓ Glaciers dynamics and their consequences (water resources, natural hazards)
  - ✓ Location and magnitude of coastal erosion (tourism activity, natural hazard)
  - ✓ Location and rates of upland erosion (agriculture)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Relevance of geomorphology

- Geomorphology is key for understanding all ecosystems on Earth, and thus for their restoration !

  - ✓ Spatial distribution of sediment type and size on hillslope, valleys, deserts
  - ✓ Slope, shape and stability of hillslopes
  - ✓ Spatial and temporal dynamics of river forms
  - ✓ Spatial and temporal dynamics of coastal forms

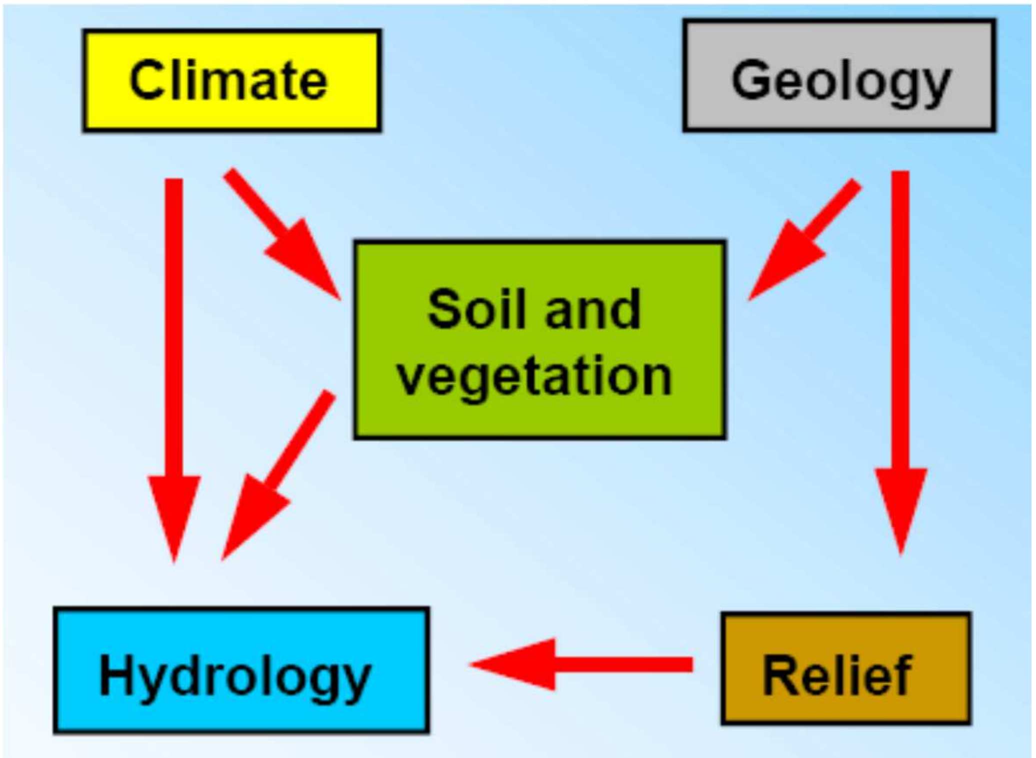



Nothing is stable !

Most people think of land, rivers and oceans as stable and unchanging…geomorphologists see landscapes constantly evolving !

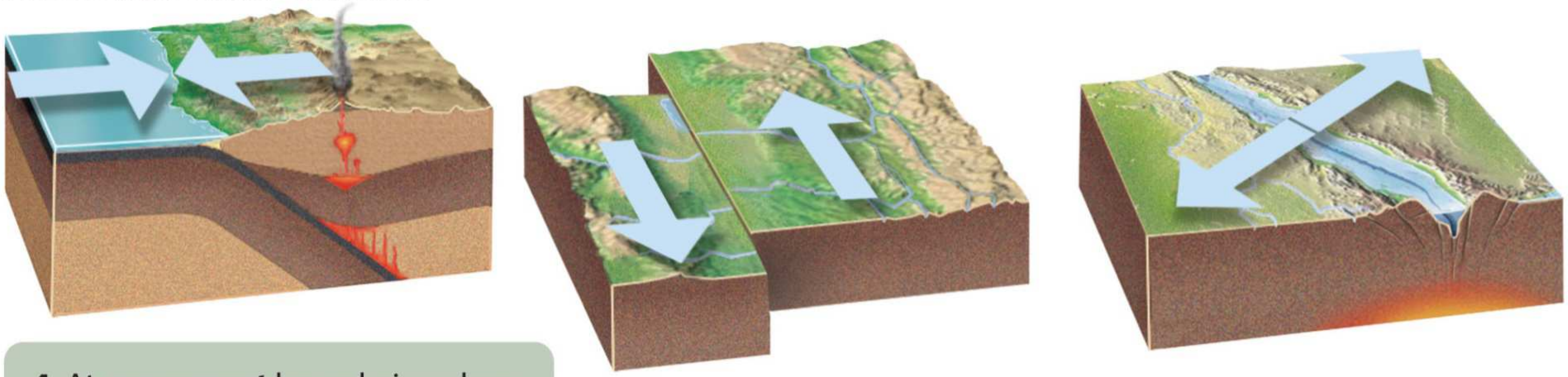
Causes of change:

- Endogenic (tectonics, volcanism)
- Exogenic (climate, biosphere)



Endogenic factors: tectonic forces

Terrestrial environments

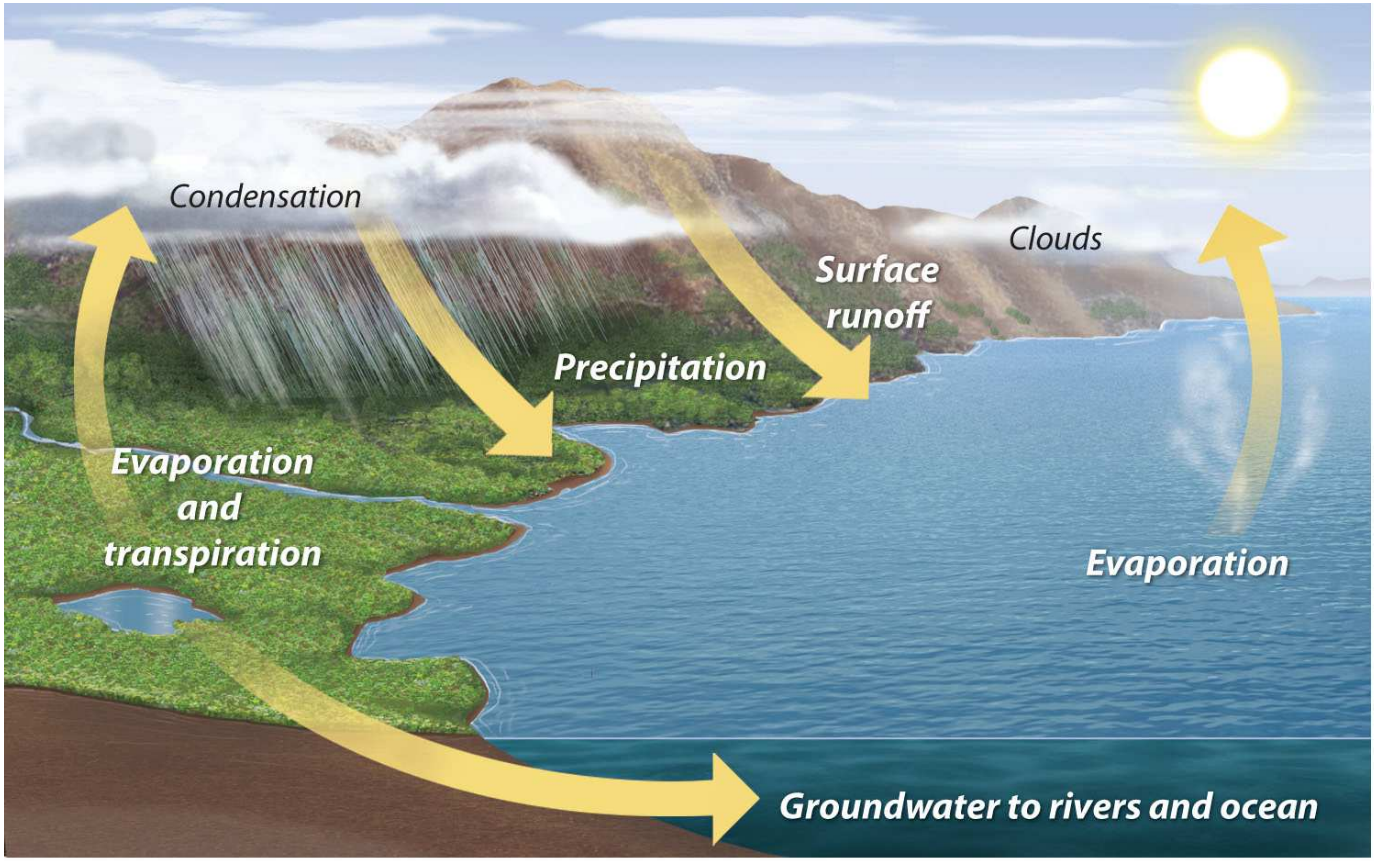


4. At **convergent** boundaries where oceanic plates subduct under continental plates, a chain of steep, explosive volcanoes forms inland of the boundary. An **accretionary wedge** of sediment scraped off the downgoing plate can form a coastal mountain belt. Continent–continent collisions result in less volcanism but greater uplift because buoyant continental crust does not subduct.

5. Transform plate boundaries generate both linear landscape elements related to the fault zone and the deformation of rocks along it as well as topography at bends along fault systems.

6. Continental divergent boundaries are areas where continental crust is moving apart and hot mantle material is moving toward the surface. Continental divergent boundaries have elevated rift shoulders bounded by steep normal fault planes. Alluvial fans form in the down-dropped basins and there can be basaltic volcanism.

Exogenic factors: the hydrological cycle



The **hydrologic cycle** drives many surface processes. Solar energy causes **evaporation** from lakes, rivers, wetlands, and the oceans as well as **transpiration** from plants. These processes move water vapor into the atmosphere where it condenses. Rainfall and snowmelt convert the **potential energy** of water vapor to the **kinetic energy** of raindrops and flowing water and do work, both as drops that impact the ground and as surface water runoff that collects and flows through channels. Groundwater, recharged by preciptation, weathers rock and destabilizes hillslopes.

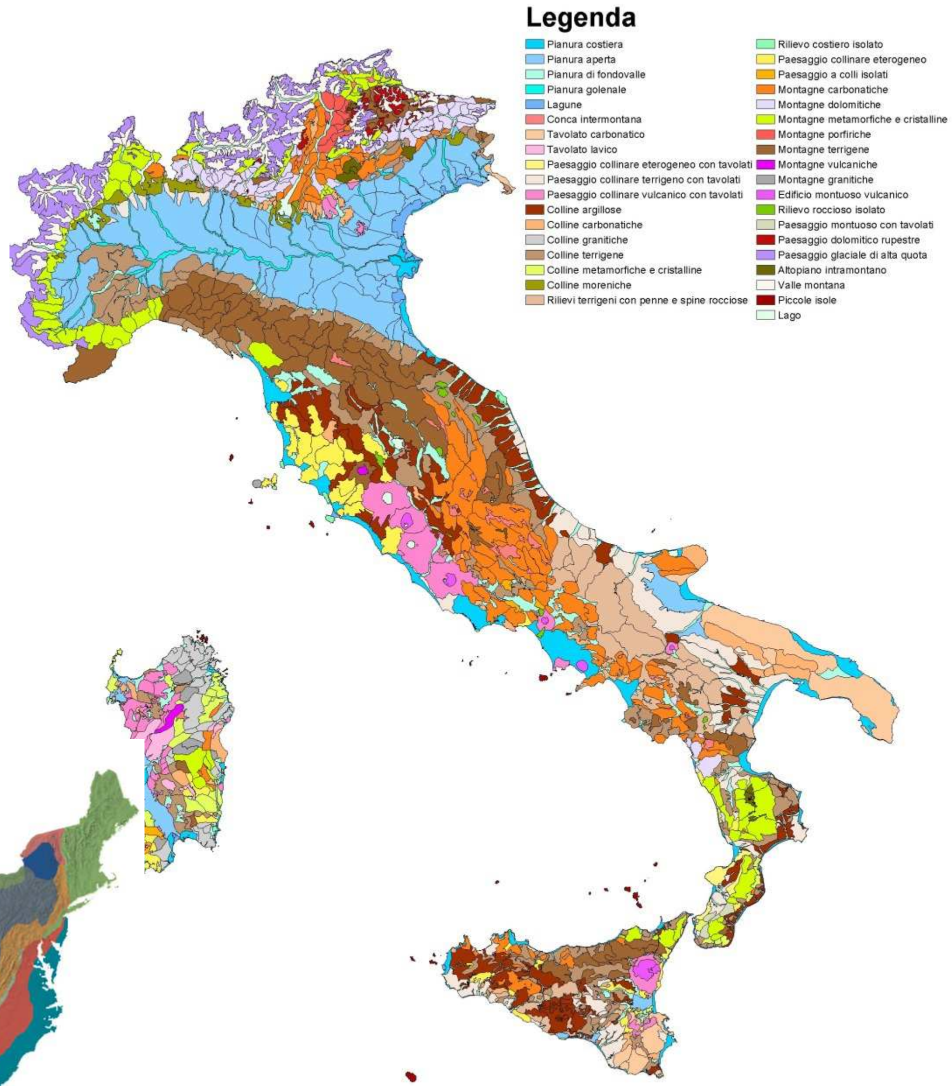
Landscapes

A geomorphological definition:

➢ Sets of landforms sharing common genesis, contiguous location, and related history

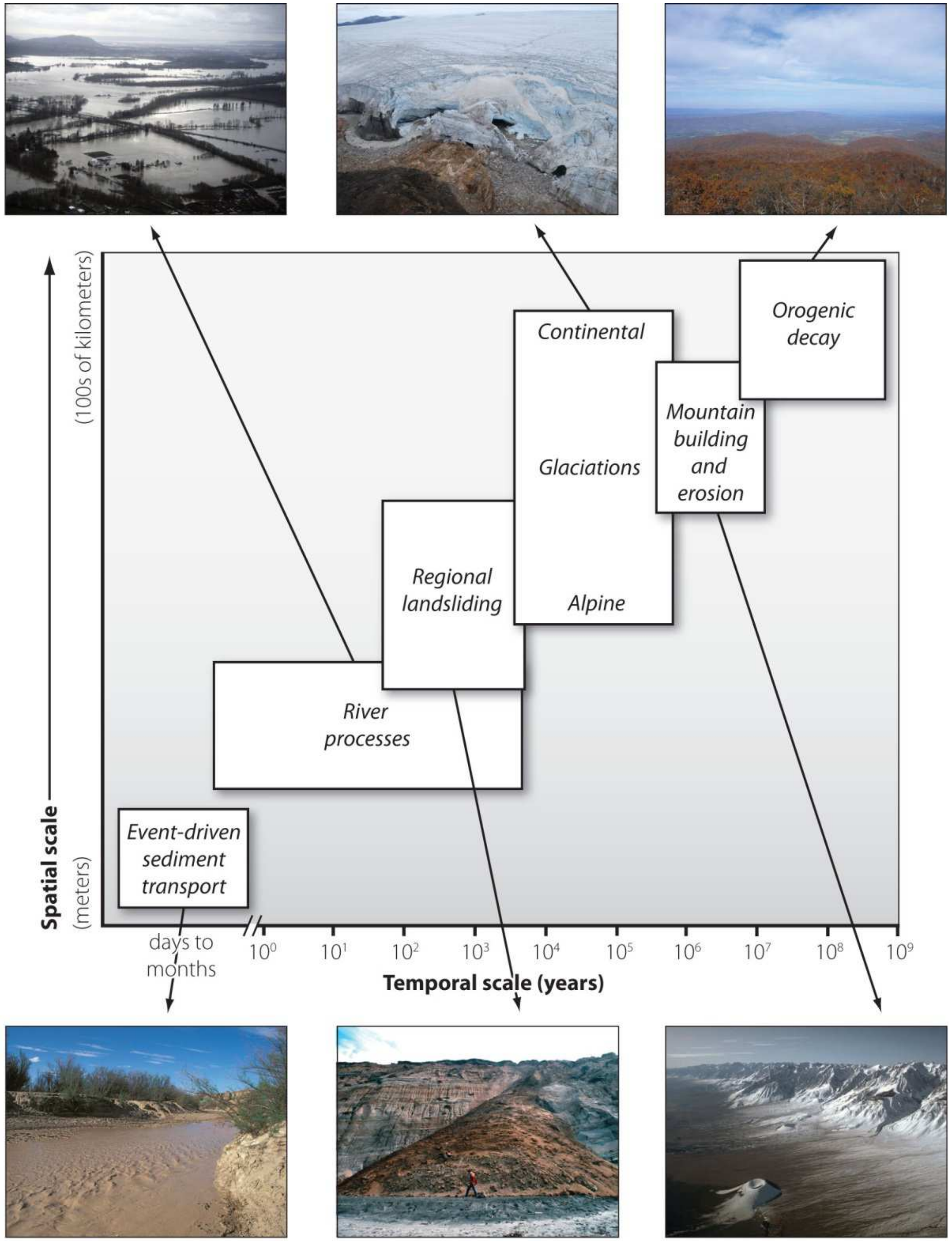
- Landscapes can be divided into different units (physiographic units), each featuring relevant spatial and temporal scales for their analysis

Example of landscape / physiographic units and provinces

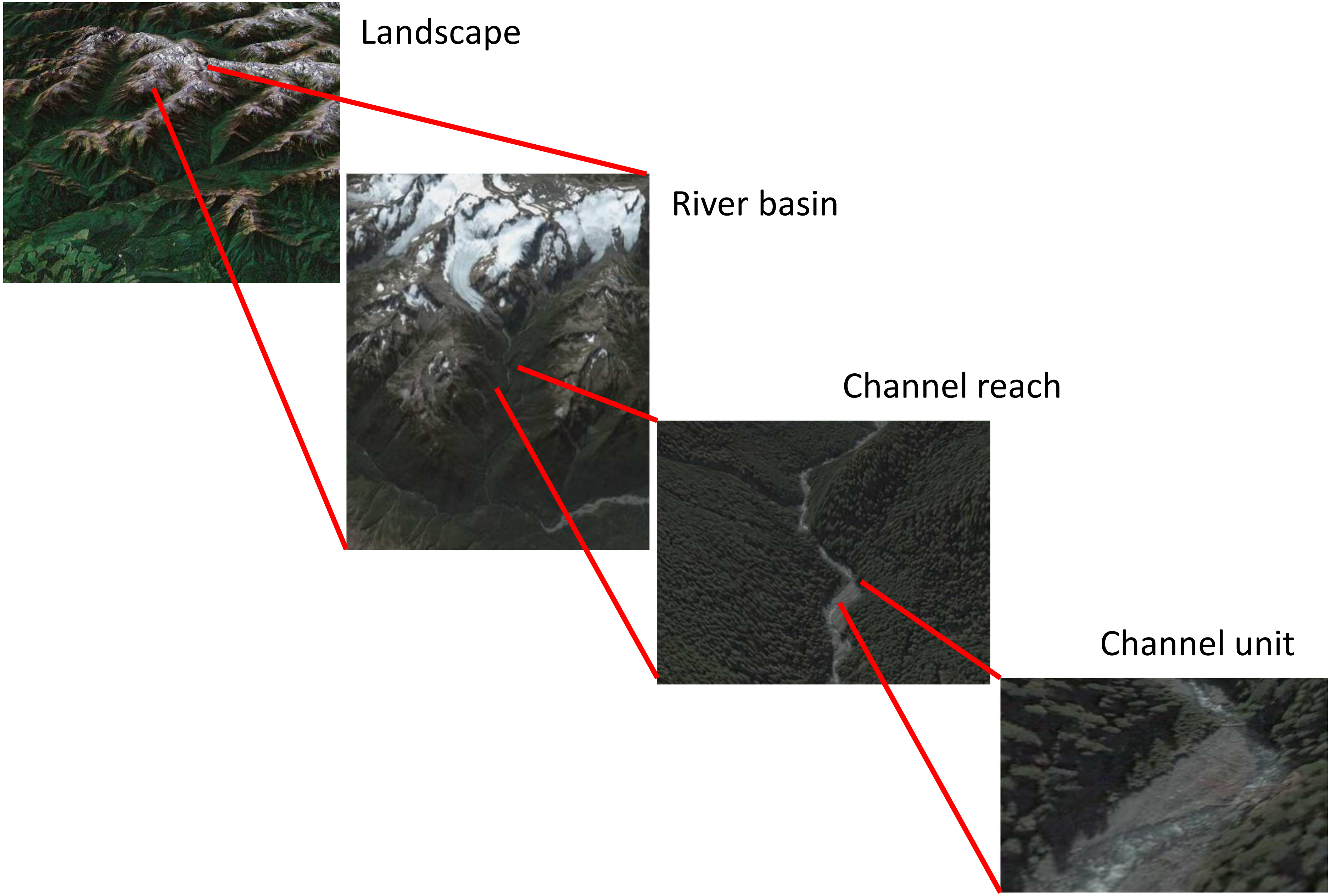


The United States can be divided into **physiographic provinces** that share similar landforms, similar landscape-forming processes, and in some cases, geomorphic history. For example, the **Coastal Plain** of the southeastern United States is generally a low-relief surface that is underlain in large part by marine or shoreline deposits.

Spatial and temporal scale in geomorphology



Spatial scales in fluvial morphology



The key spatial scale: river basins

The **headwaters** of a **drainage basin** are a sediment source where weathering breaks down rocks and erosional processes deliver sediment to streams and rivers.

Streams and rivers both transport and store material through the interchange of sediment in transport with that stored in **floodplains.**

Lowland floodplains and **estuaries** are long-term depositional areas where sediment inputs may exceed sediment outputs.

Sediment making it through lowland and estuarine areas to the coast is exported to the marine environment, which is a long-term sediment sink.

Landscapes: hillslopes, floodplains and channels

Hillslopes → Gravity force dominant → Colluvial processes

Floodplain and channels → Hydraulic forces dominant → Alluvial (fluvial) processes

Colluvial processes

• Driven by gravity, but helped by water (saturation). Also called mass movements

• Favored by steep slopes, but also on milder gradients (soil creeping on clayey material)

• Topographic gradient controls the speed

• Landslides (rockfalls, shallow, deep seated)

With increasing water content:

↓

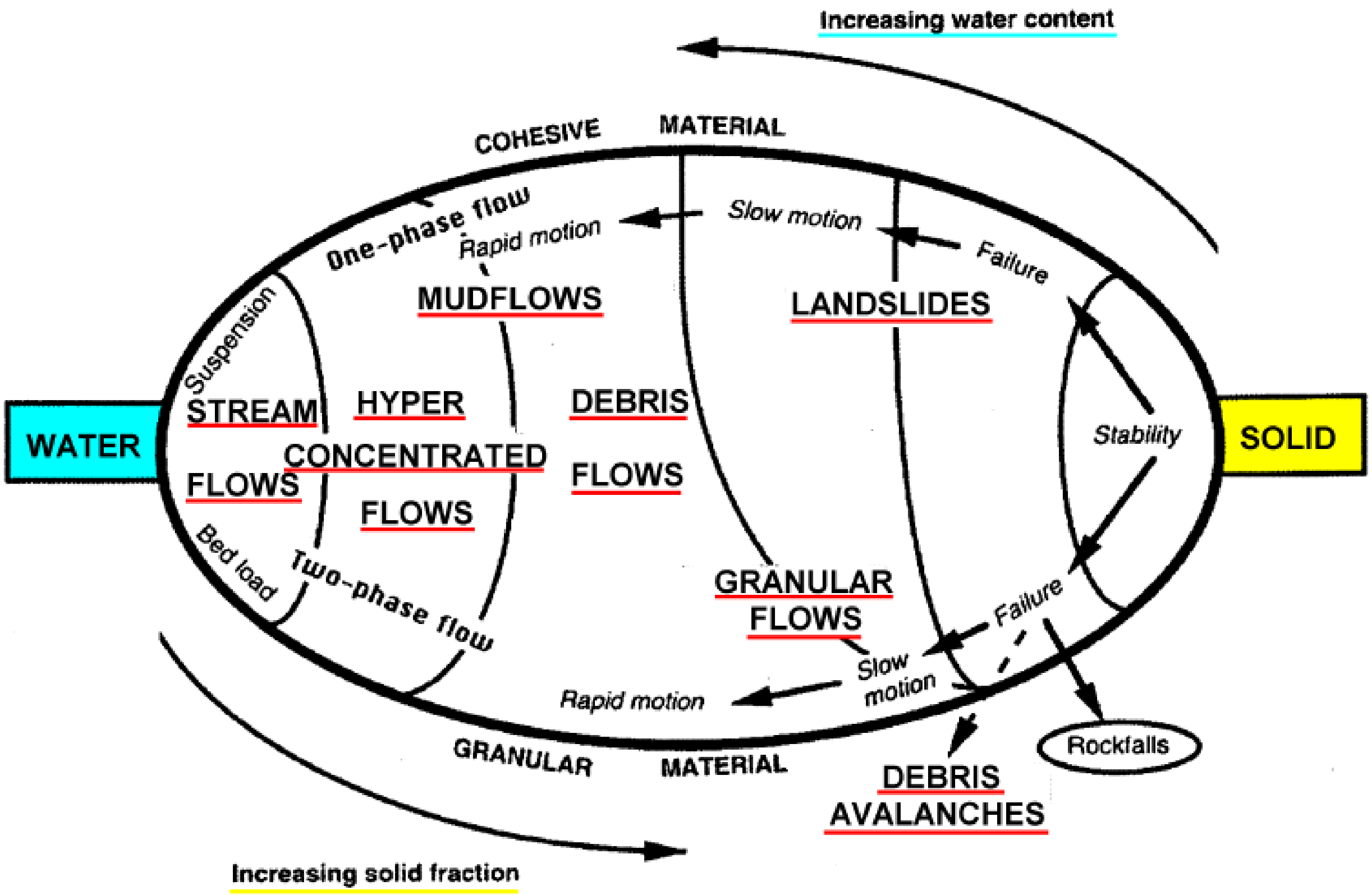
• Debris flows and mudflows

Alluvial processes

- Sediments are mobilized by forces due to flowing water
- Newtonian flow (linear stress – strain rheology)
- Sediment concentration depends on gradient (<5% but up to 10% in volume)

- Density about 1,000 kg m^{-3}
- Velocity <3-5 m s^{-1}

Sediment transport types on Earth's surface



Sediment transport types on Earth's surface

Source		10	20	30	40	50	60	70	80	90	100	
	Concentration Percent by Weight (100% by WT = 1,000,000 ppm)											
		23	40	52	63	72	80	87	93	97	100	
	Concentration Percent by Volume (S.G. = 2.65)											
Source		10	20	30	40	50	60	70	80	90	100	
Beverage and Culbertson (1964)	High	Extreme	Hyperconcentrated				Mud Flow					
Costa (1984)	Water Flood		Hyperconcentrated			Debris Flow						
O'Brien and Julien (1985) using National Research Council (1982)	Water Flood		Mud Flood		Mud Flow	Landslide						
Takahashi (1981)	Fluid Flow			Debris or Grain Flow				Fall, Landslide, Creep, Sturzstrom, Pyroclastic Flow				
Chinese Investigators (Fan and Dou, 1980)	Sediment Laden	<-------------- Hyperconcentrated Flow ---------->		<------ Debris or Mud Flow ------>								
Pierson & Costa (1984)	Normal:	STREAMFLOW Hyperconcentrated			SLURRY FLOW (Debris Torrent), Debris & Mud Flow, Solifluction			GRANULAR FLOW Sturzstrom, Debris Avalanche, Earthlow, Soil Creep				Fast Slow

Differences between alluvial and colluvial

- Alluvial processes are investigated through fluid mechanics concepts

- Colluvial processes are geotechnical problems

➢ Alluvial processes take place over a certain time span during a year

➢ Colluvial processes are almost instantaneous
(apart from slow creeping phenomena in plastic soils)

▪ Alluvial deposits feature sediment layers according to grain size (coarser particles are deposited before smaller ones)

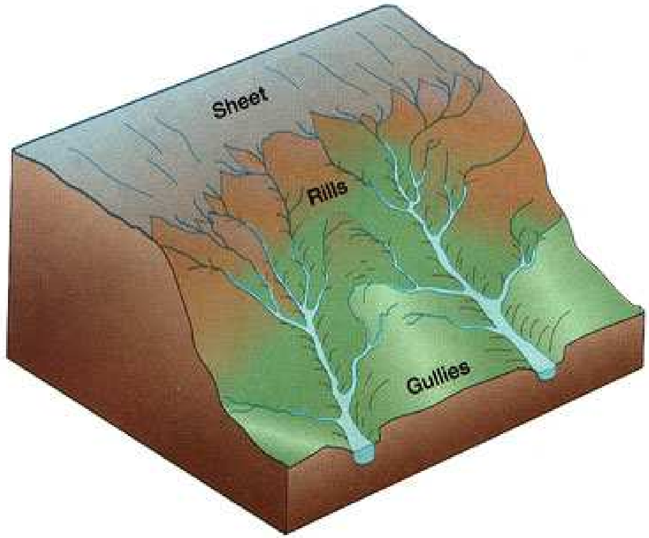
▪ Colluvial deposits are very heterogeneous (especially debris flows)
Coarser particles are often carried further down because of inertia

➡ **Both colluvial and alluvial processes can be either erosive and depositional**

Erosional processes

•Erosion: the displacement of rock/soil particles by flows (wind, water, ice), by gravity, or by living agents (bioerosion)

• Different from weathering (physical/chemical degradation of rocks)



Water erosion mechanisms:

Splash erosion: by raindrops

Sheet erosion: by surface runoff on hillslopes

Rill erosion: in ephemeral concentrated flow paths on hillslopes

Gully erosion: in ephemeral entrenched channels migrating upward for headcutting

Stream erosion: in perennial channels

Erosional forms

Landslide
crown

Gully

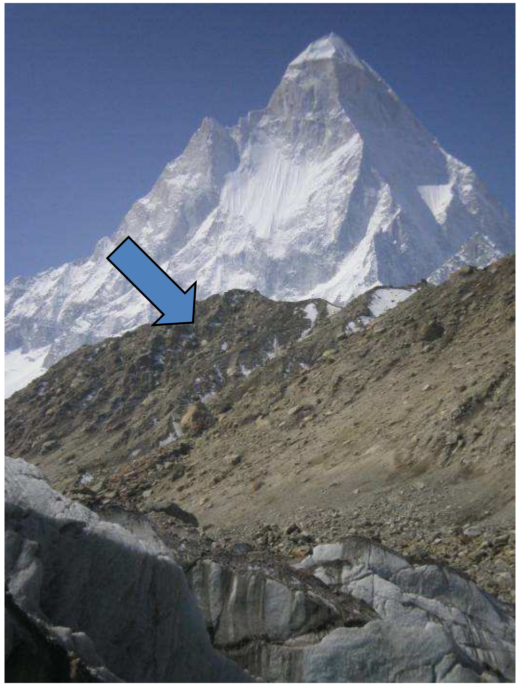
Rill

Stream

Depositional processes

•The settlement on a landform of transported sediments occuring when the kinetic energy reduces below a certain threshold

• Glaciers deposit moraine at their sides and front



• Colluvial (and moraine) deposits tend to be as steep as the angle of repose of the material (about 40° for gravel and rocks)

•Debris flow deposits (debris fans) are steeper than alluvial fan

• Alluvial deposits feature much lower slopes, down to flat surfaces

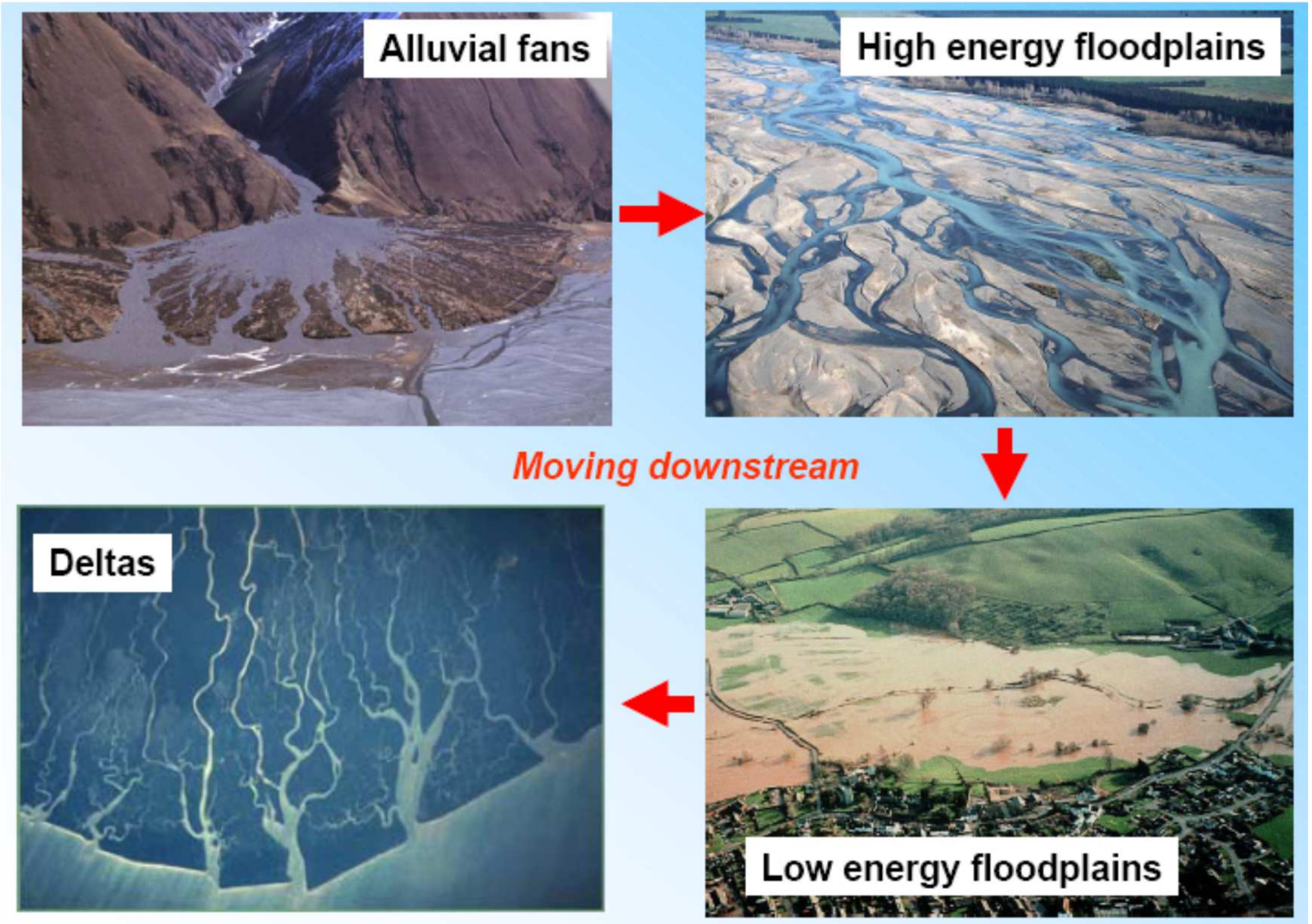
Depositional forms

- Colluvial deposition

Talus slope
(gravity driven)

Depositional forms

- Fluvial deposition



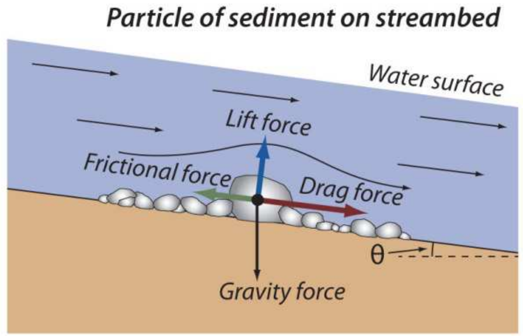
Main geomorphological concepts

- Conservation of mass → Input – Output = Δ Storage
- Conservation of energy → $E = E_{pot} + E_{kin}$
  $E_{t0} - E_{t1} = \Delta E$
- Force balance → $\frac{\text{Driving forces}}{\text{Resisting forces}}$
- Dynamic equilibrium and steady state
- Magnitude-frequency relationships

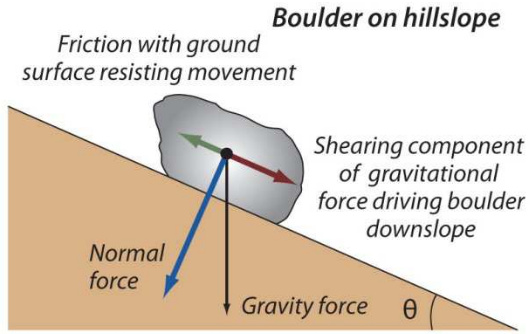
Main geomorphological concepts

- Force balance

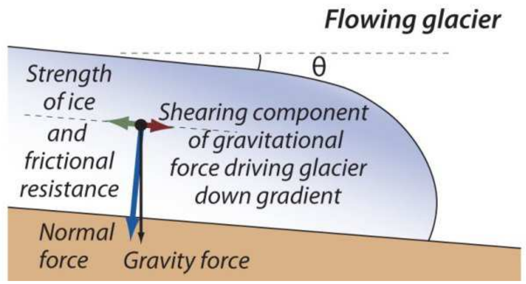
Many surface processes are driven by gravity. To calculate force balances and determine whether a landscape element will be stable, it is helpful to resolve the downslope force into the components resisting and driving movement, respectively oriented perpendicular to the slope (**normal force,** →) and parallel to the slope (**shearing force,** →).



Sediment on a stream bed is subject to a variety of forces. The **gravity force** holds the grain on the bed opposing the **lift force** generated by the current. The current also applies a **drag force** to the grain. The drag force is resisted both by **frictional forces** and by the resistance offered by neighboring grains if the clast is embedded. When the lift and drag forces exceed the forces of gravity and friction, the grain of sediment moves.



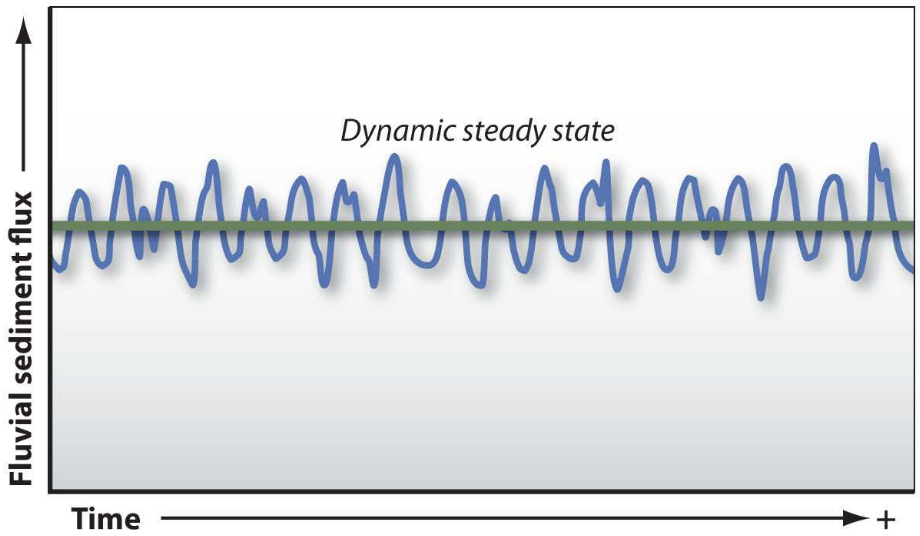
A boulder on a hillslope remains stable as long as the frictional force, holding the boulder in place, exceeds the **driving force,** in this case a **shearing force** parallel to the slope. Once the driving force exceeds the frictional force, down goes the boulder. Earthquakes, tectonic tilting, and slope undercutting can increase the driving force or reduce the normal force.



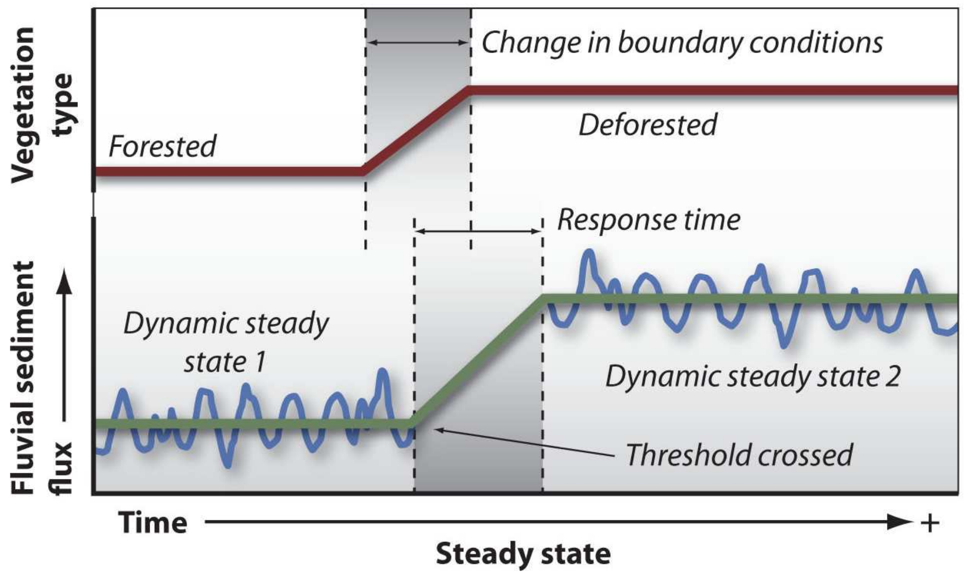
Glaciers flow by deforming and sliding along their bed. The driving force is the shear stress governed by the slope of the ice surface. The **resisting forces** include the strength of ice to resist internal deformation and the frictional resistance to sliding of material at the bed of the ice.

Main geomorphological concepts

- Dynamic equilibrium and steady state

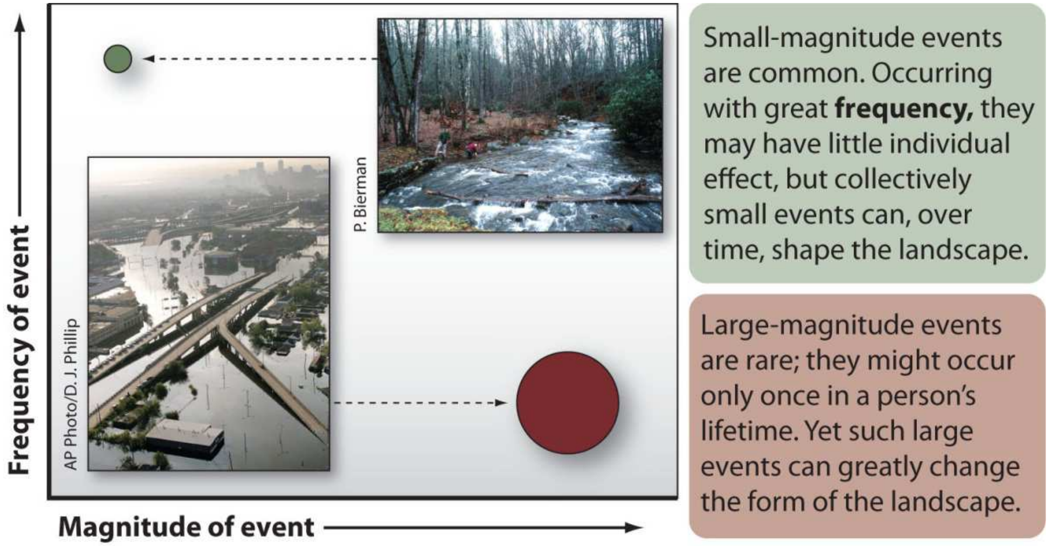


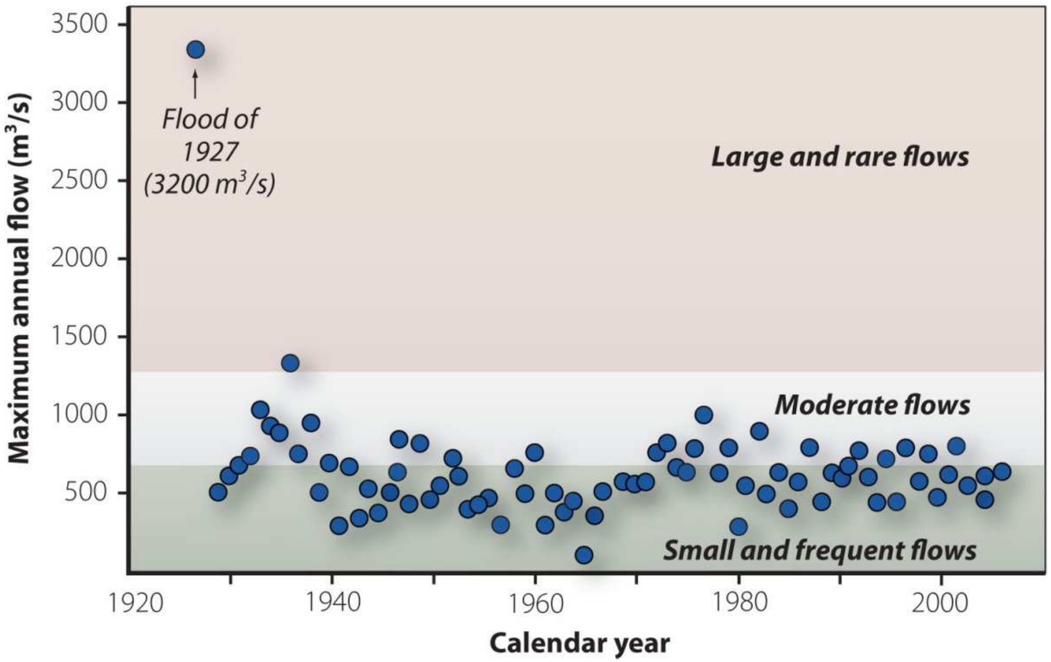
The flux of sediment from an undisturbed drainage basin changes over the short term as rainstorms come and go, individual hillslopes fail in mass movements, and riverbanks collapse. Over the long term, the flux of sediment from a drainage basin oscillates around a mean value, producing a **dynamic steady state,** unless there are significant changes in **boundary conditions,** such as climate, vegetation cover, or uplift rate.



When boundary conditions change significantly, geomorphic systems adjust. Such adjustment does not happen instantaneously, rather it lags the change in boundary conditions, over a **response time.** In this case, deforestation and land conversion to agriculture increased the fluvial sediment flux to a new and higher dynamic steady state because soils are now disturbed by plowing and thus more vulnerable to erosion.

Main geomorphological concepts





- Magnitude-frequency relationship