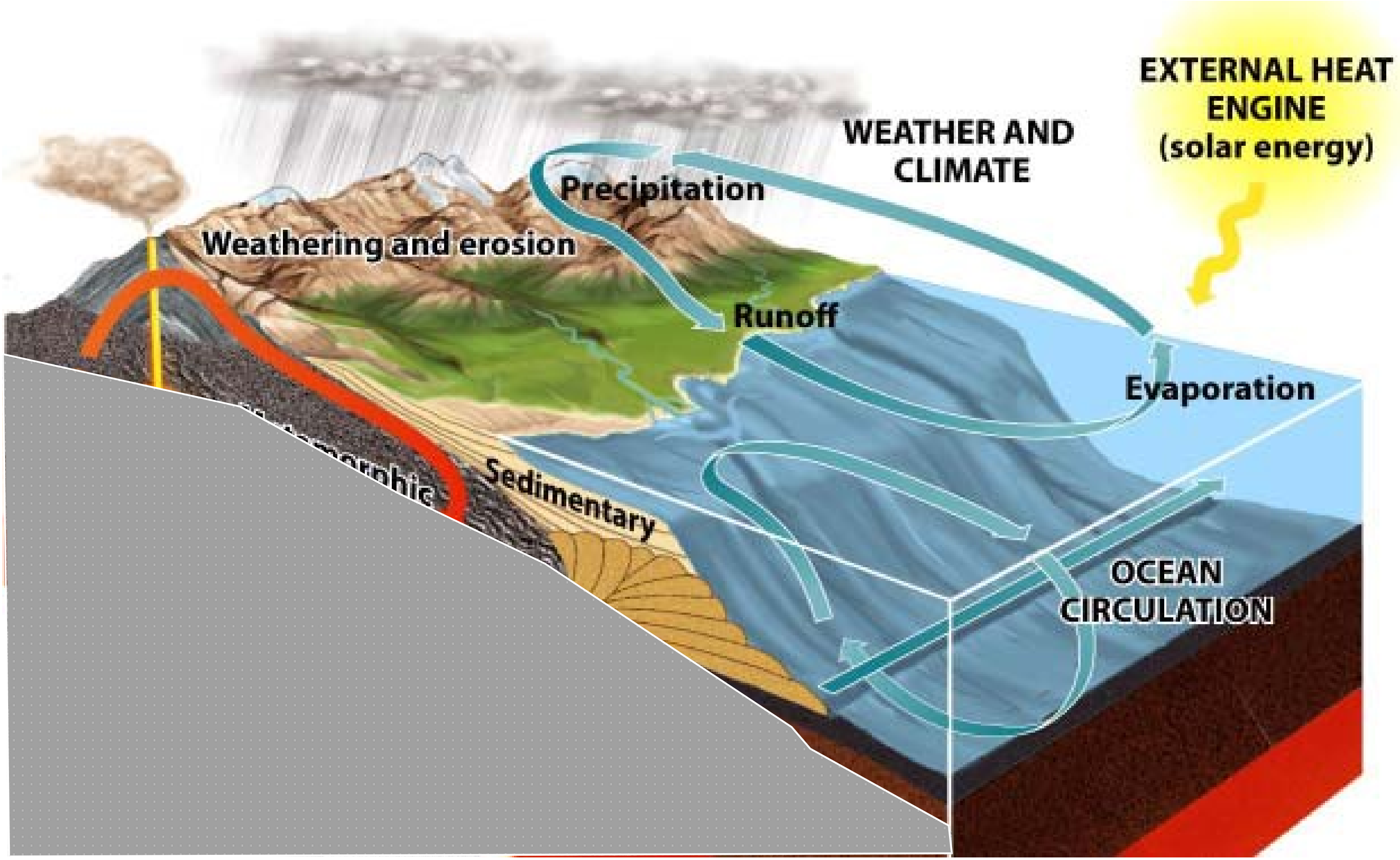
Water & Sediments

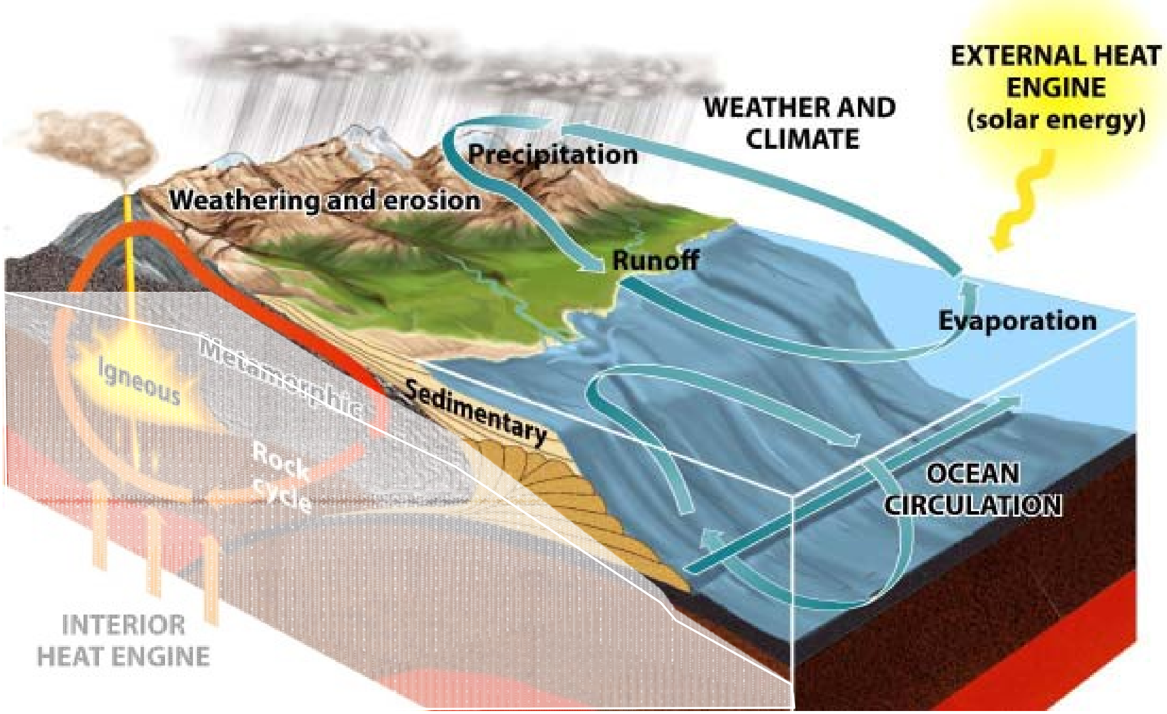
Geology 1

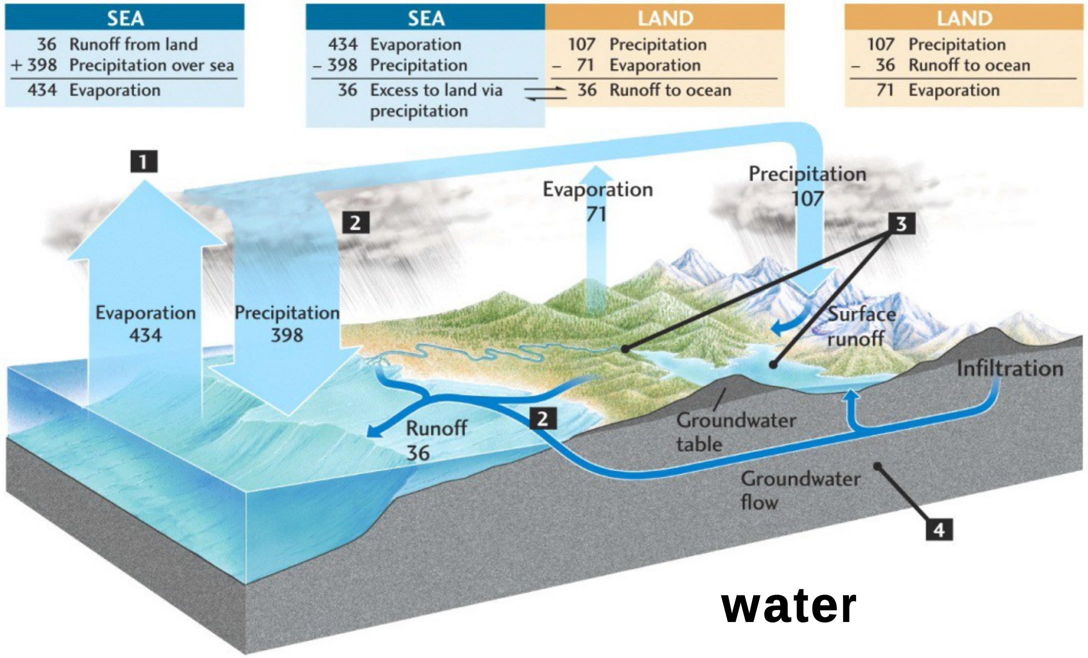
G. Bertotti



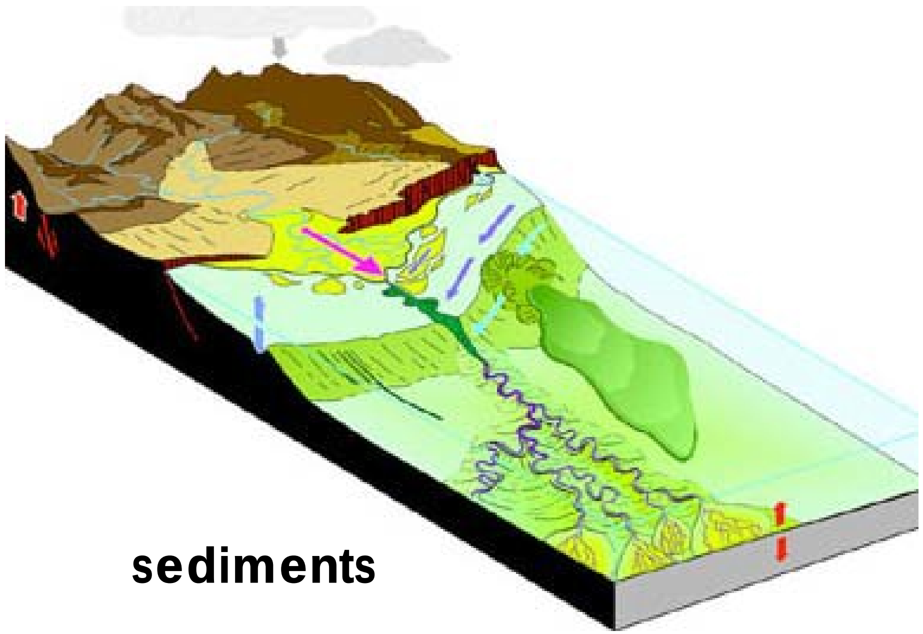
We have mountains, valleys, plains and deep seas
We have water and wind
Let us start moving

We trace material (sediment) and water from source areas (high mountains) to the sea following a source-to-sink approach





water



sediments

1 The sources (mainly high-relief areas)

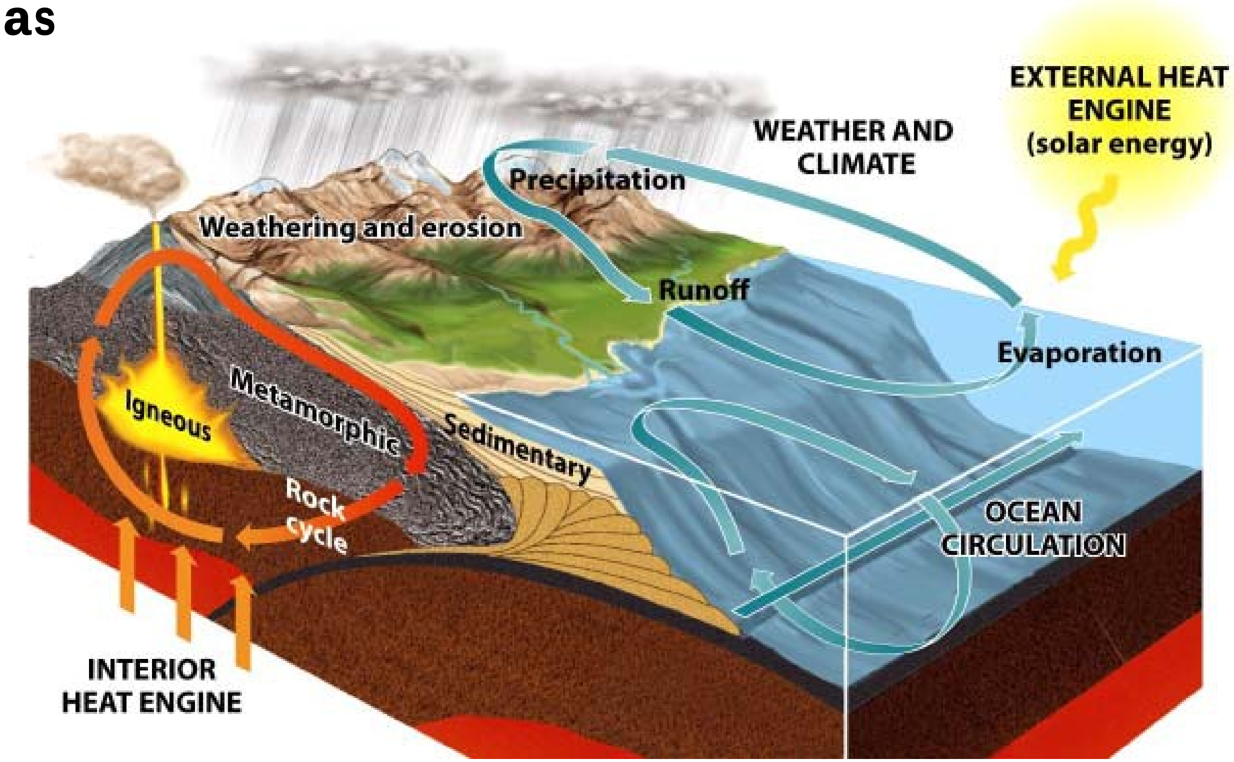
- **preparing the sediments (mechanical and chemical processes)**
- **their transport to the river floor, ready for export (mass wasting)**
- **the first organization of the river network**

2.The low-relief domains: transport and temporary storage

- **export out of the high relief areas (rivers with the large fans, glaciers..)**
- **rivers in low-relief areas**
- **lakes**
- **eolian deposits**

3.The marine domain (where everything ends)

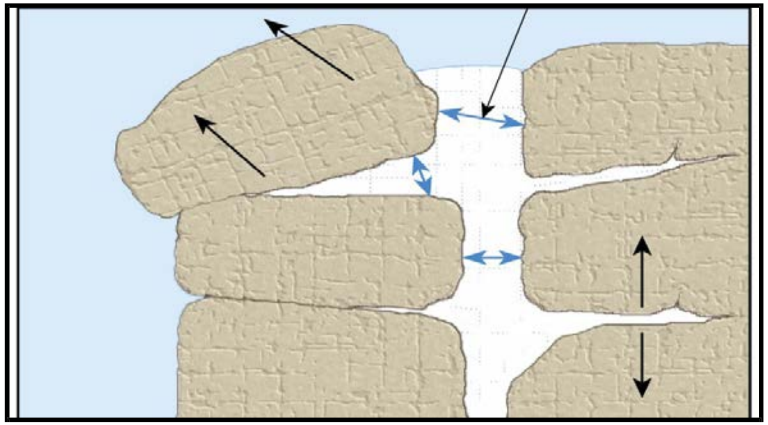
- **the coastal areas**
- **the continental shelf**
- **the abyssal plains**



The source area: mechanic processes

Thermal expansion and contraction: differential thermal expansion of minerals creates stress in rocks. Important in dry area

Frost widens pre-existing cracks and creates loose blocks

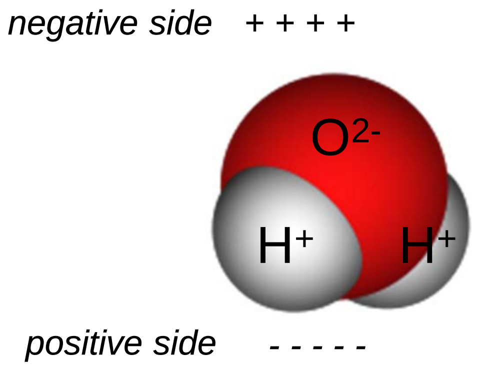


Biologic activity also helps

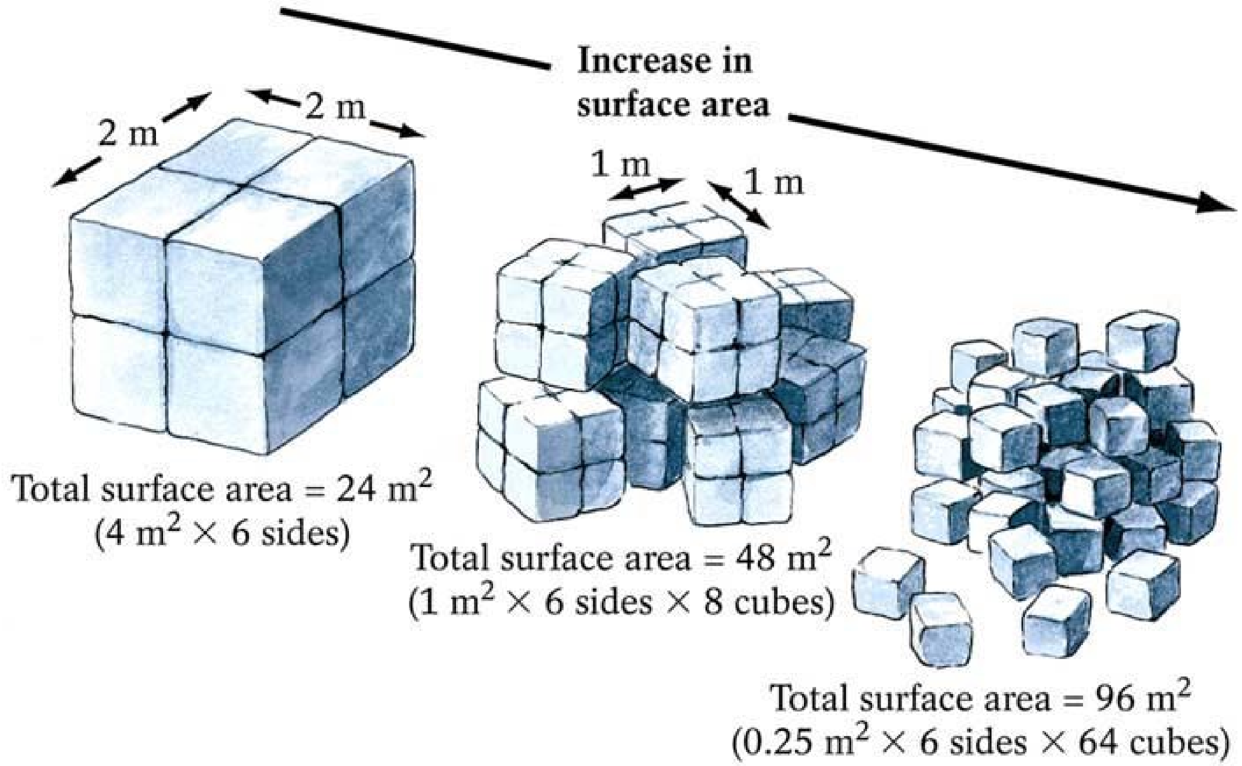
Tectonics is very good in fracturing rocks

The source areas: chemical weathering

- Occurs when minerals react with water
- Produce dissolved sediments: solutes which are used in different cycles and settings (cementation…)



Water. although neutral, the water molecule is polarized due to its molecular structure



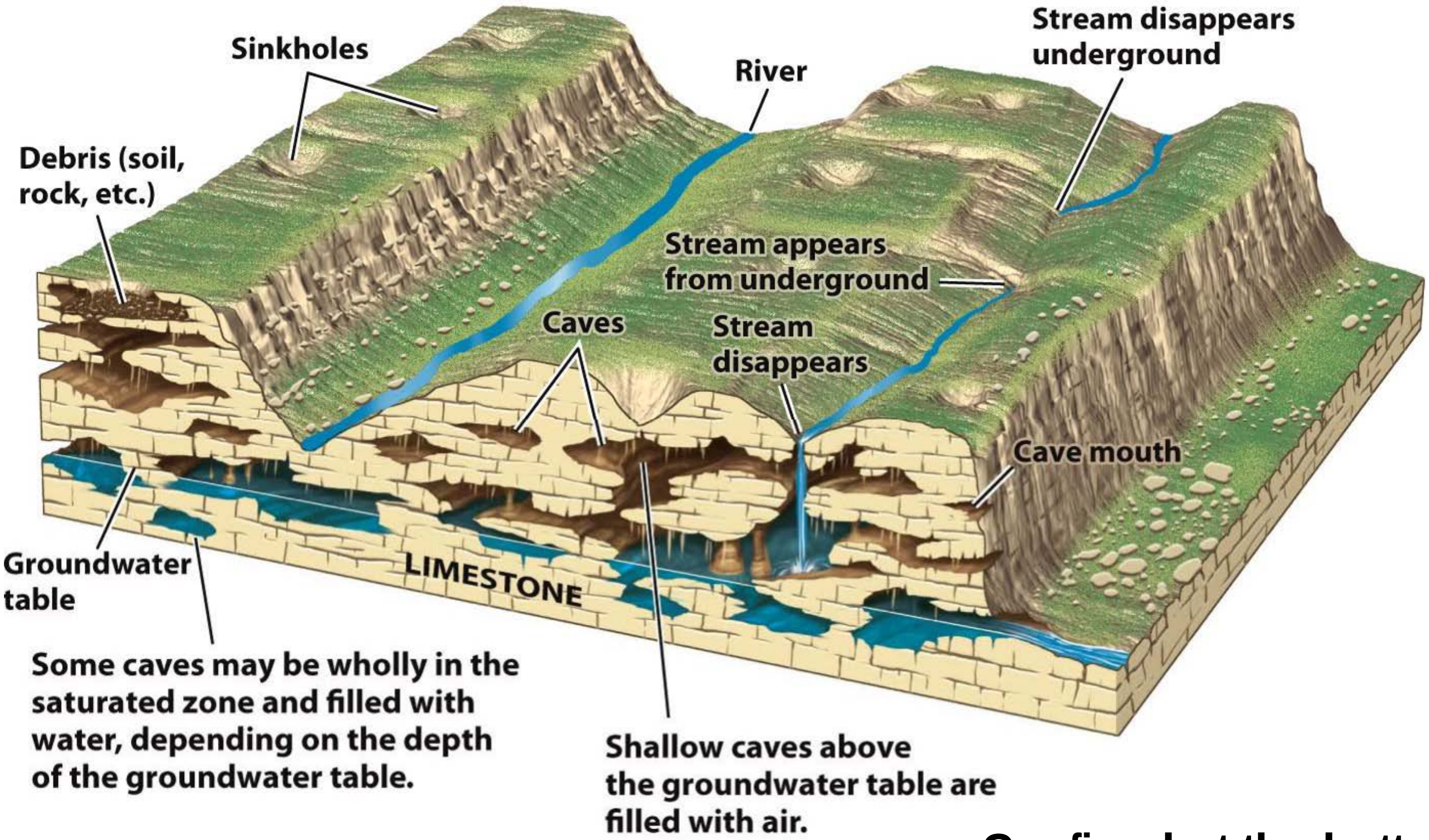
Works best if rocks are nicely fractured!!

Discussion organized around the fate of the main minerals

Some minerals are simply dissolved

Most common in limestones **($CaCO_3$ mineral) → calcium (Ca_2+) + CO_2**

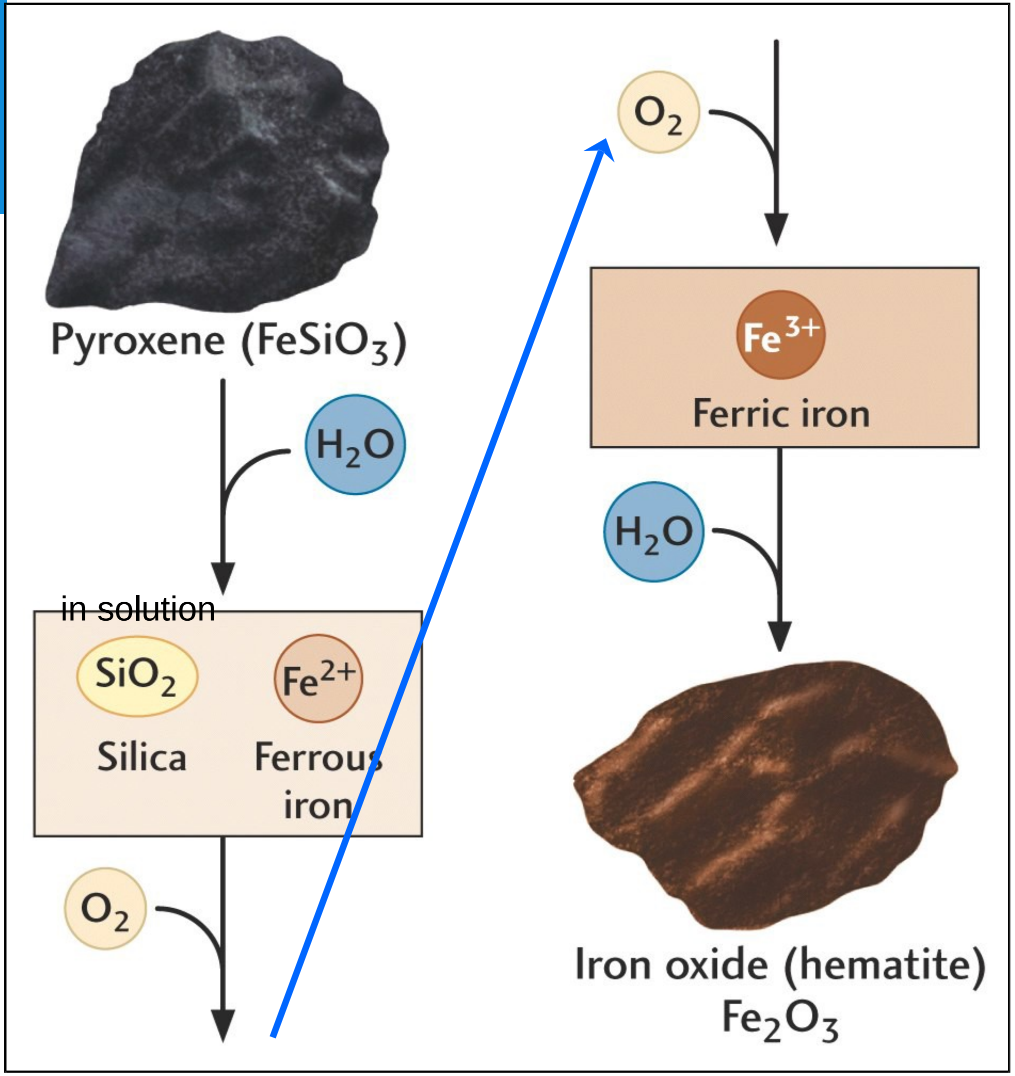
karstification



Confined at the bottom by the water table (can even be the sea)

Mineral rich in Fe are Oxidized

Most of the Fe extracted on Earth results from dissolution



1. With H_2O the silicate dissolves and Fe^{2+} is produced (the blue-green iron)
2. With substantial oxygen, Fe^{3+} forms which is very stable
3. Fe^{3+} is not as soluble and tends to precipitate out of solution as hematite

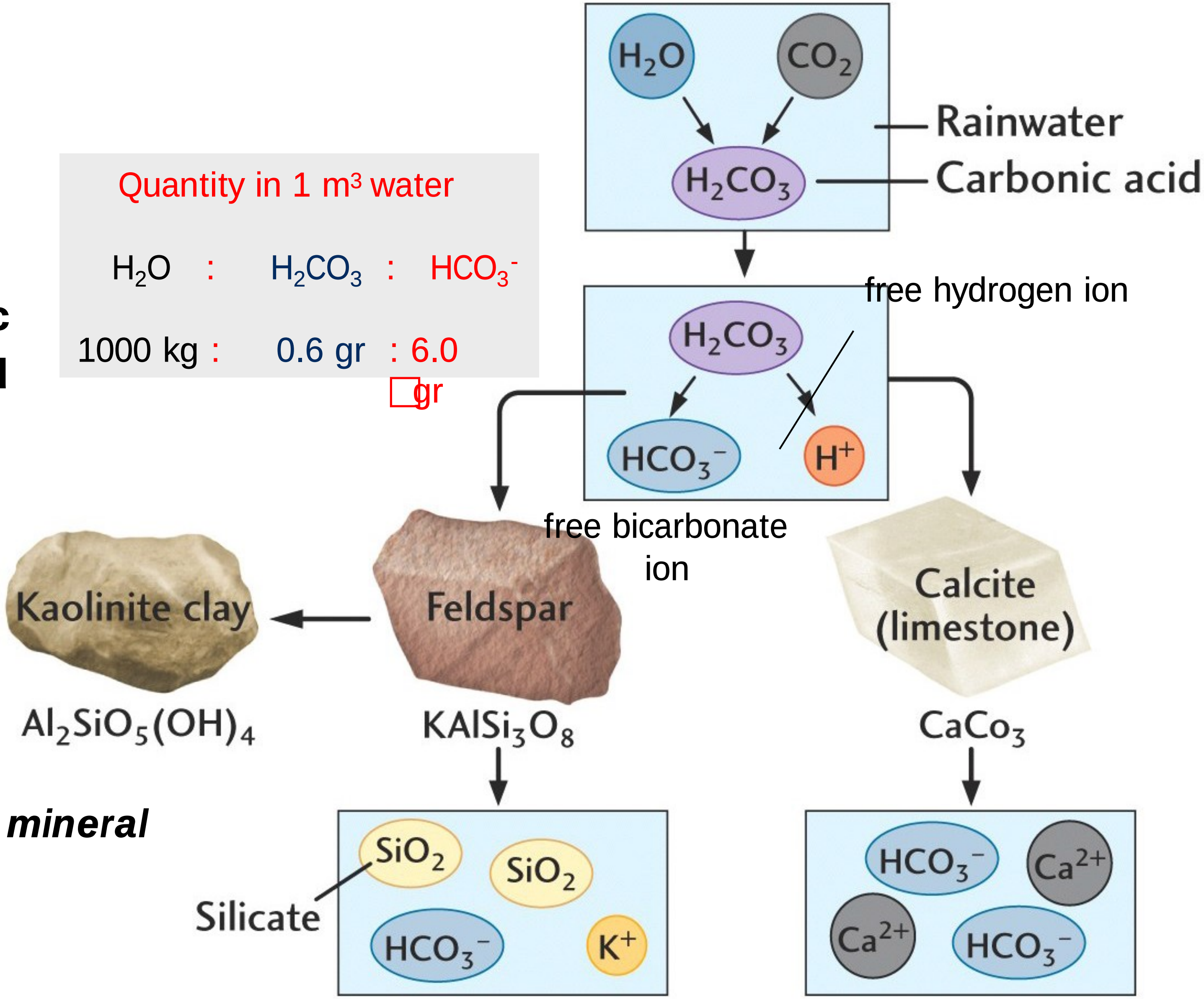
sand grains are coated with hematite

Processes affecting feldspars (very common on Earth) (hydrolisis)

- the dissolution reactions involve slightly **acidic water**
- CO_2 is the main source, others sulfuric and nitric acids (acid rain)

Quantity in 1 m³ water

H_2O	:	H_2CO_3	:	HCO_3^-
1000 kg	:	0.6 gr	:	6.0 gr

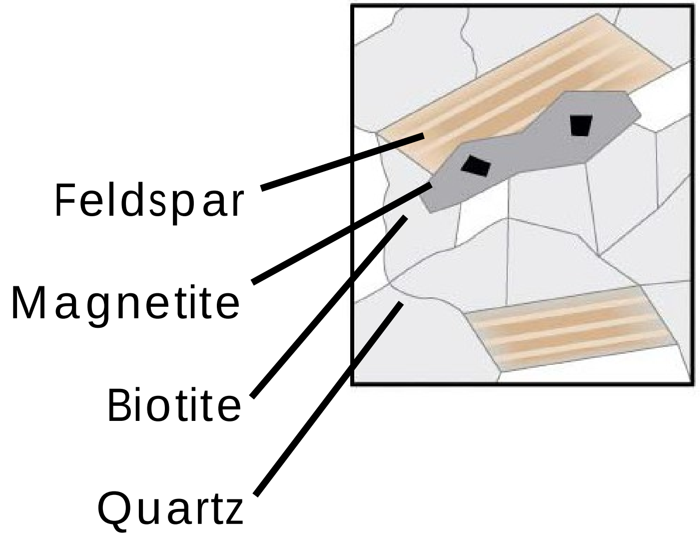


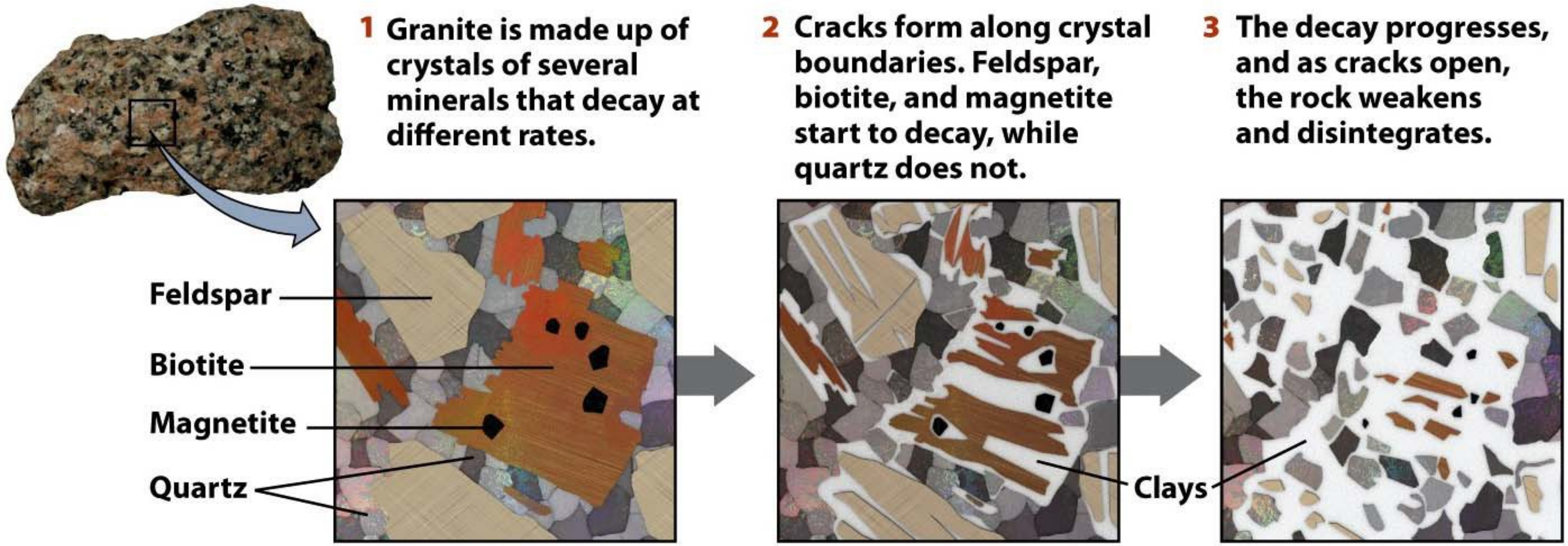
dissolved in water

$$2KAlSi_3O_8 + 2H_2CO_3 + H_20 \rightarrow Al_2Si_2O_5 + 4SiO_2 + 2K^+ + 2HCO_3^-$$

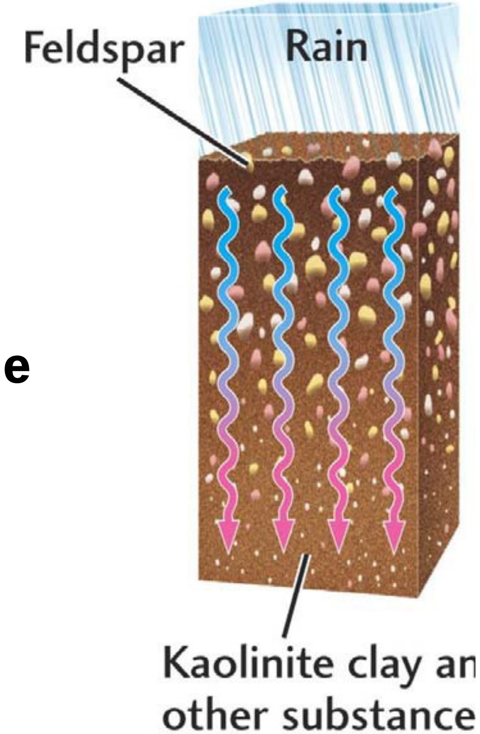
History of a granite
(several minerals that decay at different rates)

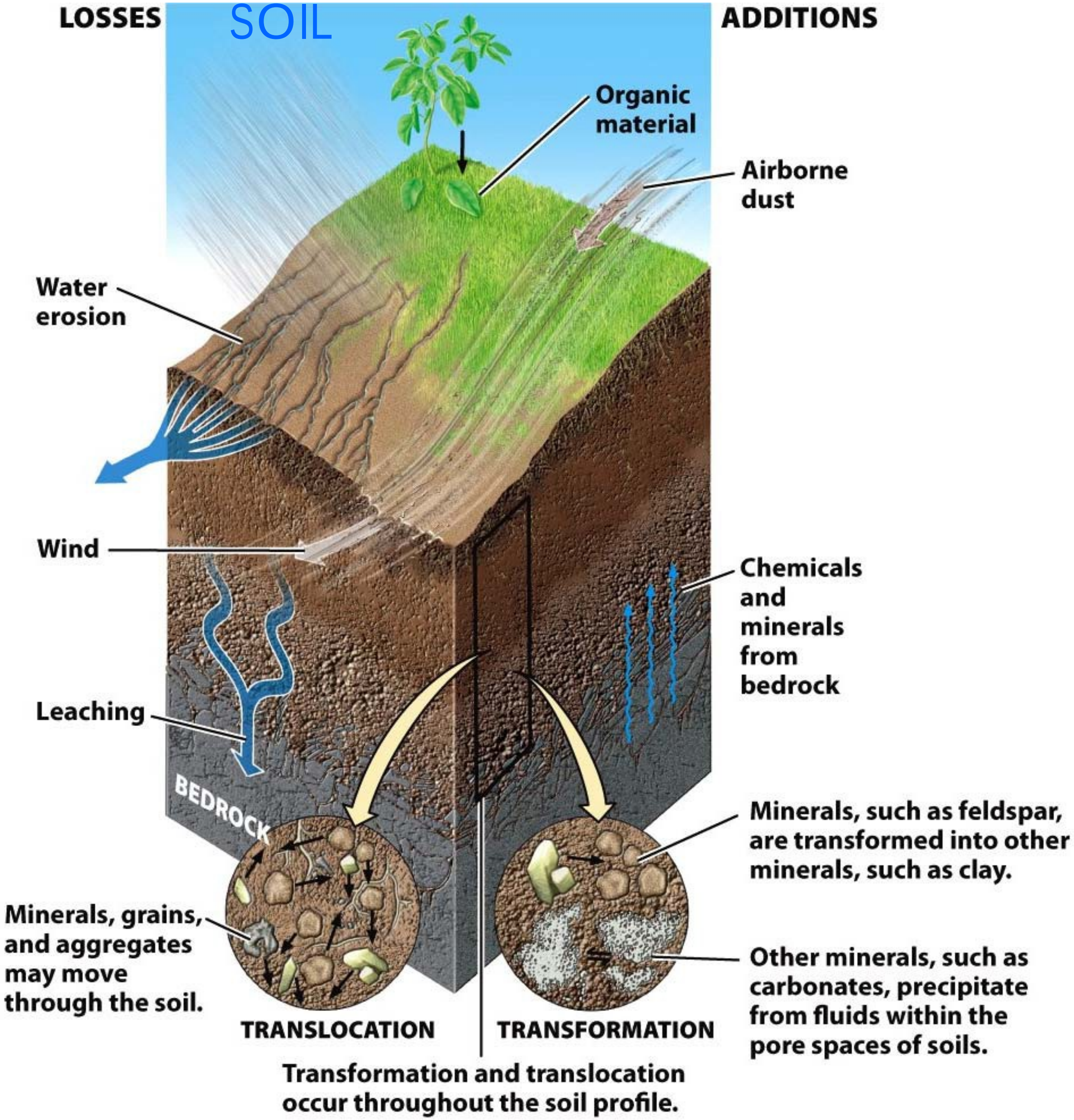
The decay progresses, and the rock weakens and disintegrates





Warm and wet conditions favour chemical weathering. A rich soil cover develops



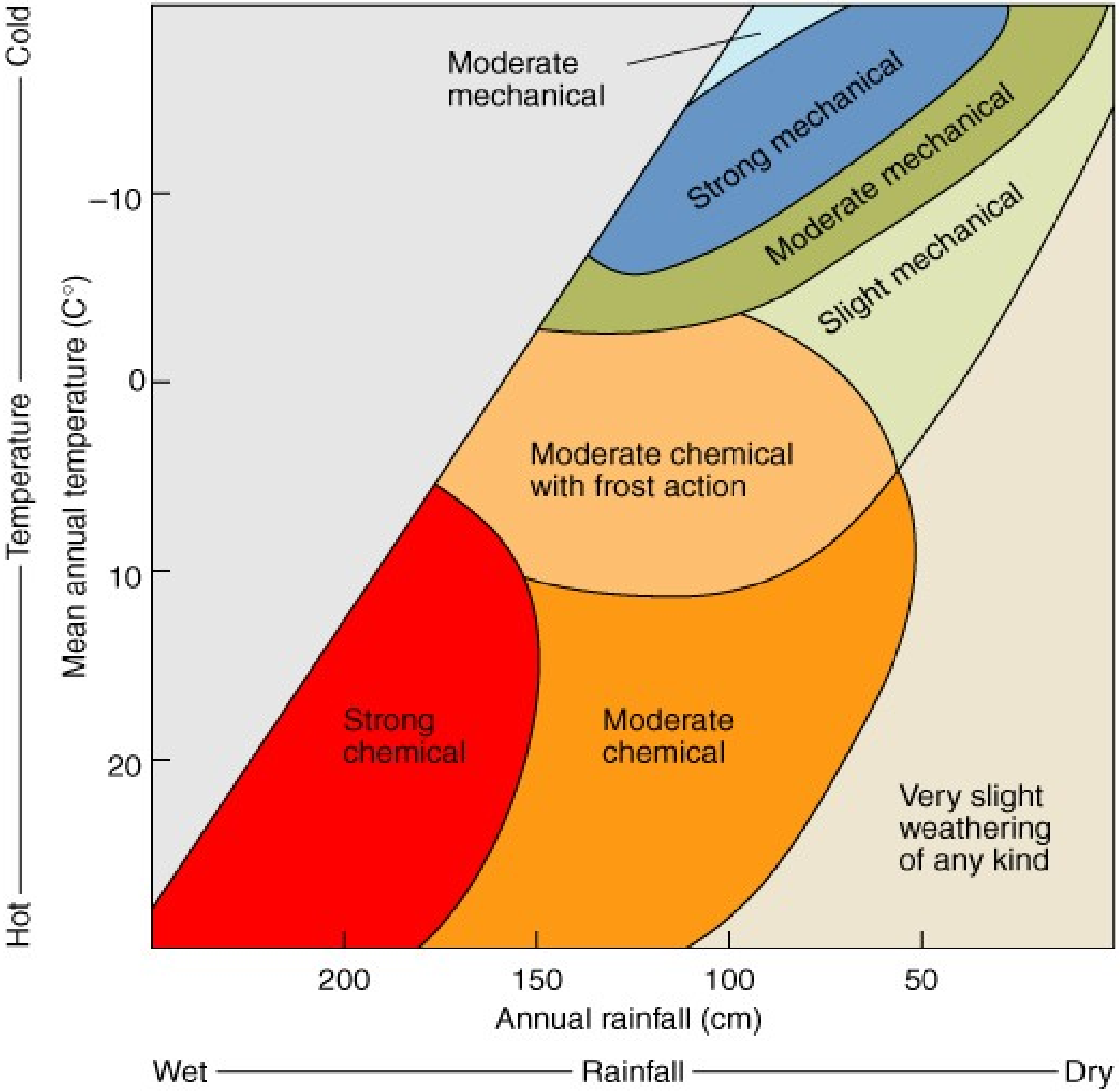


No physical processes removing the soil

rate of weathering depends on :

- **Temperature of the water**
- **How much water**
- **Percolation time**

Mechanical and chemical weathering



Mechanical and chemical weathering

WEATHERING FACTORS

1. Duration of weathering		Less weathering, erosion, and soil formation over short periods of time	More weathering, erosion, and soil formation over long periods of time
2. Bedrock type		More stable minerals, (e.g., quartz), result in lower weathering	Less stable minerals, (e.g., feldspar), result in higher weathering
3. Climate	Lower temperatures	Less chemical weathering (dissolution, alteration to aid physical weathering, production of clay materials)	More physical weathering (thermal expansion and contraction, frost wedging, breakage of bedrock, fragmentation to smaller sizes)
	Higher temperatures	Less physical weathering	More chemical weathering
	Rainfall amount	Little rainfall (less dissolution of minerals, physical weathering, fragmentation, erosion)	Heavy rainfall (more dissolution of minerals, production of clay materials, production of small size particles, erosion)
	Rainfall acidity	Low acidity (less dissolution of minerals, less physical weathering)	High acidity (more dissolution of minerals, more production of clay materials)
4. Topography	Steep slopes	Less chemical weathering	More physical weathering, more erosion
	Gentle slopes	Less physical weathering, less erosion	More chemical weathering

Figure 16-11
Understanding Earth, Fihh Edition

At the end of this we have

Relief areas

Precipitations (water or snow)
Incipient rivers with dissolved (natural) chemicals

A lot of material on the slopes

Movement can start

Rocks, sediments…

- **Gravity-driven (mass wasting)**
- **Driven by water etc**

waters

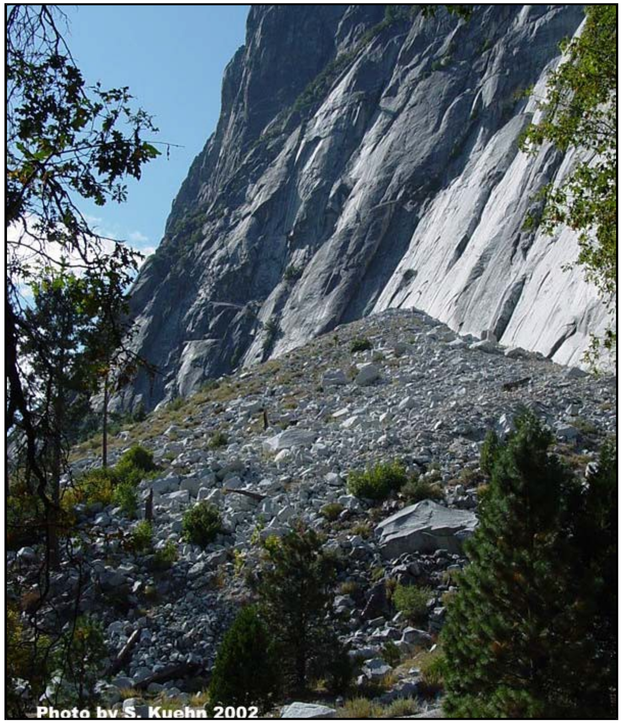
- **run-off**
- **infiltration**

Mass wasting

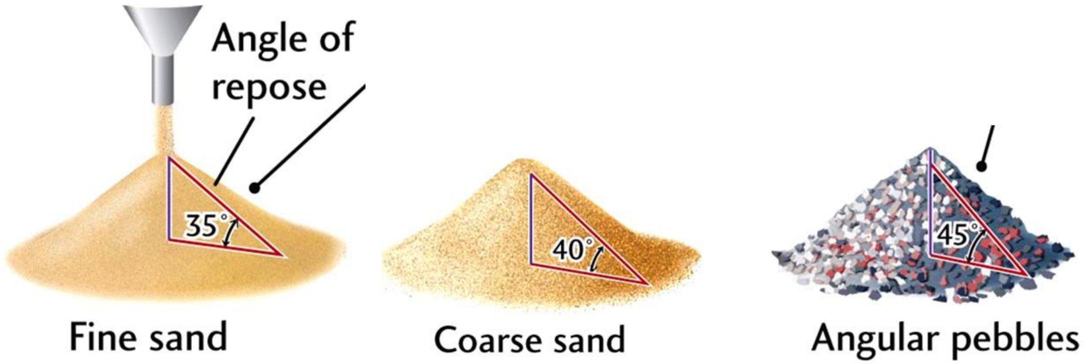
Sediment transport in high-relief areas: preparing for the export.

- ***Mass wasting*** **includes all processes by which masses of rock and soil move downslope driven by gravity**
- ***Mass movement*** **occurs when the force of gravity exceeds the strength of the material and it moves downslope**
- **Includes: Landslides, mudflows, rockfalls and debris (snow avalanches)**

Gravity-driven transport to the valley floor



Material falling forms a slope which increases until it reaches the angle of repose



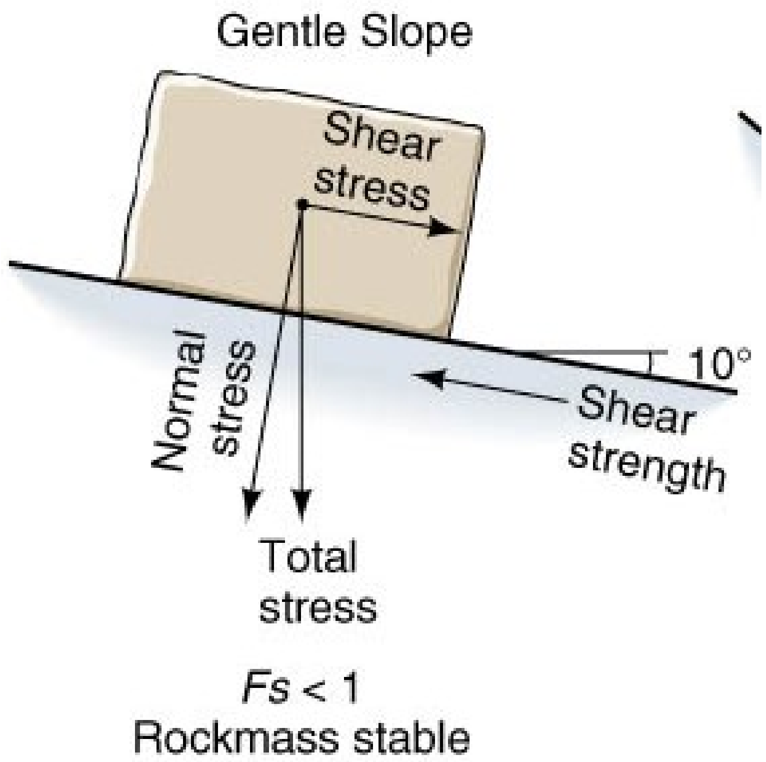
Depends on shape, type, size …of grains, on moisture content
And has large consequences, among others, for the stability of mountain falnks

Angles of repose

Nature of Slope Material	Water Content	Steepness of Slope
UNCONSOLIDATED		
Loose sand or sandy silt	Dry	Angle of repose
	Wet	
Unconsolidated mixture of sand,	Dry	Moderate
silt, soil, and rock fragments	Wet	Steep
	Dry	
	Wet	
CONSOLIDATED		
Rock,jointed and deformed	Dry or wet	Moderate to steep
Rock, massive	Dry or wet	Moderate
	Dry or wet	Steep

Mass movements: how does material move from the slope to the "valley" floor?

In principle everything is easy: rocks are stable unless the forces and parameters are changed



Factors which can cause a shift from stable to unstable

increase the weight of the potentially sliding mass

- **water**
- **vegetation**
- **...building and other human activities**

Favour sliding

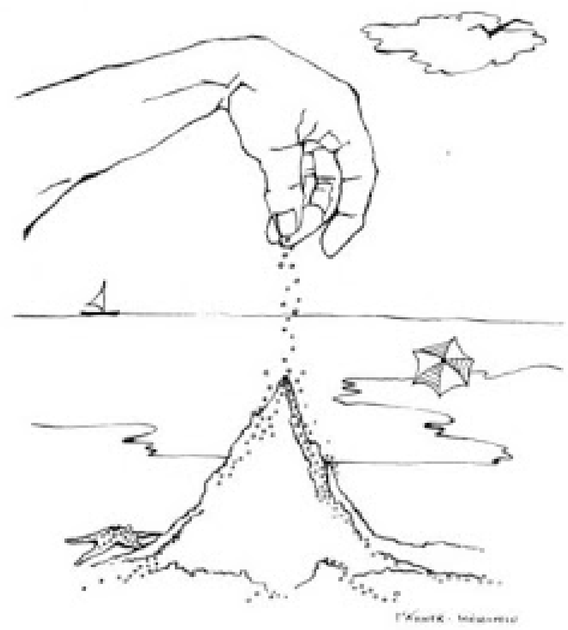
- **Water**
- **Increasing steepness**
- **Earthquakes**

impose short term accelerations (shake)

Depending on boundary conditions, different types of mass wasting can occur

In reality, things are, even in very simple situations, more complex

Letting sand grains fall on a flat surface will lead to the formation of a cone following deterministic (Newtonian) laws.



Once the cone is formed, things change and

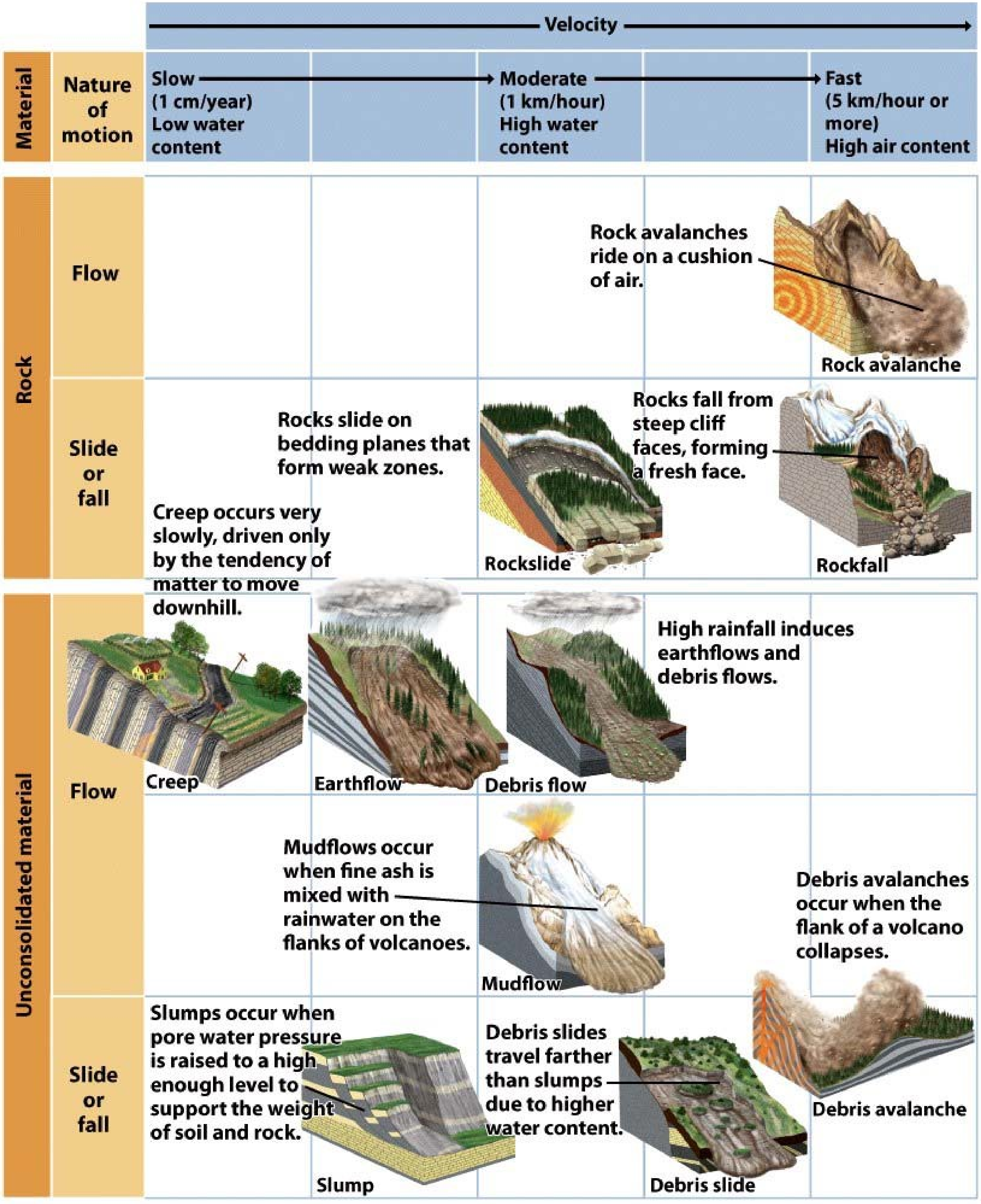
-The cone grows in a self-similar fashion (= preserves the angle of repose)

- it does this in an unpredictable manner as interactions between grains dominate

Depending on geology and geomechanics a lot of different types of mass wasting phenomena

1) Relatively sudden failure of a slope resulting in movement of relatively coherent mass of rock, or rock debris
2) The downward flow of mixtures of solid material and water and air (unconsolidated material)

different velocities and material concentration



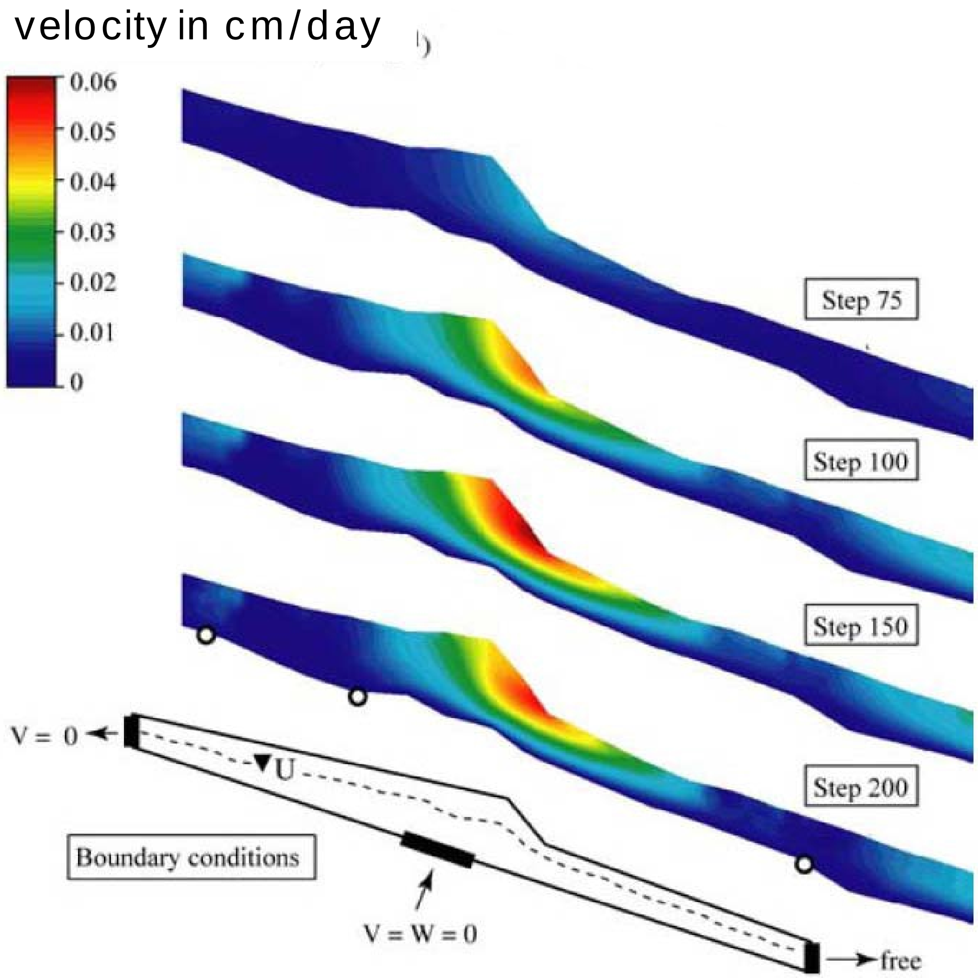
All this makes the prediction of landslide a very tricky business

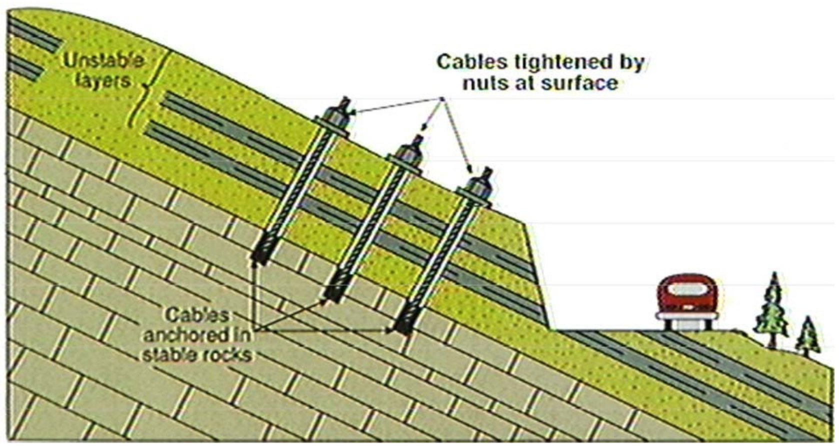
A good prediction gives information on
Timing
locality
magnitude

Preventing and predicting

A multi-step approach:

1) **Defining areas of potential danger (paleo-landslides, paleo avalanches ..geology!!)**
2) **Numerical models of scenarios**
3) **Engineering interventions**
4) **Installing a monitoring system**
5) **High alert in critical moments (heavy rains, earthquakes swarms…)**

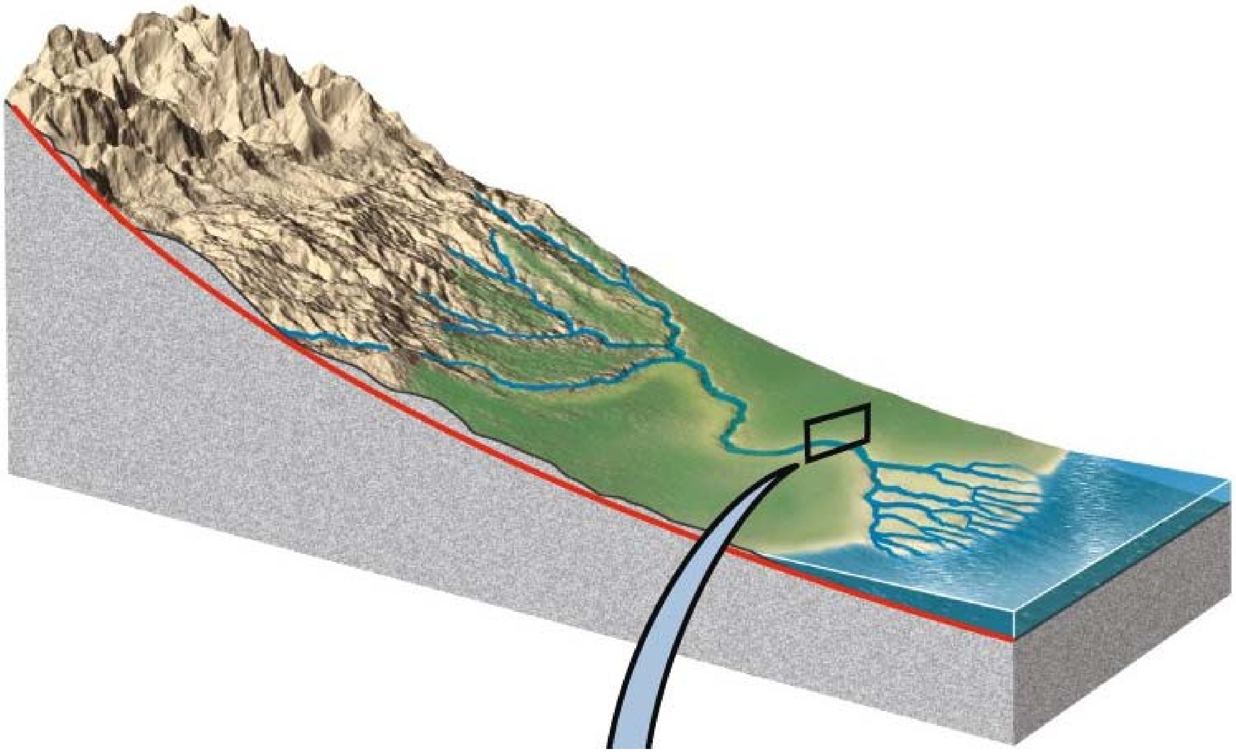




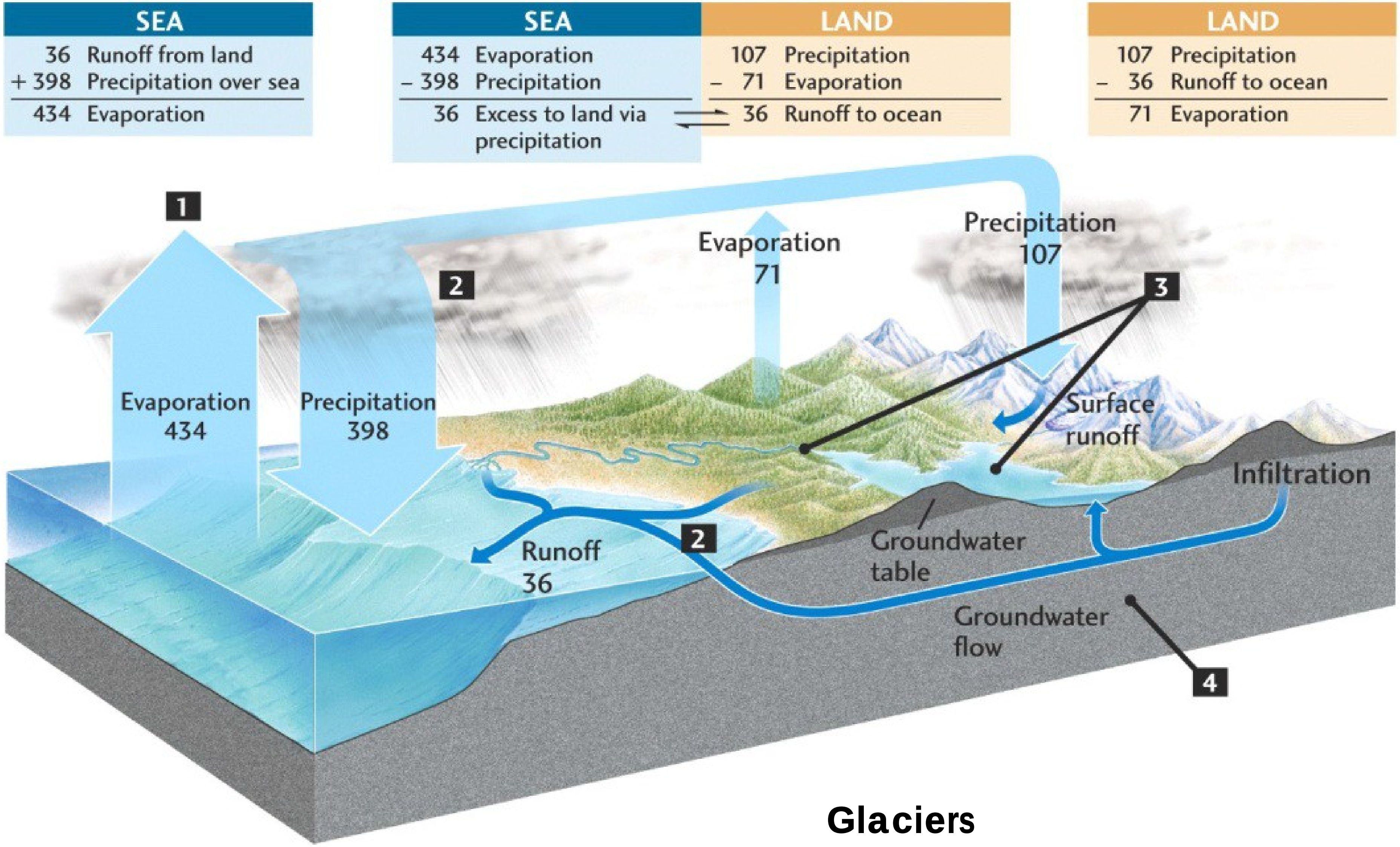
Stabilize potentially dangerous areas (a lot of $ needed)

The routing system: collecting sediments from the mountains (source) and delivering them to their final destination

Water is the main carrier

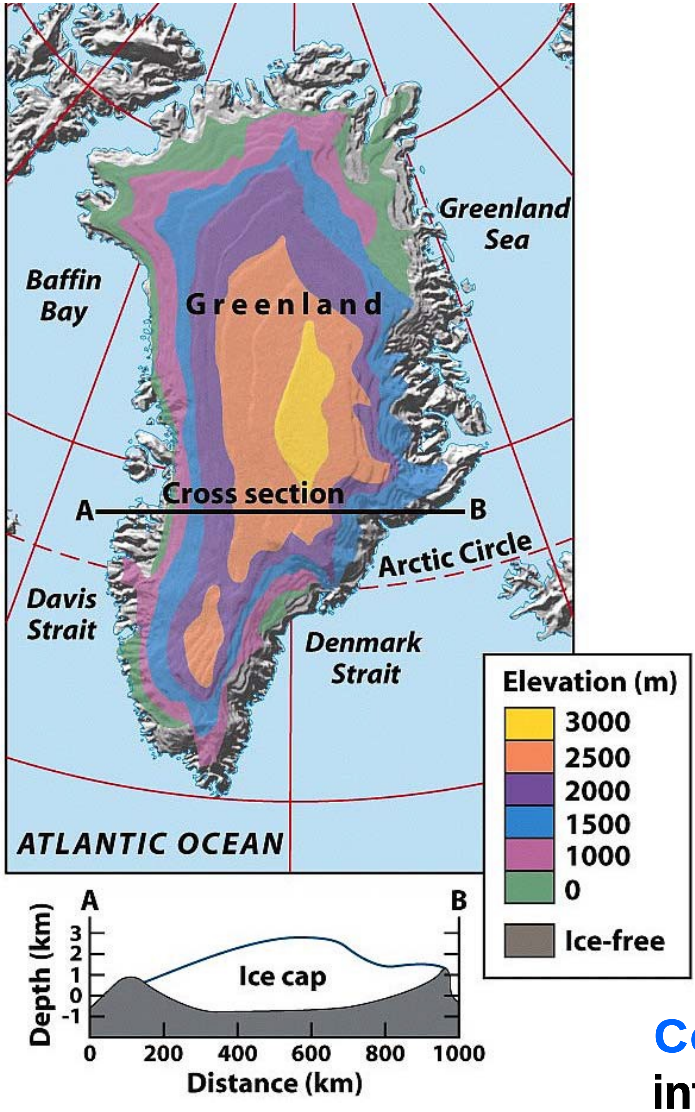


The water cycle



Glaciers
Creeks and rivers

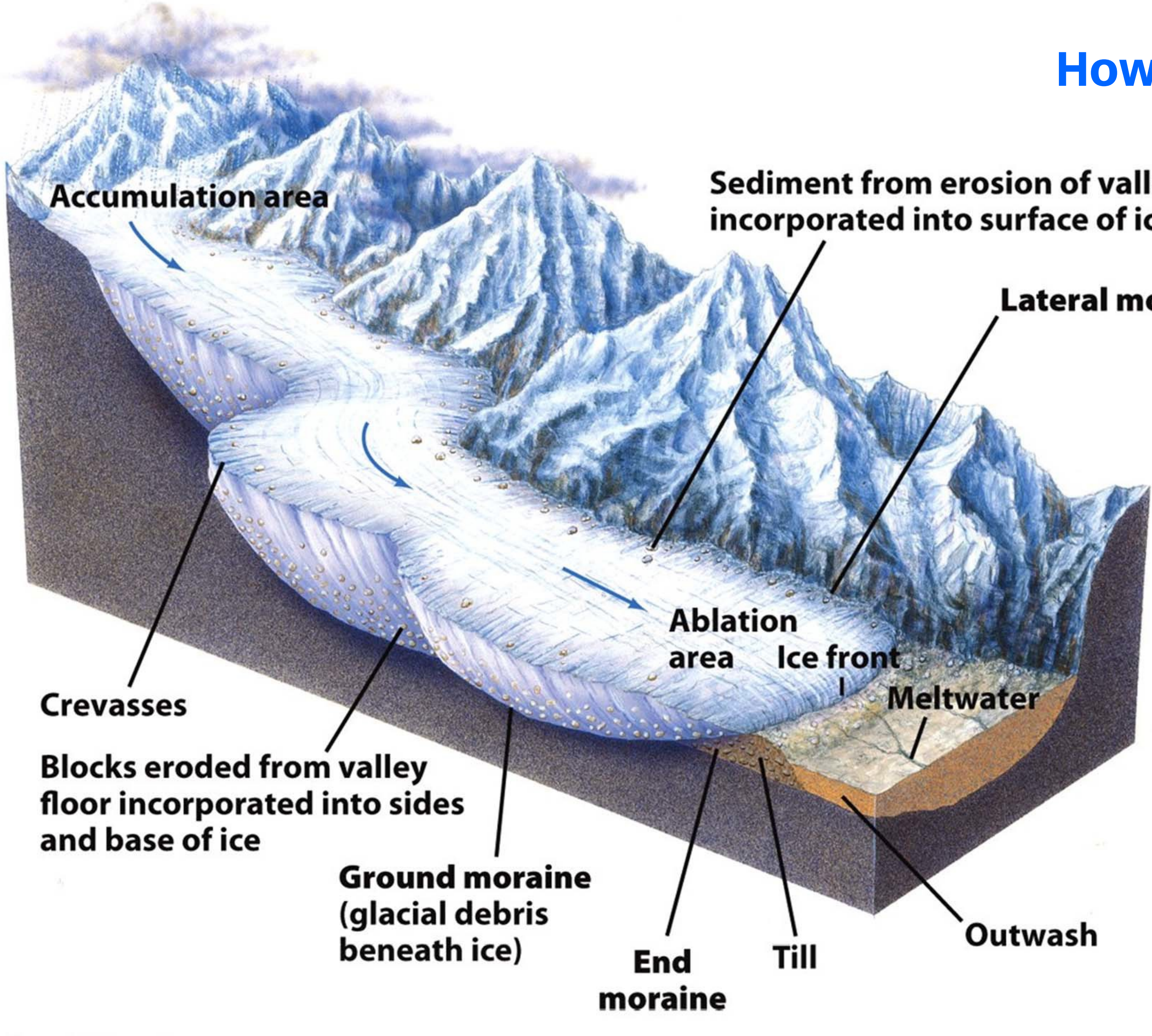
Glaciers: major agents of erosion and deposition



Valley glaciers: very important!

Continental glaciers: too stable to be of interest to us in this part of the class

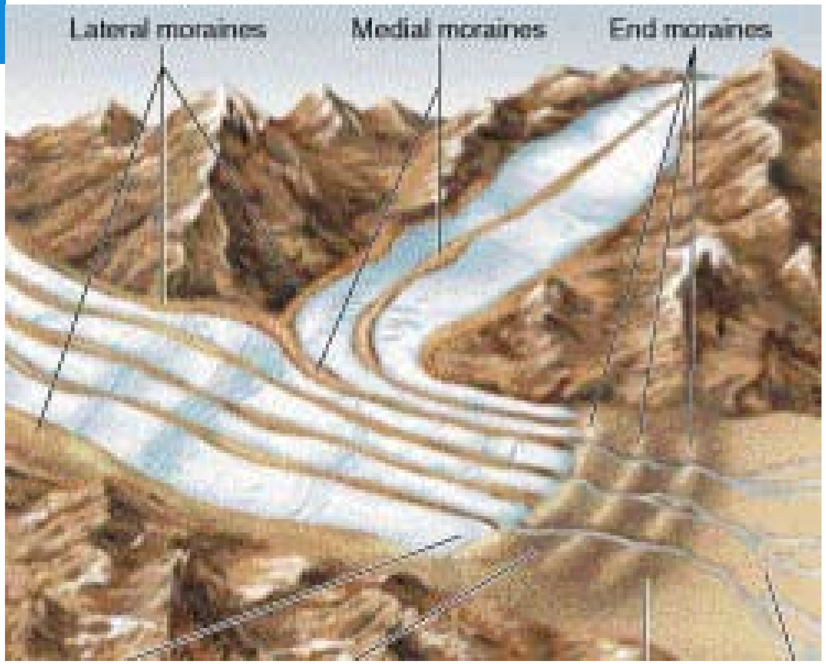
How glaciers work

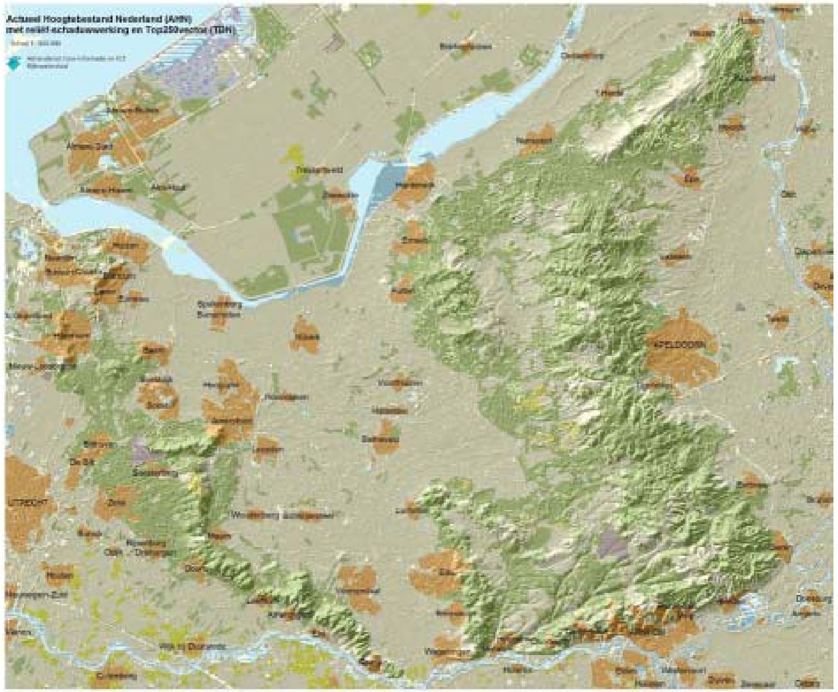


- velocity of particles in different parts of the glacier
- velocity of its front

Glaciers have enormous erosion power

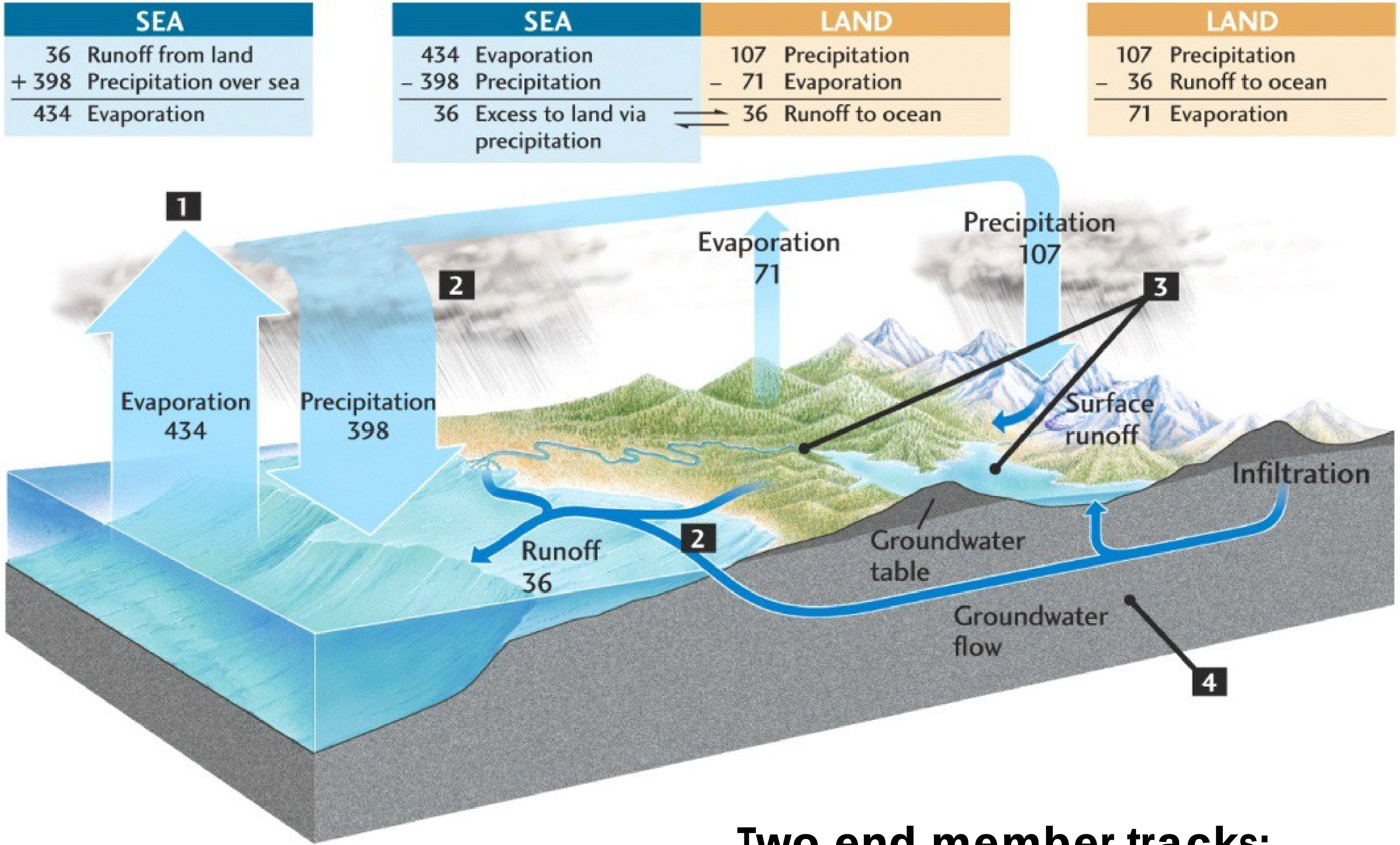
Huge glacial valleys are excavated and large amounts of sediments are transported by the glacier until most of it reaches its front





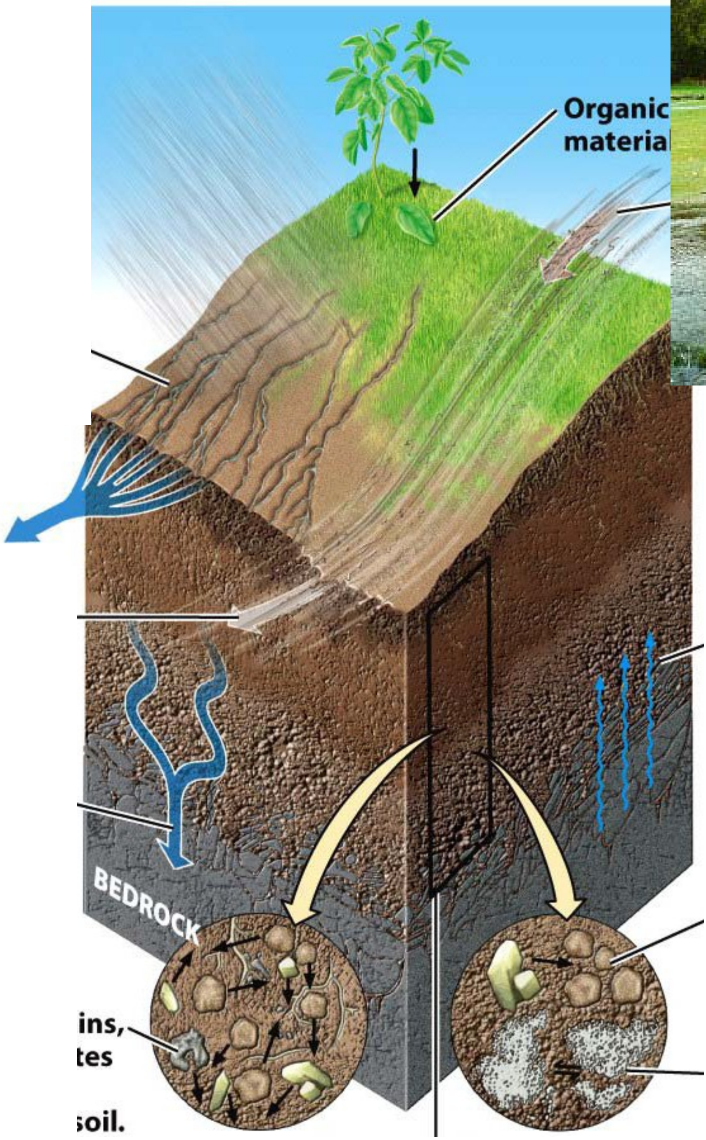
Moraines form in front of glaciers are left behind at the end of glaciation

If it is not that cold…



Two end member tracks:

1) **Infiltration and groundwater flow**
2) **Surface run-off , creeks and rivers**

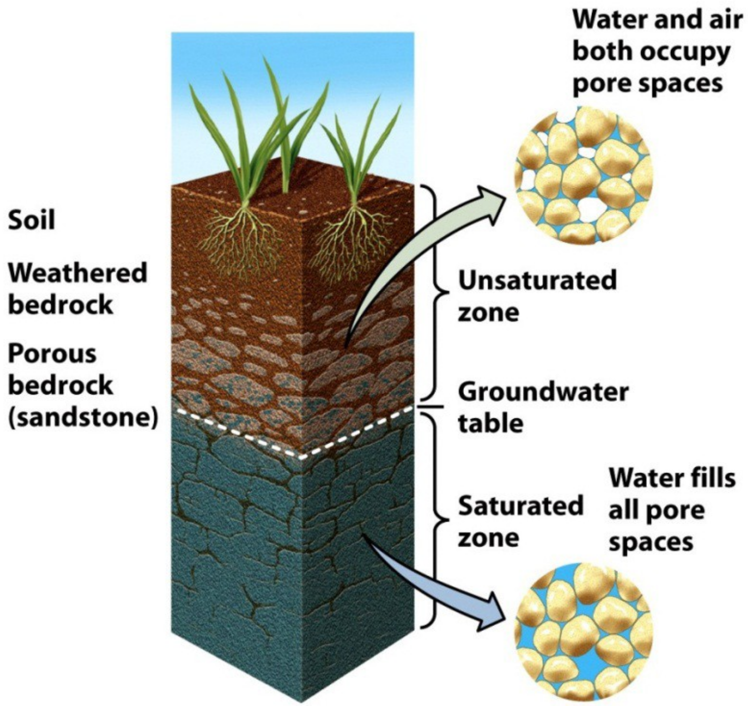


Run-off waters flow on the surface forming creeks, rivers etc

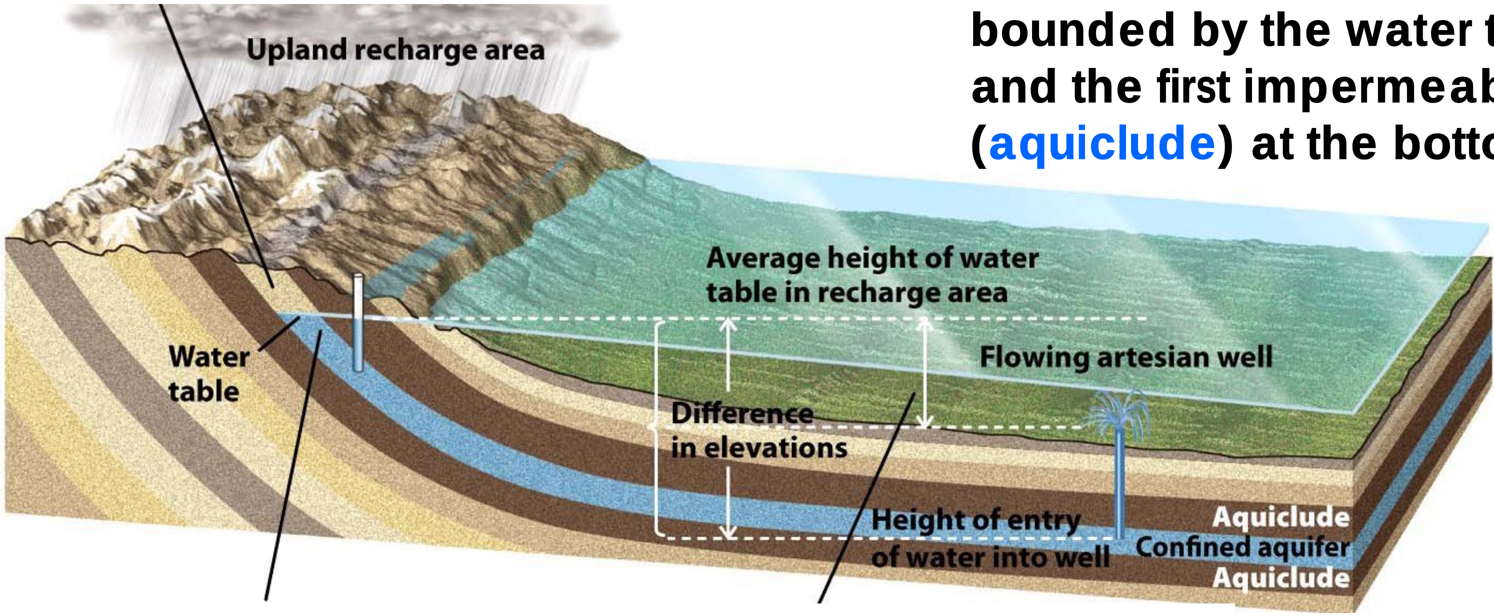
Favoured by vegetation, non-permeable rocks, crusts formed in very dry area and ...human products such as road and greenhouses

Waters entering the ground becomes ground-flow.

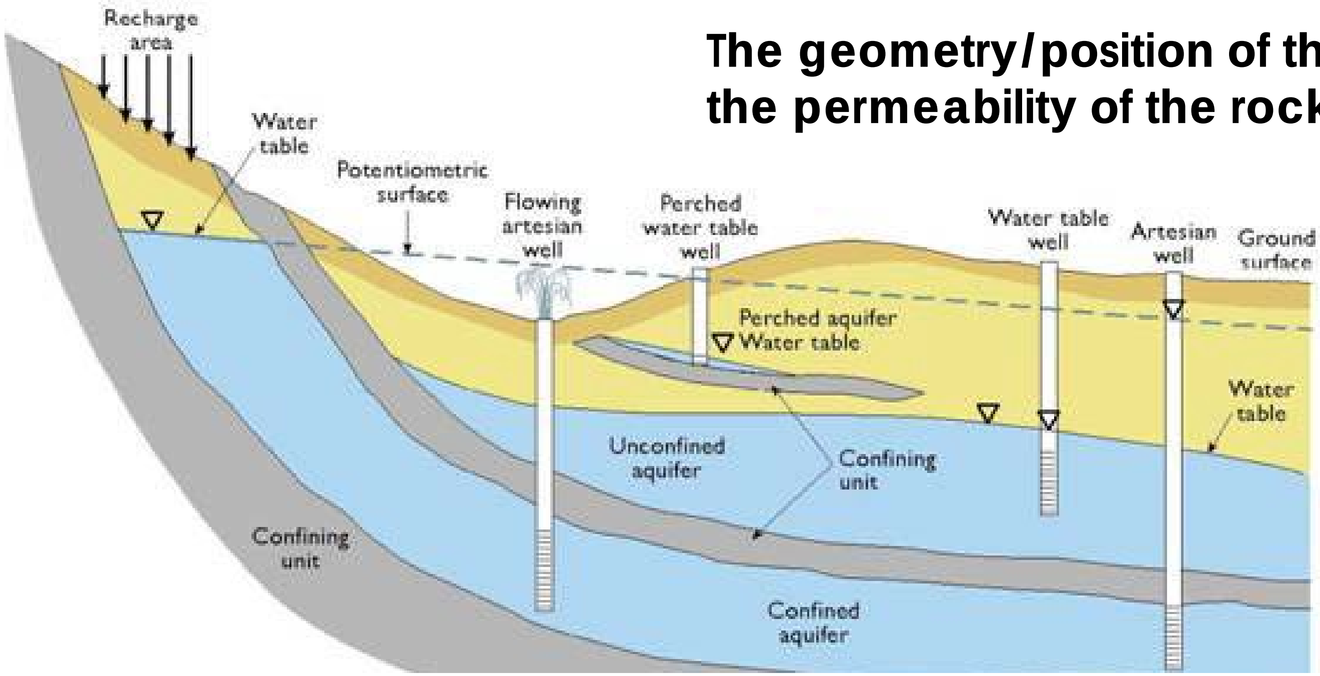
Pass through the unsaturated domain, crosses the water table and enter the saturated domain.



The first aquifer is the unconfined aquifer bounded by the water table at the top and the first impermeable layer (aquiclude) at the bottom

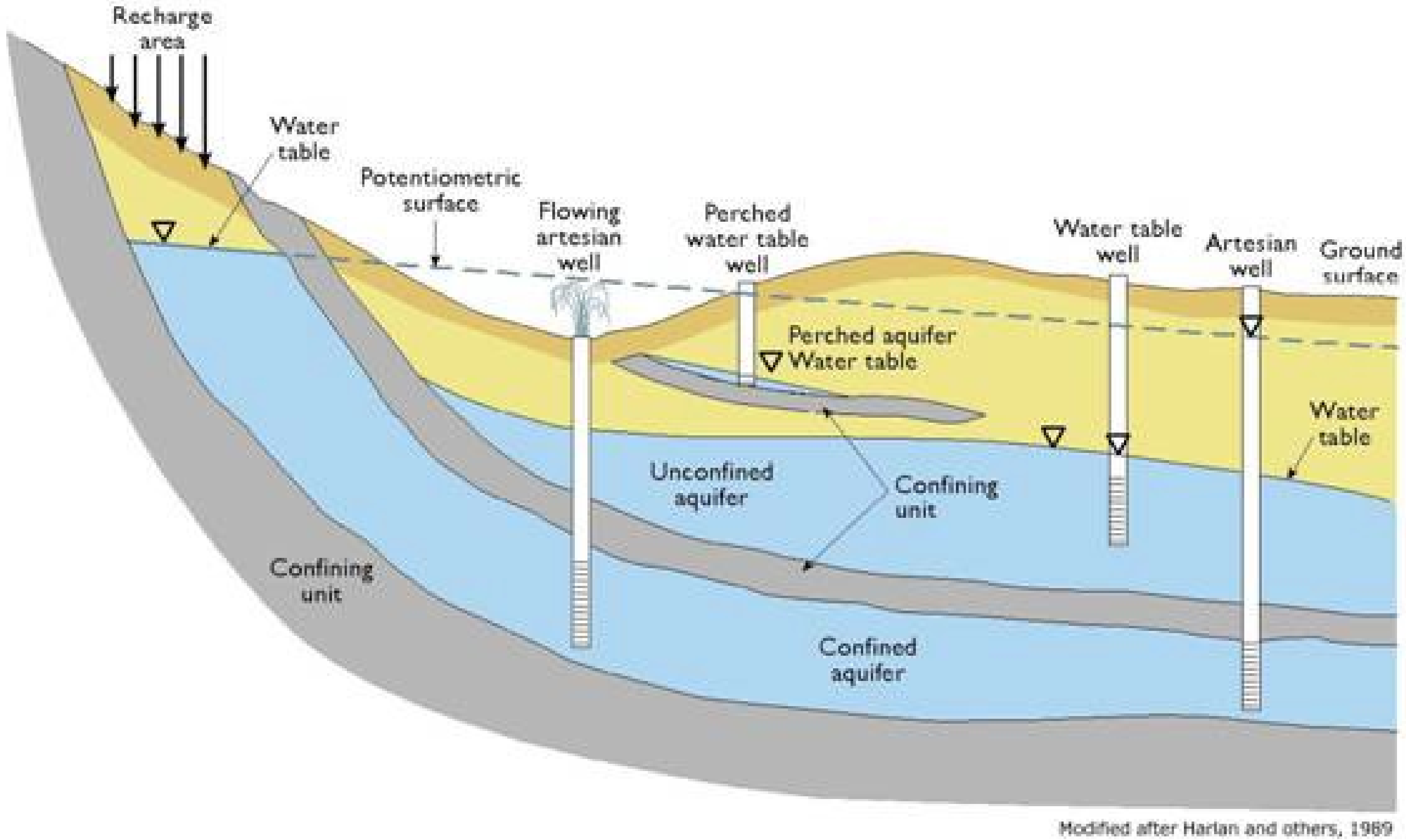


The geometry/position of the water table depends on the permeability of the rocks (generally sediments)



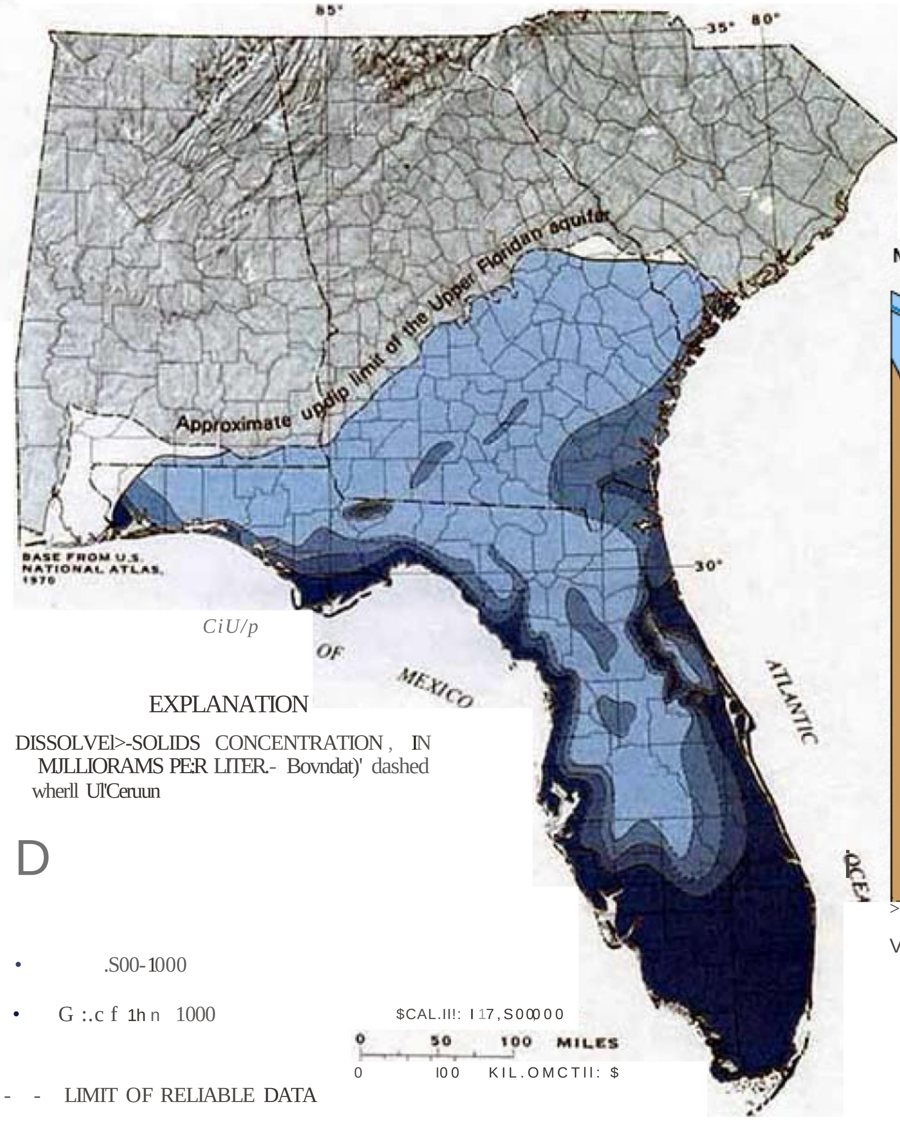
Very easily accessible ….. to pump water but also very vulnerable to pollution

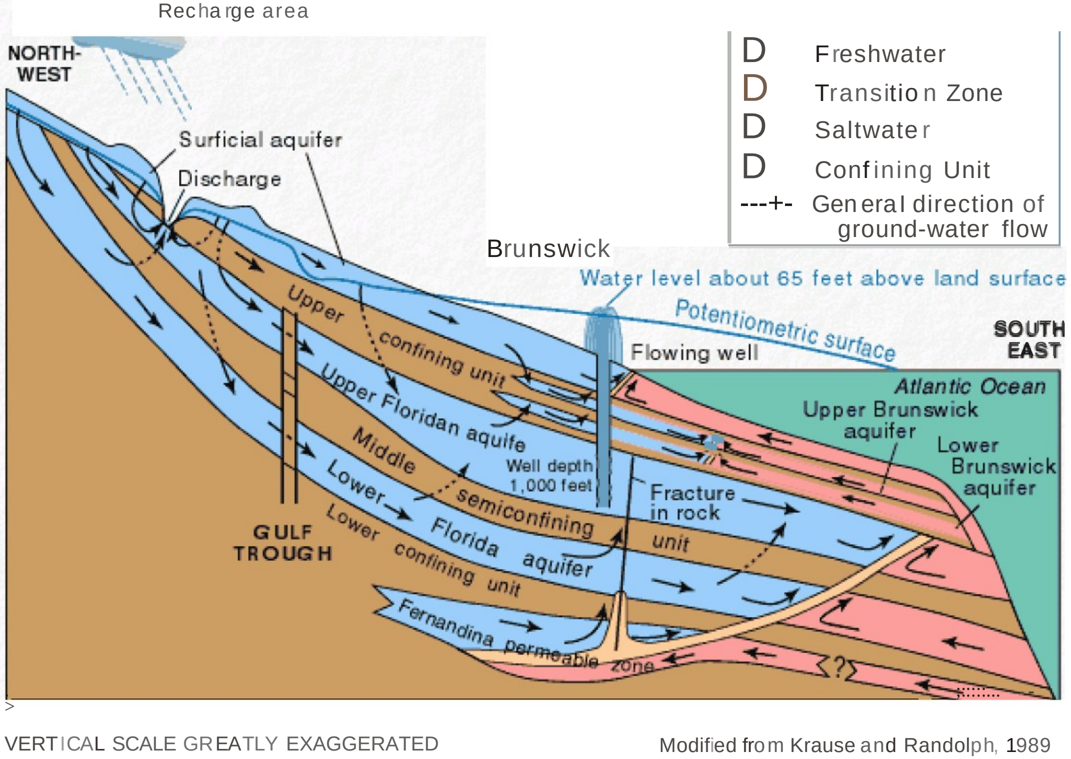
Water can enter packages of permeable rocks dipping into the sub-surface creating confined aquifers



Characterized by i) huge amounts of water, ii) travelling for very long distances

The Floridan aquifer: the largest confined aquifer on Earth (?)



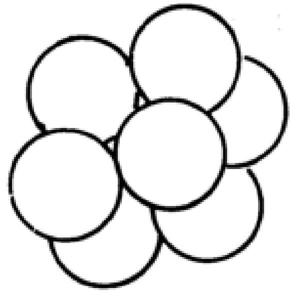


Modified from Krause and Randolph, 1989

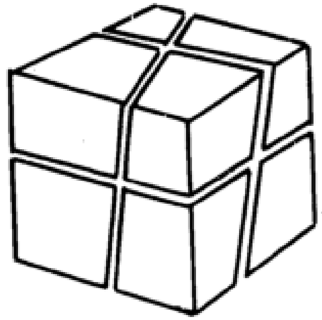
Porosity permeability are crucial

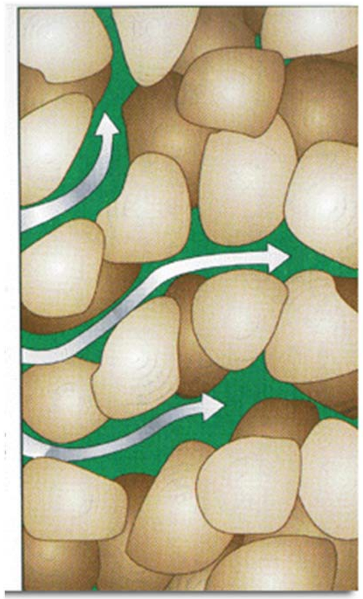
Porosity is the ***% of the total volume of the body which consists of pores (=open spaces)***

between grains



fracture-controlled



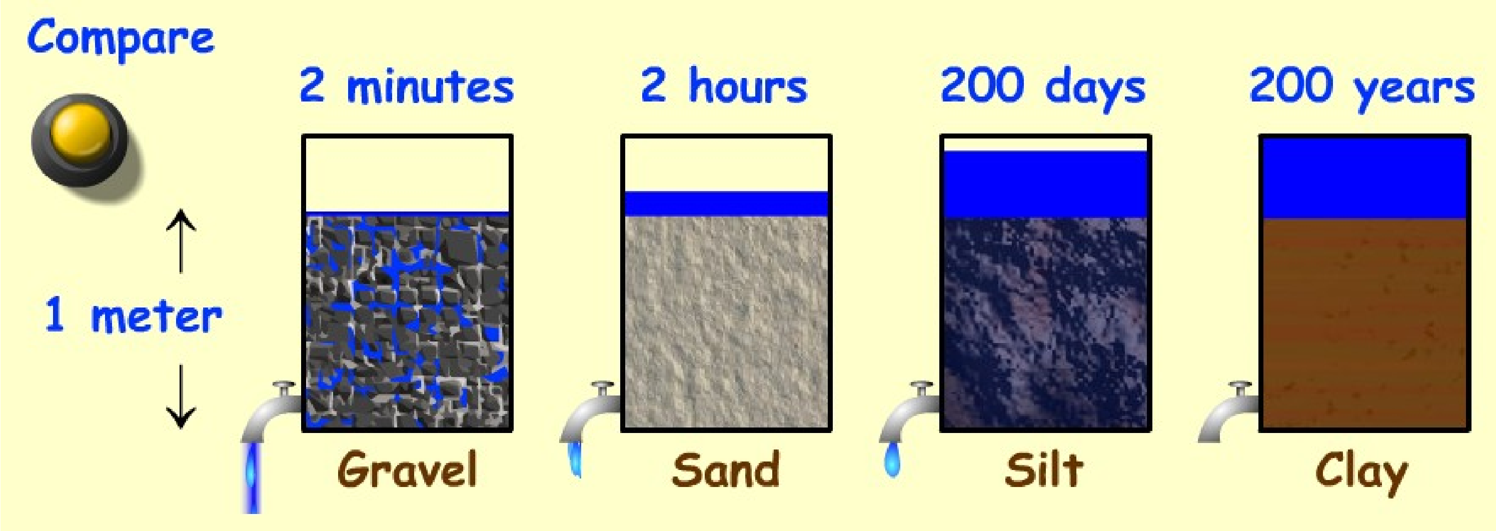


Permeability is a measure of ***how easily the solid allows a fluid to pass through it***

$$v = \frac{\kappa}{\mu}\frac{\Delta P}{\Delta x}$$

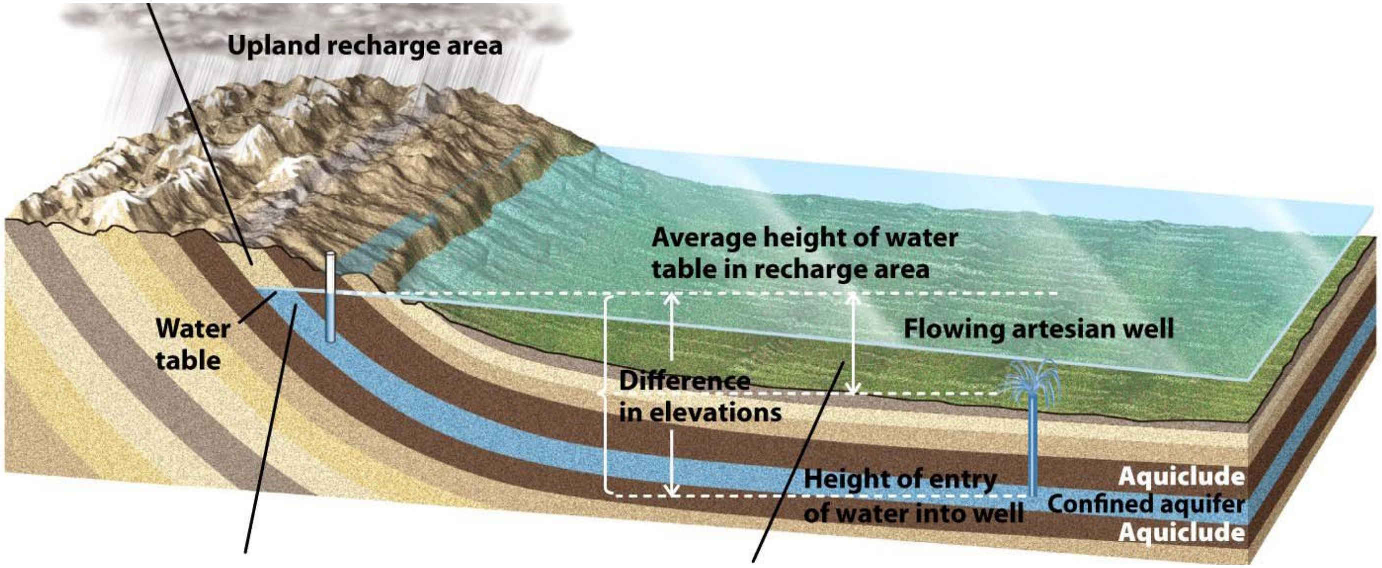
Where v= velocity of fluid
κ = permeability
μ = fluid viscosity
ΔP = pressure gradient
Δx = layer thickness

Some numbers

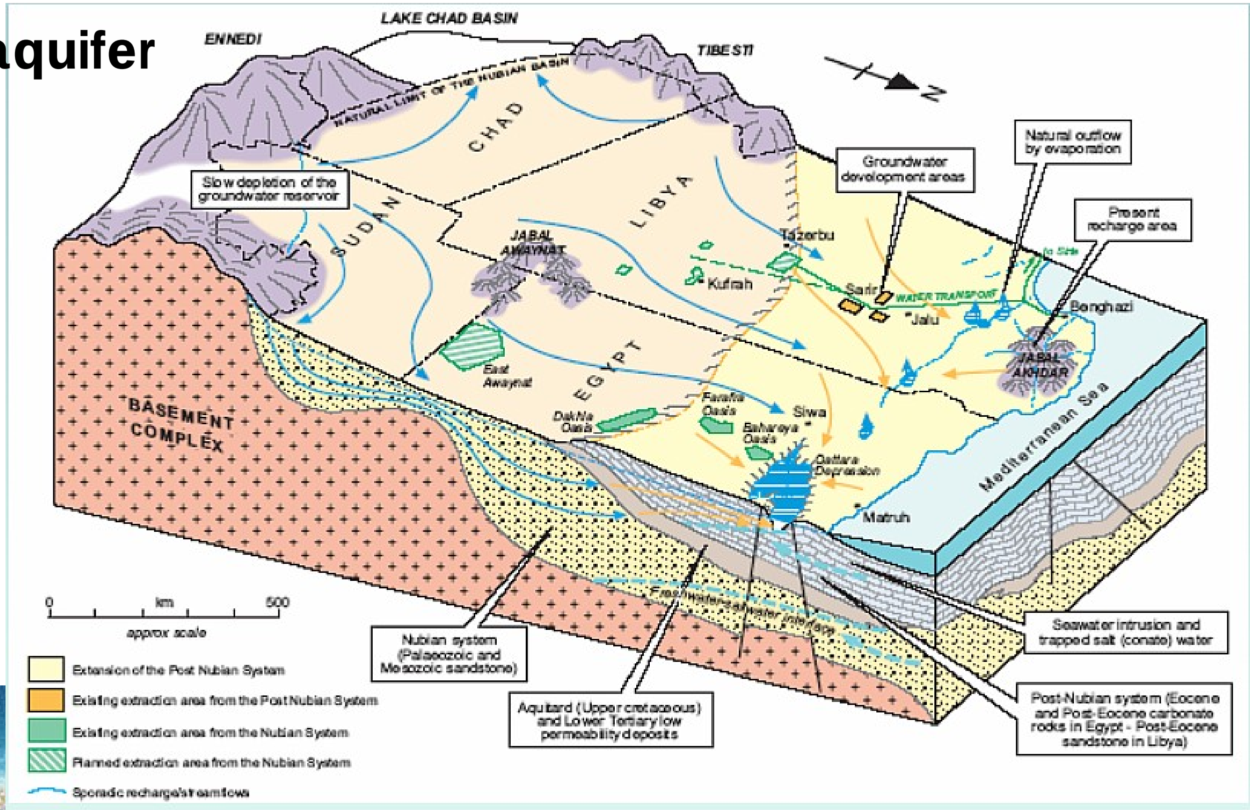


http://techalive.mtu.edu/meec/module06/Permeability.htm

How long does it take for the water to reach the plains (there where most people live?) =How old is the water we will tap?



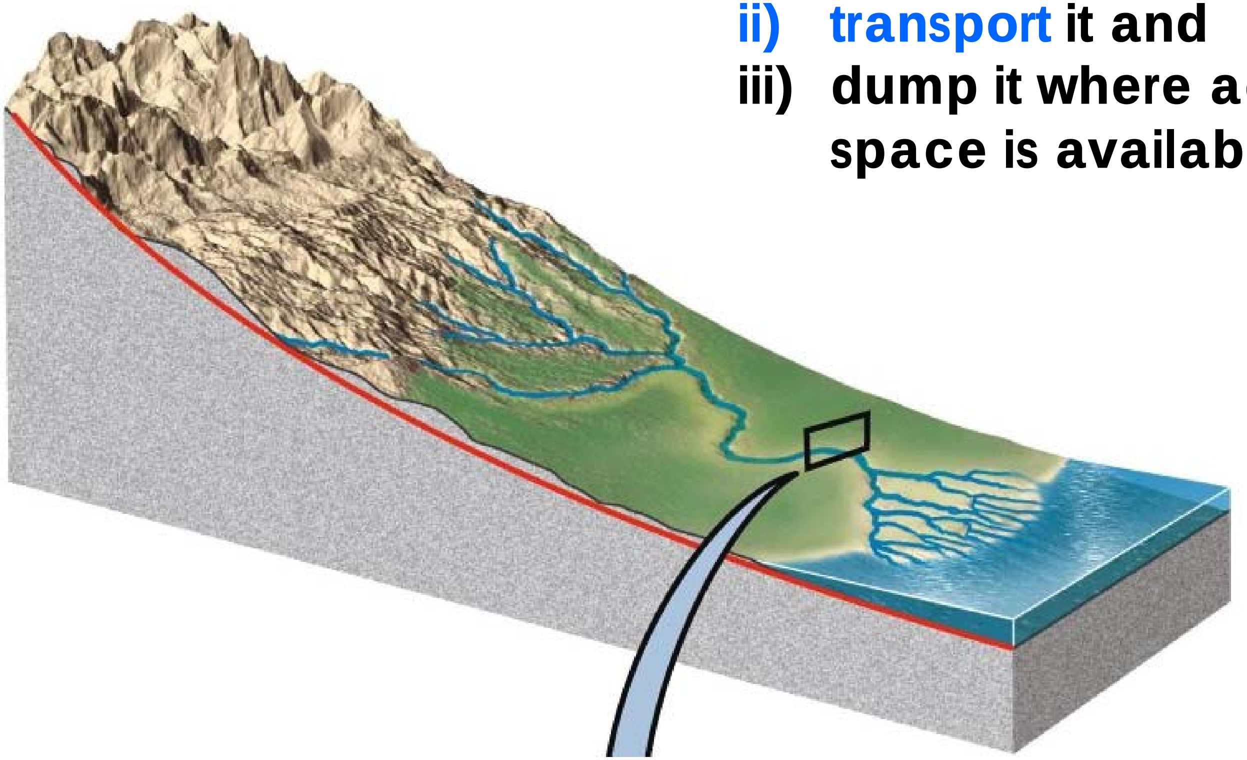
The Nubian sandstone aquifer



The geology

Some dreams (?)

The **routing** system: delivering from the mountains to the sea

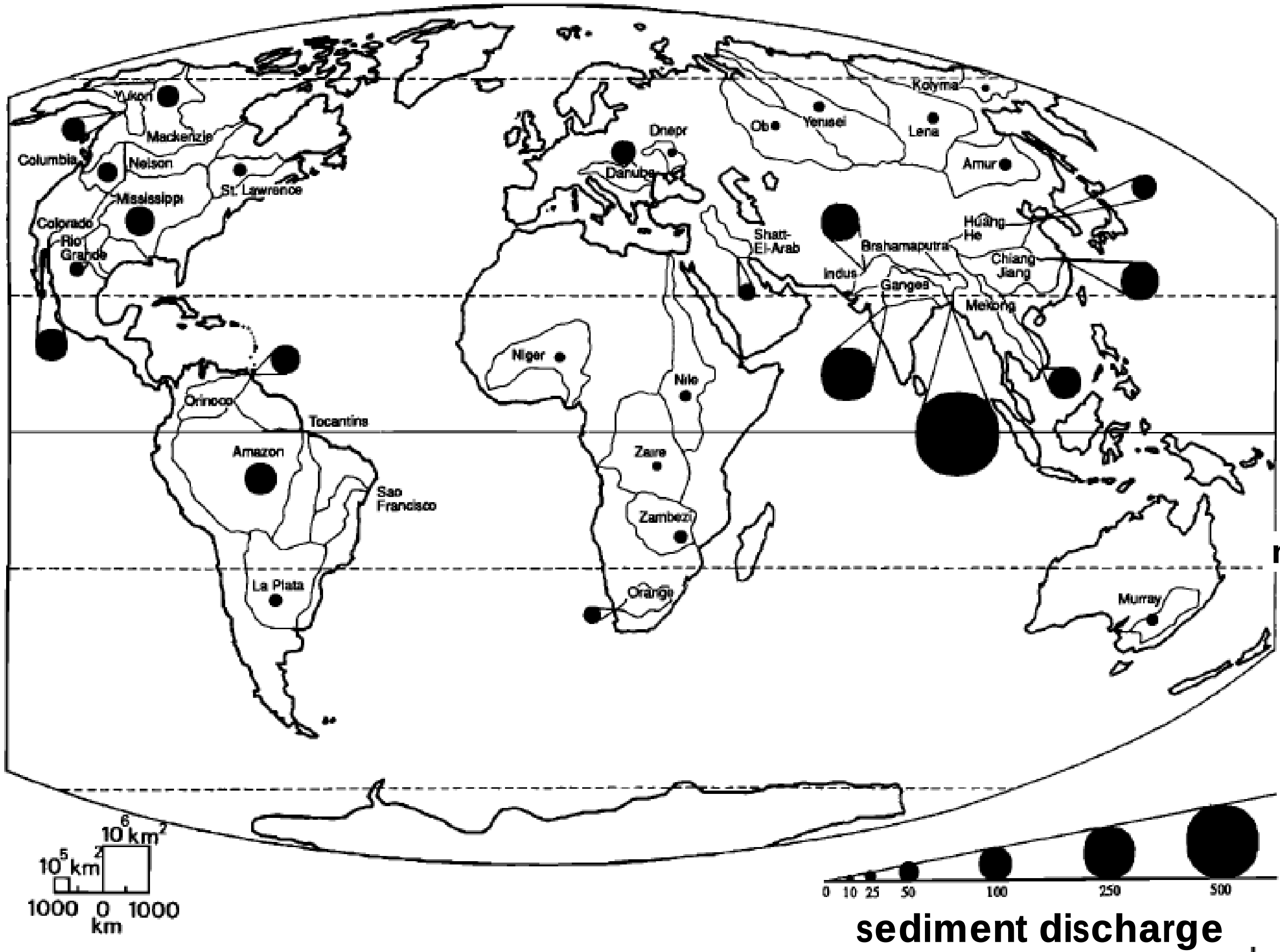


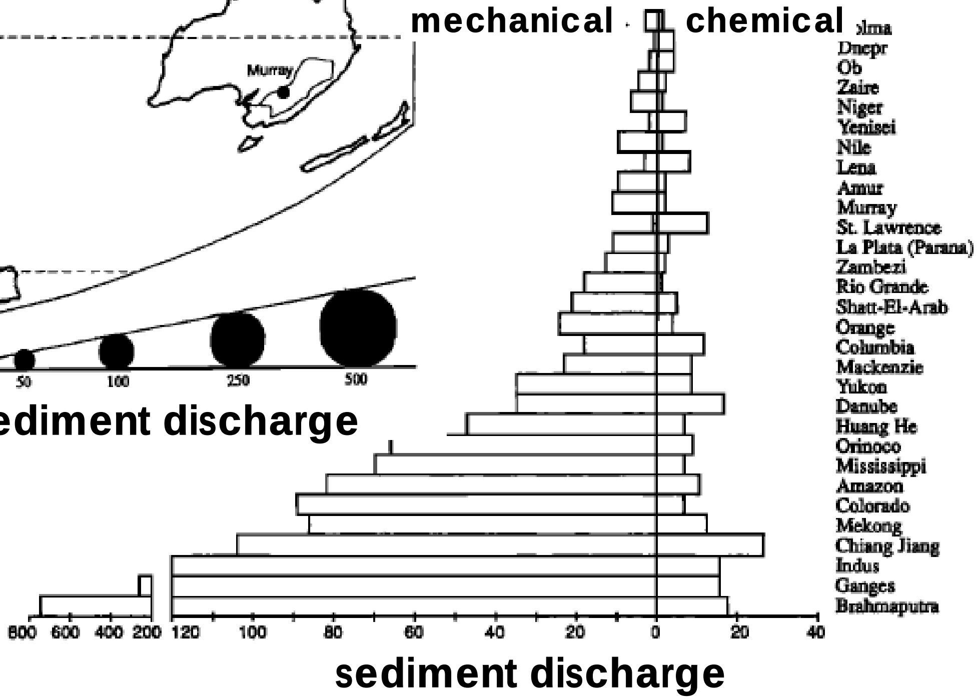
Rivers:

i) Collect material (erosion),
ii) transport it and
iii) dump it where accommodation space is available (deposition)

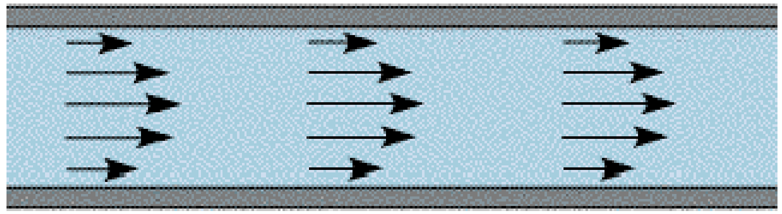
A very efficient distribution system discharging huge amounts of sediments

Dimensions of drainage basins are important but largest yields are from on-going orogens

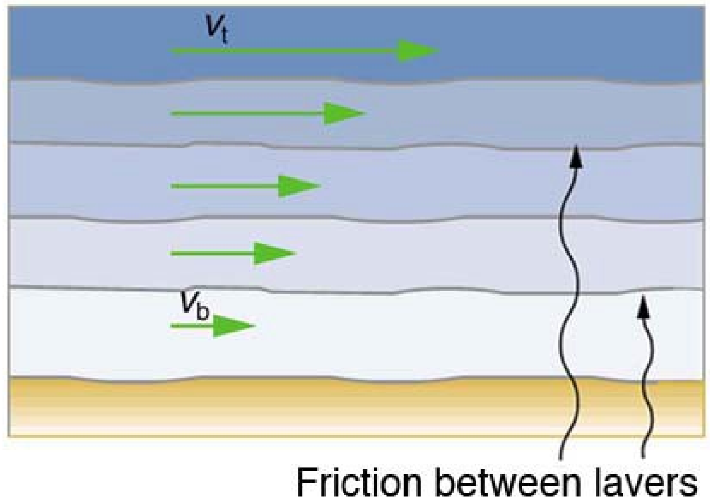


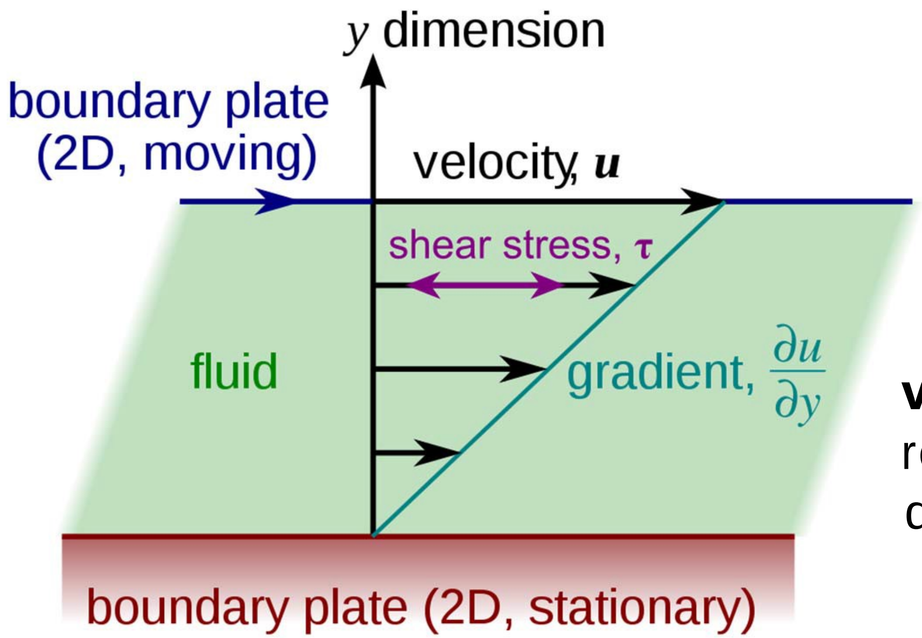


The simplest life of a river: laminar flow



One has laminar flow when the displacement vectors are parallel to each other and only gradually change in magnitude



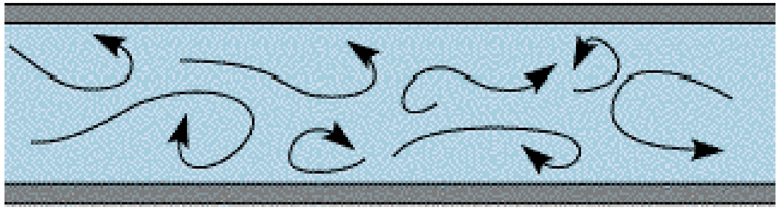


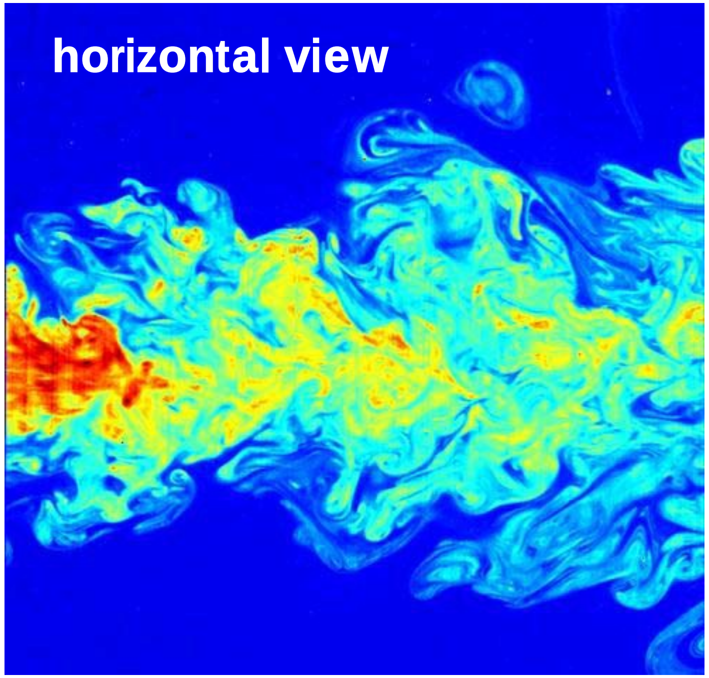
viscosity: A measure of the resistance of a fluid being deformed by shear stress

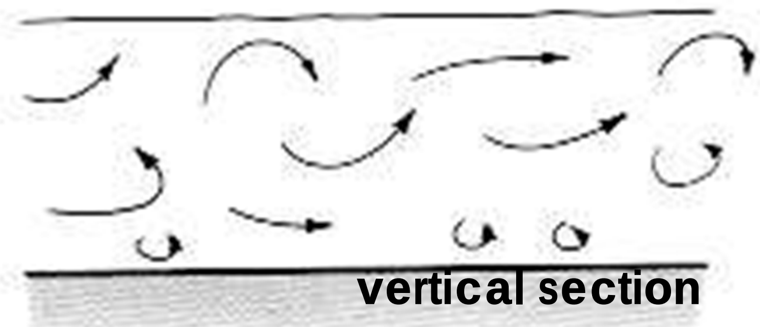
$$\tau = \mu \frac{\partial u}{\partial y}$$

Laminar flow

Flow in a channel can become turbulent







Local properties are very different from the "ambient" ones. Non-steady vortices and eddies appear at various scales imposing substantial downward and upward movement components to the fluid

Laminar or turbulent?

Controlled by Reynolds number

$$Re = \frac{inertial\ forces}{viscous\ forces} = \frac{\rho v L}{\mu}$$

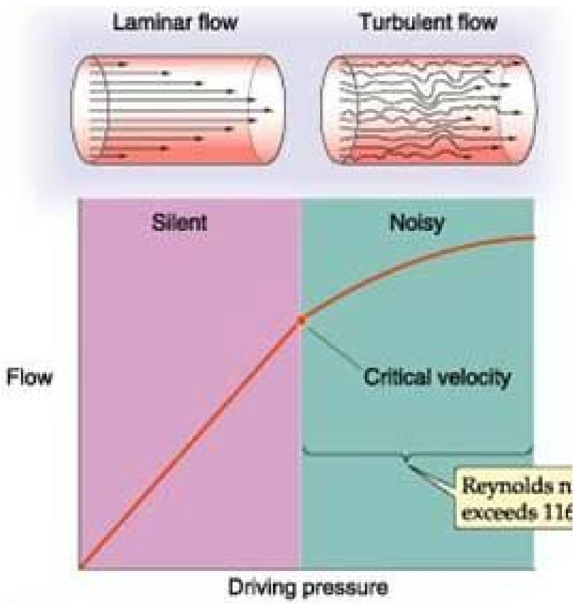
ρ = density (**mainly dependent of suspended sediment**)

v=average flow speed

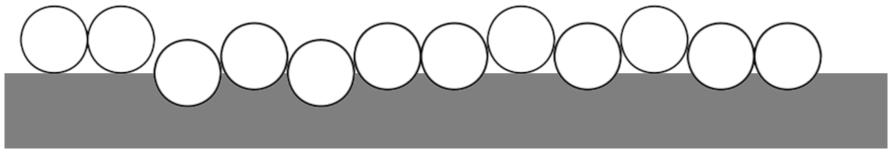
L = diameter, width

μ= viscosity

low Re = laminar flow
high Re = turbulent flow



Implications for water flow and sediment interactions
(grains, clays are more complicated)



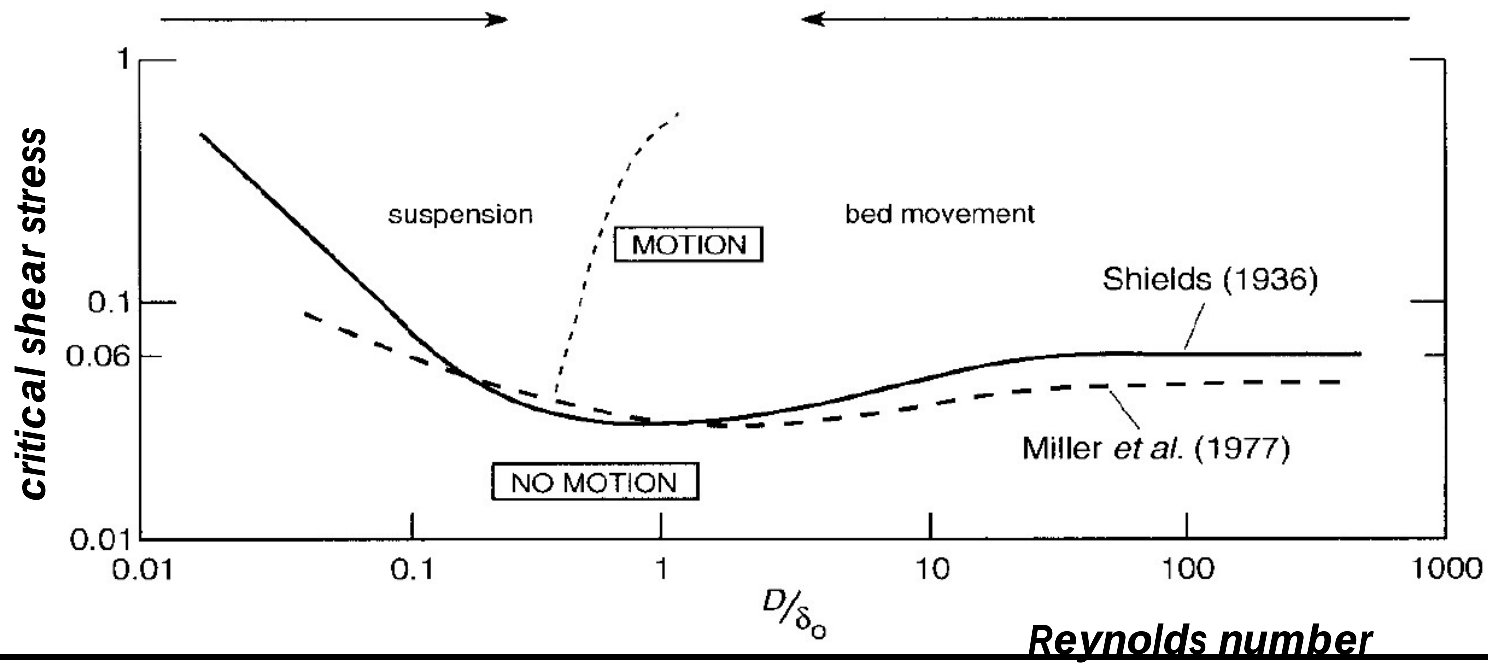
1. Setting grains in motion (erosion)
2. Moving grains (bottom and in the fluid) (transport)
3. Settling grains (deposition)

Detaching grains from their substratum and moving them

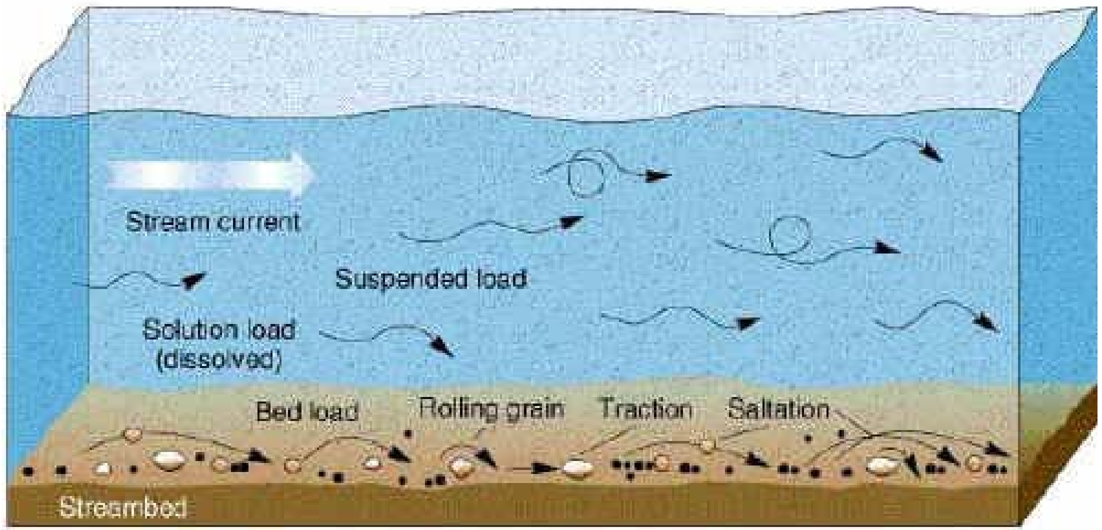
The moving fluid provides the energy (shear velocity)

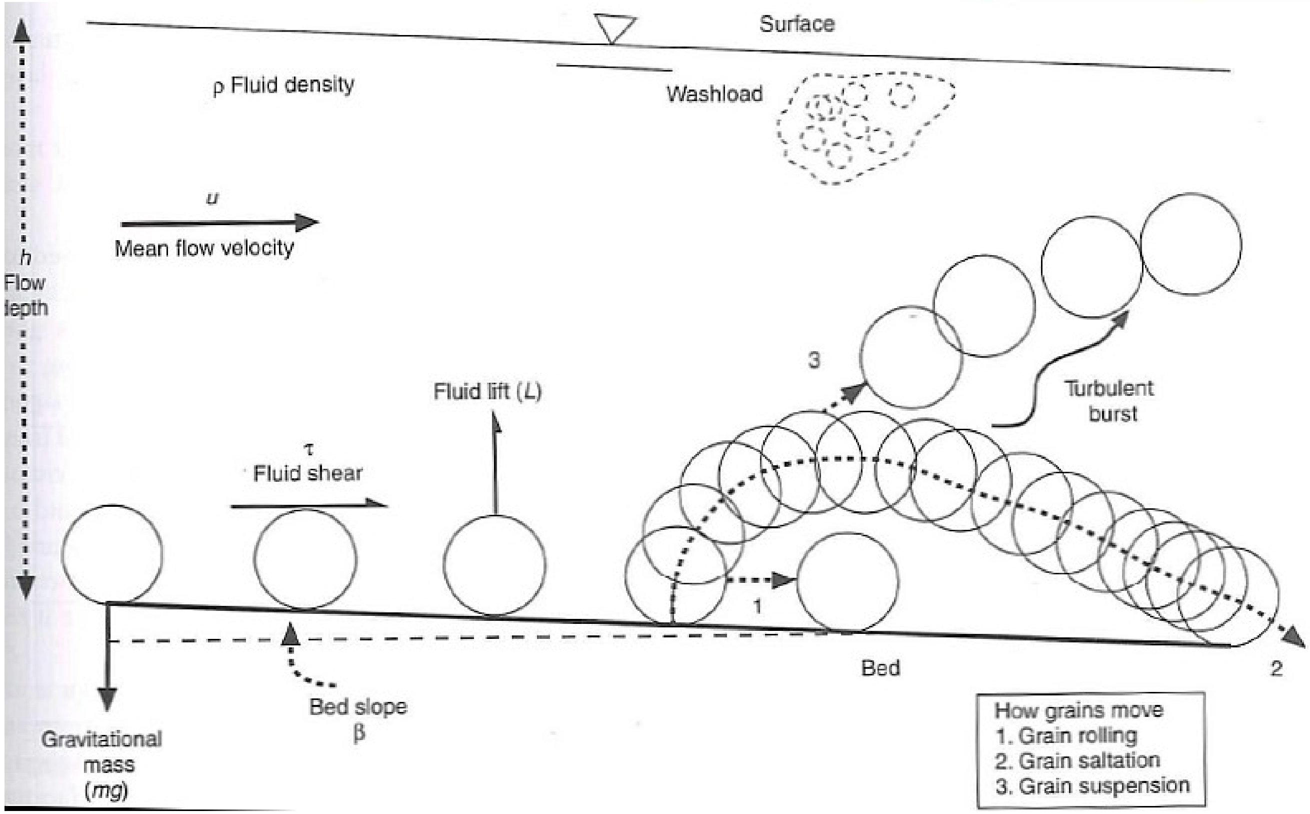
A critical shear velocity can overcome the friction of the grain with its substratum and its weight

Turbulent flow helps!



Once grains are in motion they can roll, saltate (bedload) or moved remaining in suspension (suspended load)





In more physical terms

High velocities are obviously good

Away from the walls, grain enter in the area of turbulent flow
Collisions are important as they help transforming horizontal in vertical movement

A simple representation

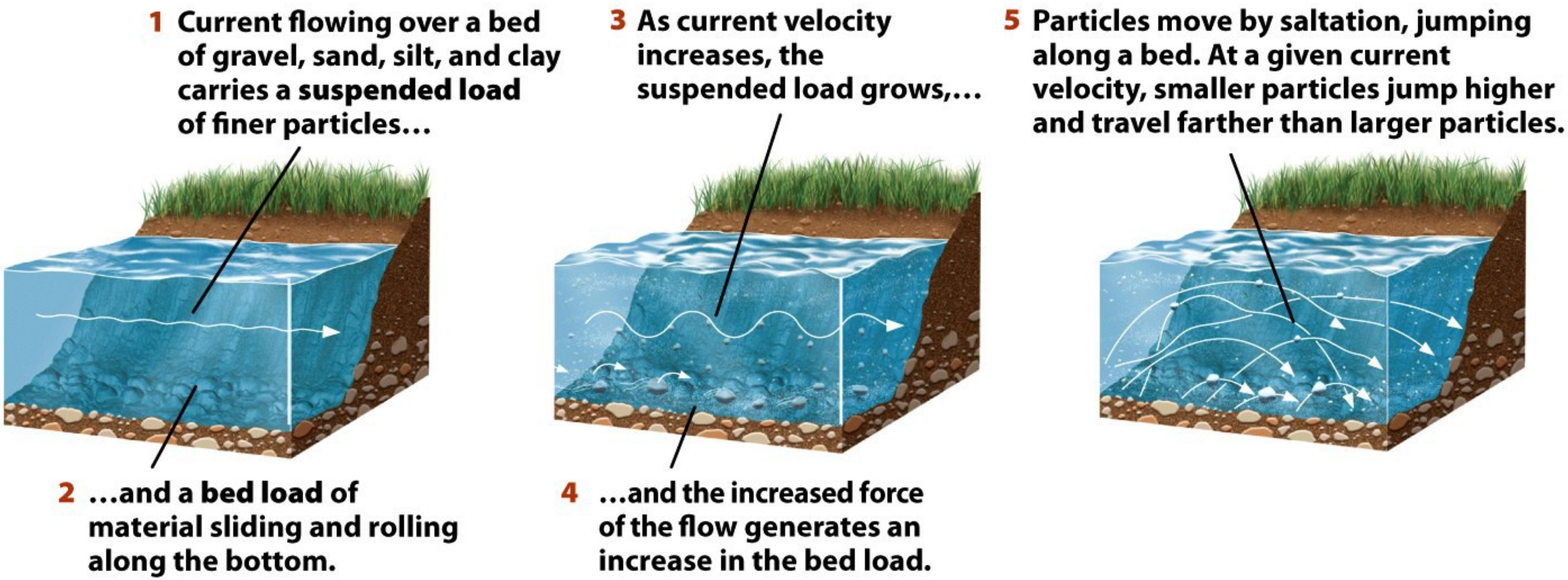


Figure 18.15
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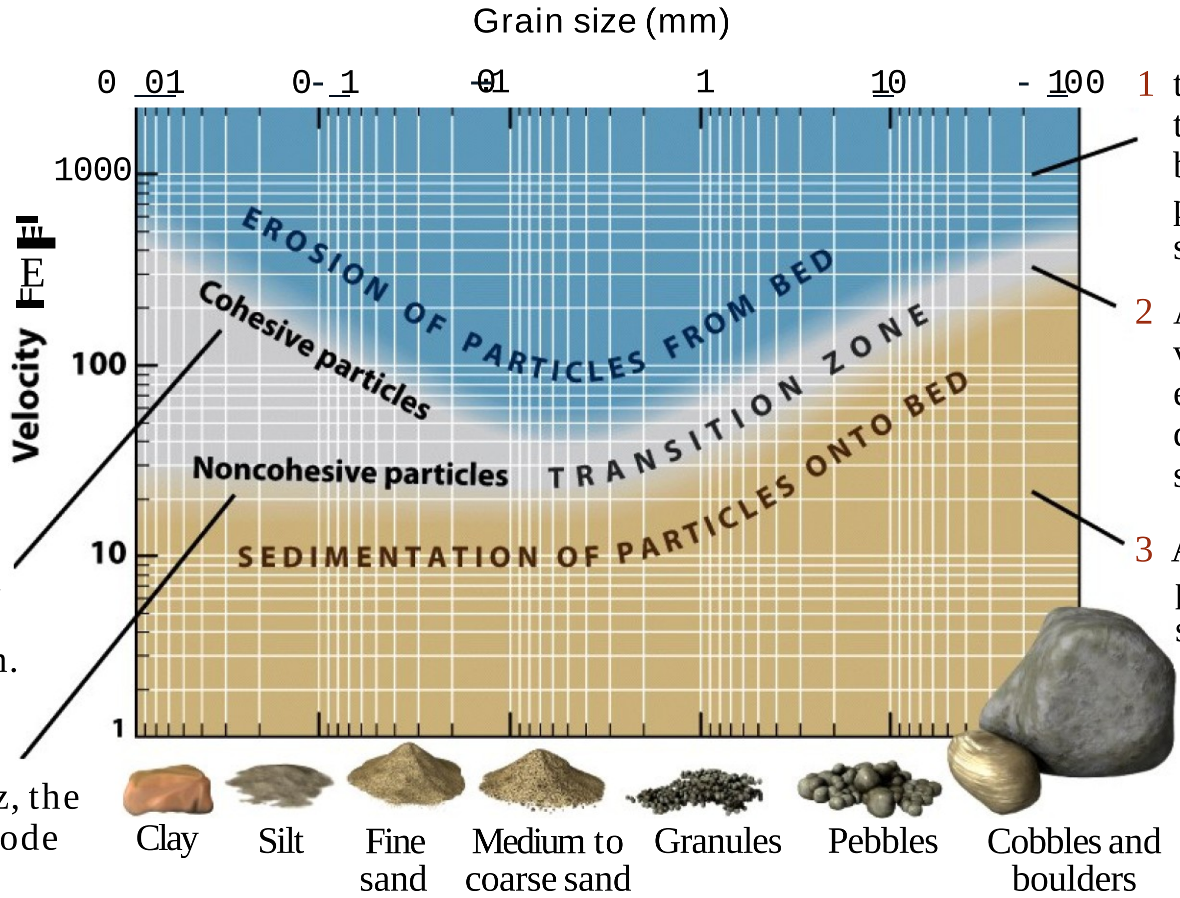
Things are expected to change with fluid speed

These different relations are summarized in a Hjulstrom plot



1 thehighe loci ties, currents erode both large and small particles from the streambed.

2 At intermediate velocities, particles may erode or settle depending on their grain size and cohesiveness.

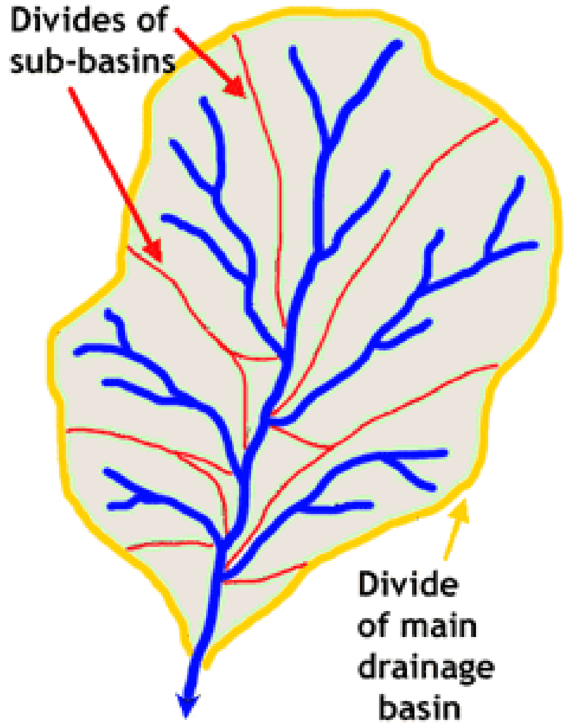
3 At the lowest velocities, particles of all sizes settle on the streambed.

4 For small but cohesive particles such as clay, a stronger current is required to erode them.

5 For small noncohesive particles such as quartz, the gentlest current can erode them.

We can start our trip along the river from the mountains to the sea

A drainage basin is an extent or area of land where surface water converges to a single point, usually the exit of the basin, where the waters join another water body (e.g. sea or ocean). It is bounded by water divides



The Mississipi drainage basin

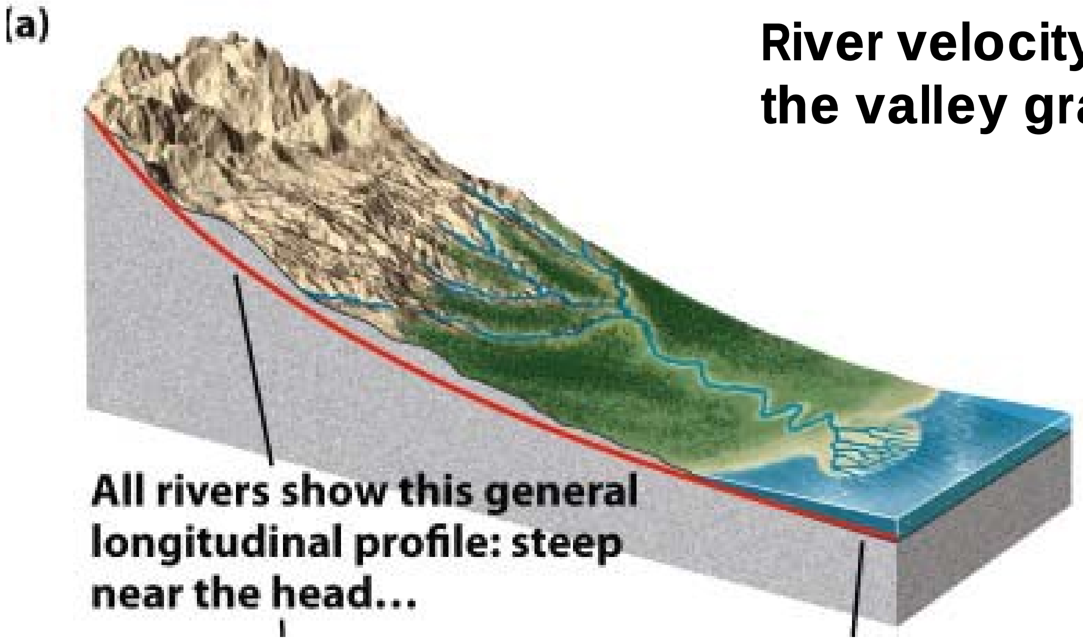
The amount of water increases downstream. The velocity depends on:

$$D = A*u$$

D = discharge (volume of water passing through a point in a given time (m^3/sec)

A=stream cross section (m^2)

u=velocity (m/sec)



River velocity is essentially controlled by the valley gradient.

Vertical profiles of rivers

Rivers tend to acquire a parabolic topographic profile, steep in the upper parts and gentler downstream. The detail shape is modulated by rock properties, climate, etc.
Flattening occurs at the base level (sea level, but there are also local ones)

Velocities tend to decrease downstream

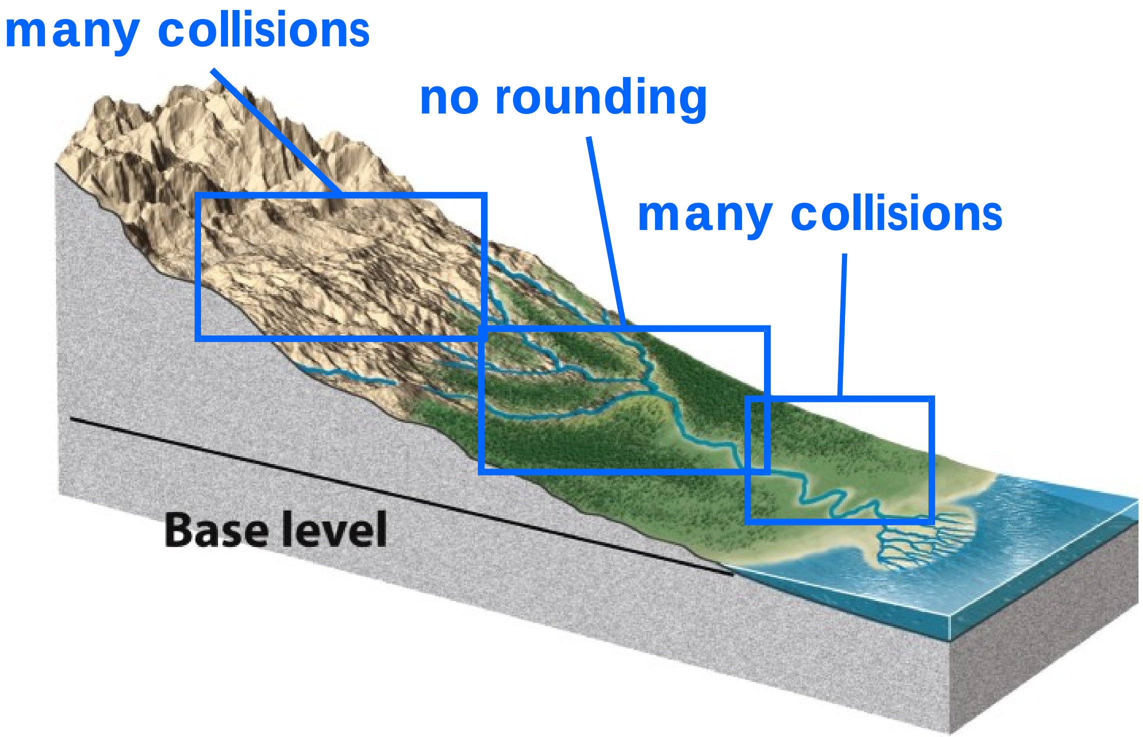
D = A*u

The velocity decrease needs to be compensated by an increase in area to allow the imposed discharge

What does this mean for sediments:

Sediments are removed there where velocities are high, transported where they decrease and deposited when they become very low

The type of sediments also changes

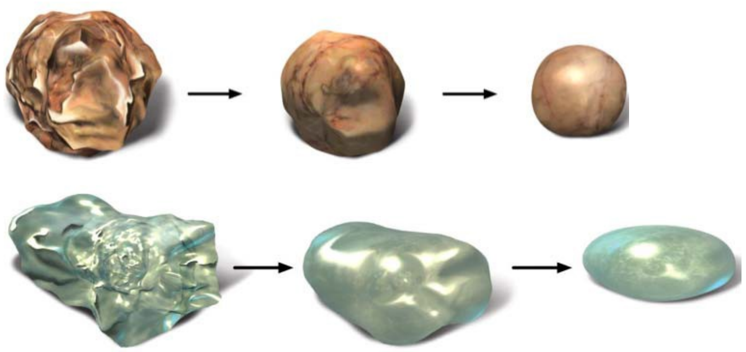


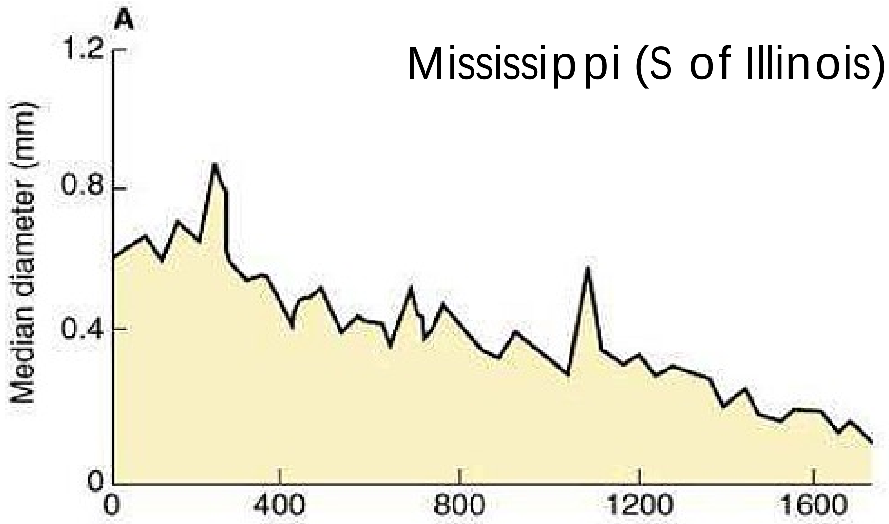
On the whole, distance from source exerts a poor control on grain size and shape.
What counts is the number of collisions between grains (and substratum), this depends on the energy of the system

In addition, a lot of other factors play a role: initial shape, composition (many vs. uni-grains), inherited partings, ...

Sediment characteristics from source to the sea

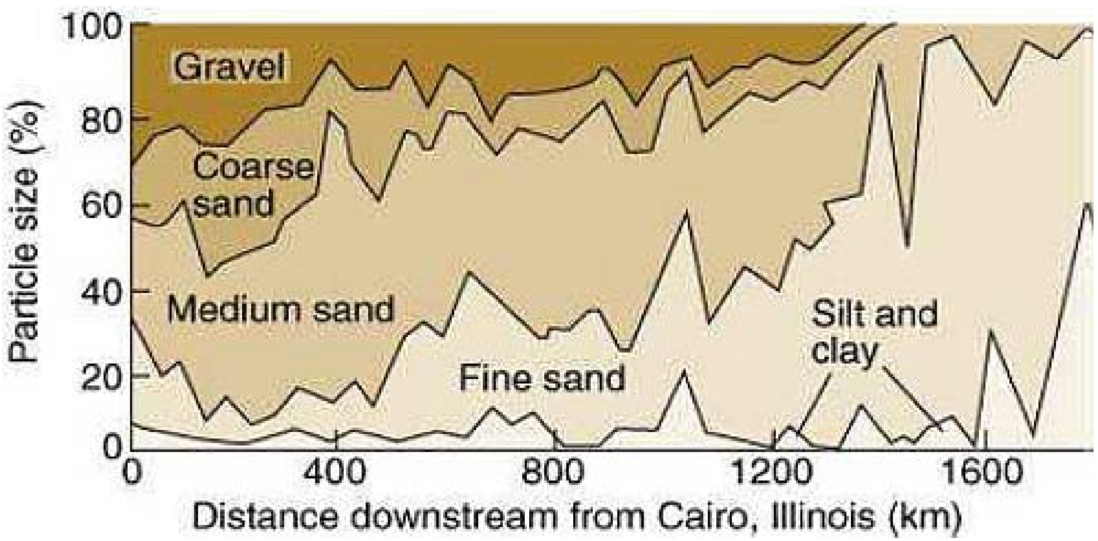
How big are changes in clasts' size and shape as a function of transport distance?





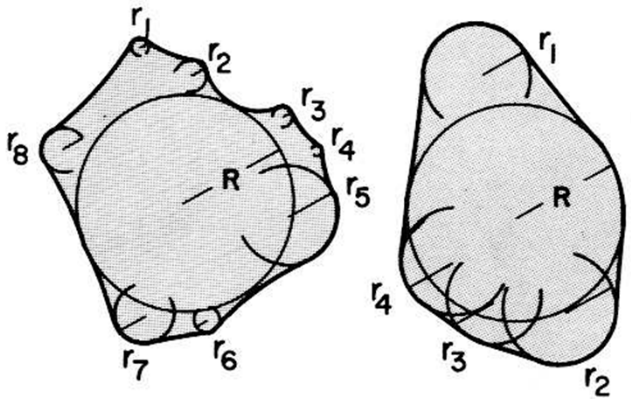
The best fit line shows a decreasing trend

But what is the cause? decreasing competence or grain collisions, abrasion..

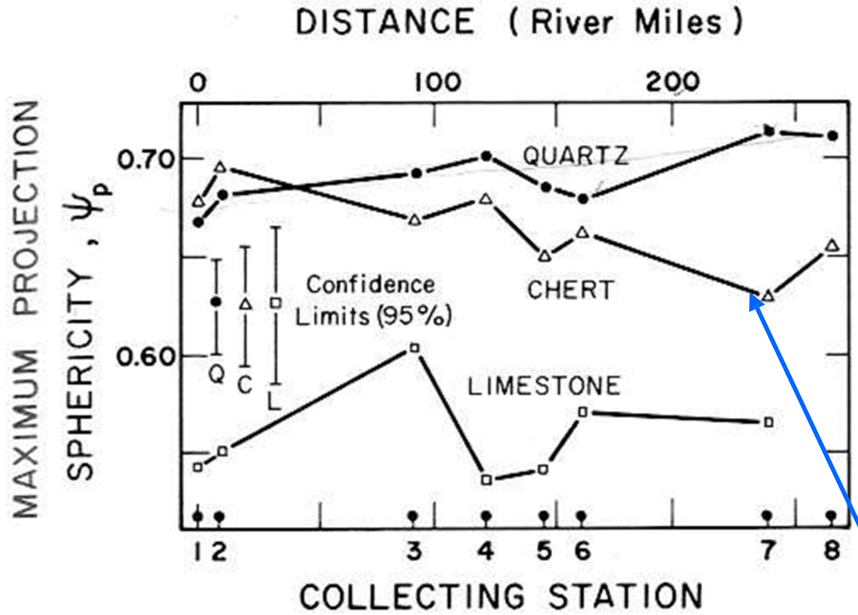


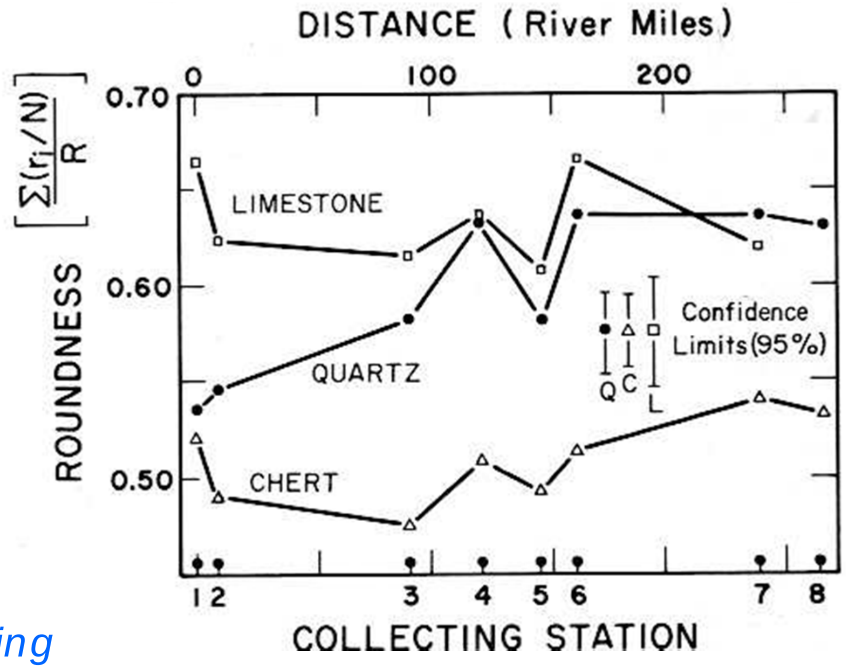
Changes in shape

Parameters have been designed to quantify the shape of grains (sphericity, roundness..)



Grains along the lower Colorado river





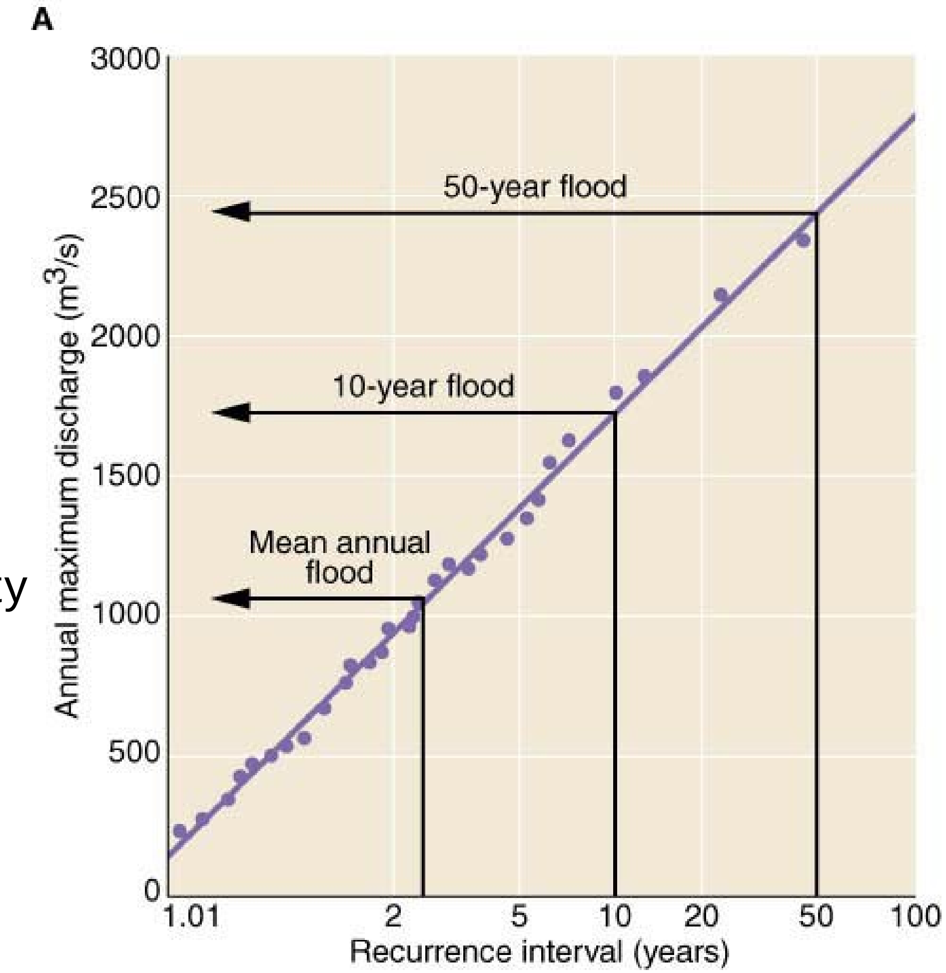
splits along bedding

The changes (rounding) are not directly and easily related to distance.

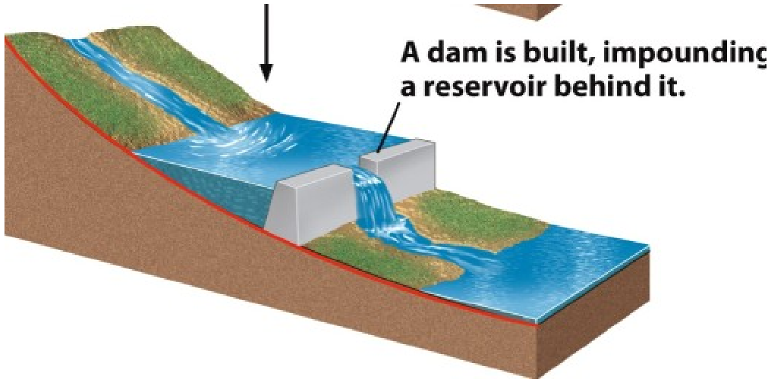
Destabilizing the system

Discharge is not constant through time but is strongly influenced by precipitations. These can lead to floods

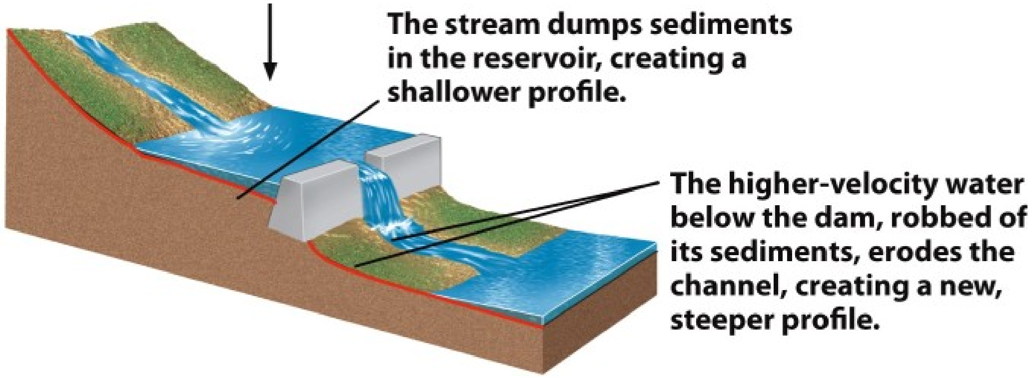
remember?
D = A*u
Can be compensate by increase in velocity and/or by an increase in A



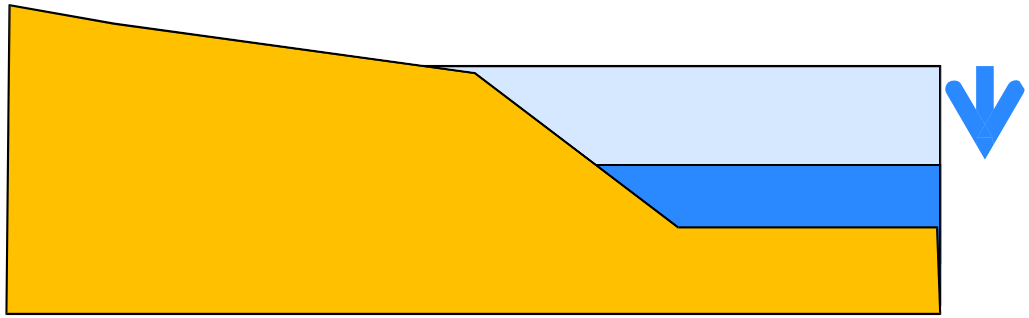
River gradients are can also change through space and time



Human intervention

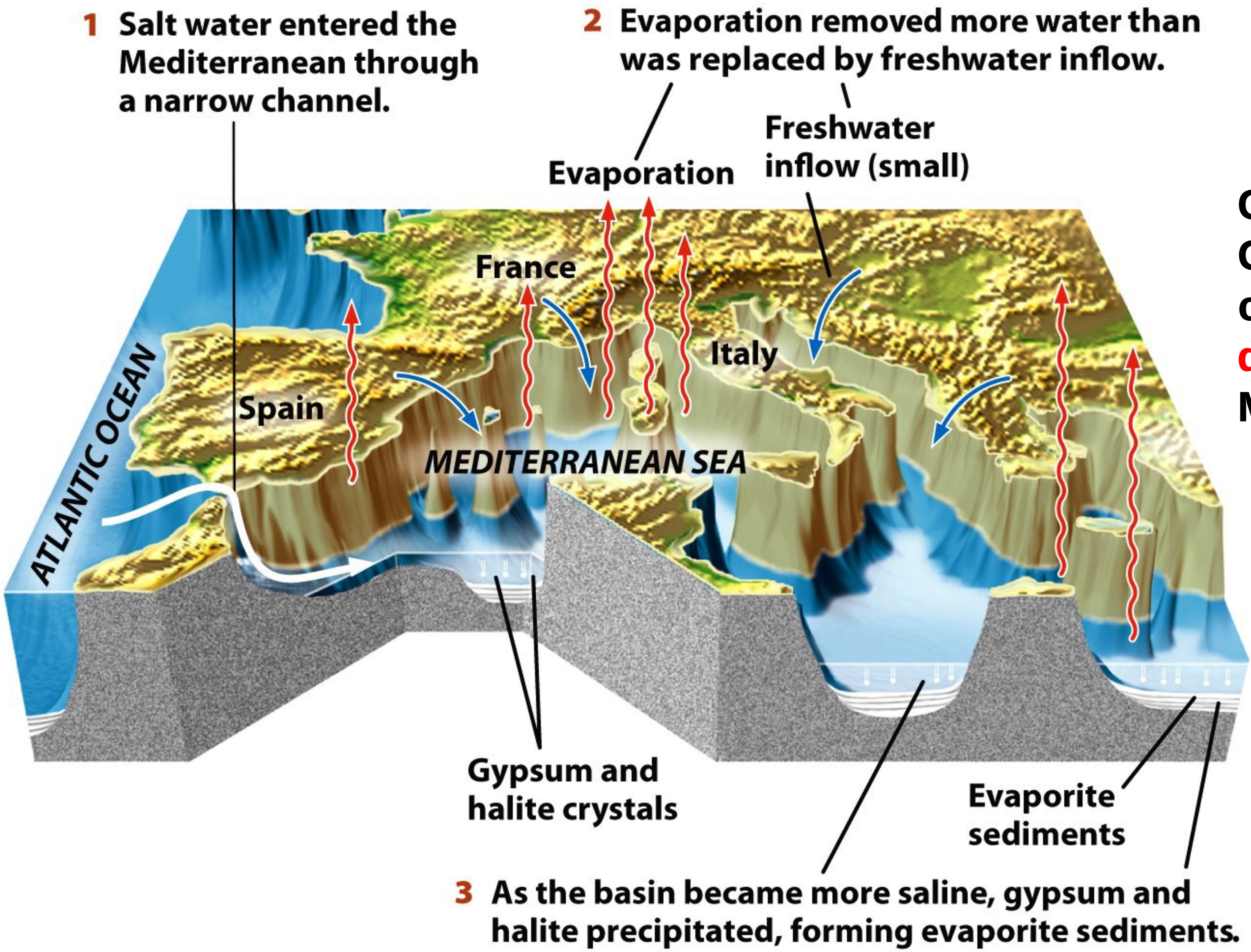


Rivers do not like local base levels and do all they can to back to one (or more) global curves



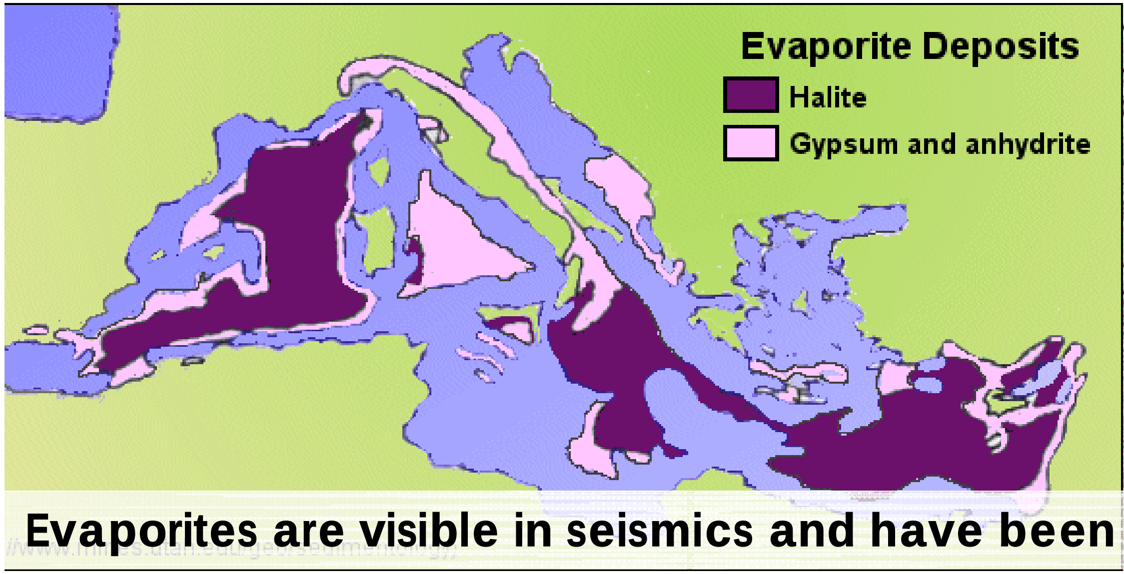
Major changes in river profile are caused by absolute sea level changes.

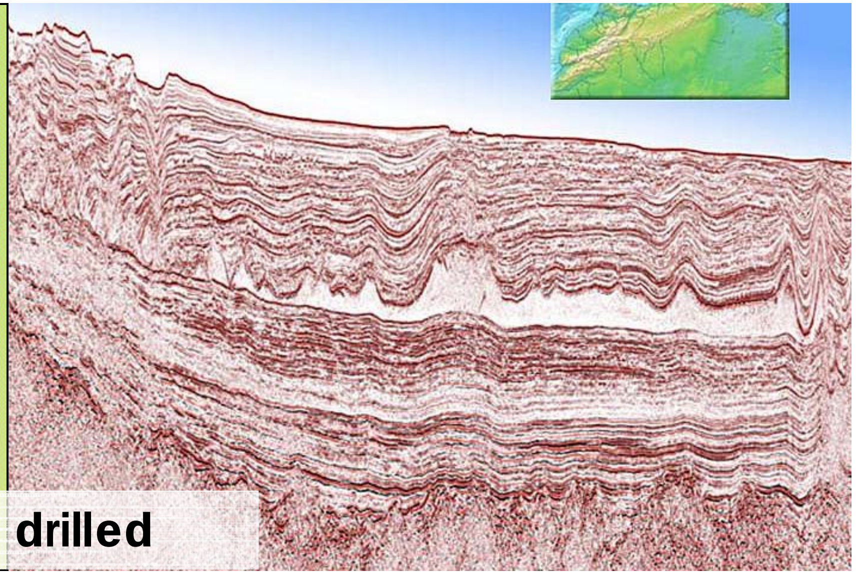
A major episode of sea level drop: The Messinian salinity crisis (5.8Ma)



Closure of the Gibraltar straight caused repeated desiccation of the Mediterranean

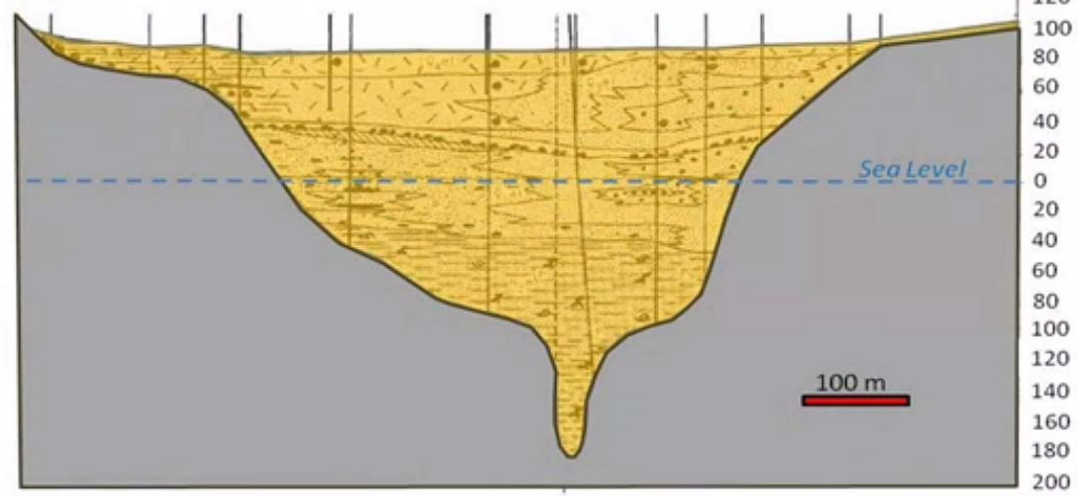
Evaporites are found presently at depths of up to 3-4 km





Evaporites are visible in seismics and have been drilled

What about the erosion? Check the Asswan dam!



http://www.youtube.com/watch?v=U5qTQpws5H0&noredirect=1

Rivers from mountains to the sea

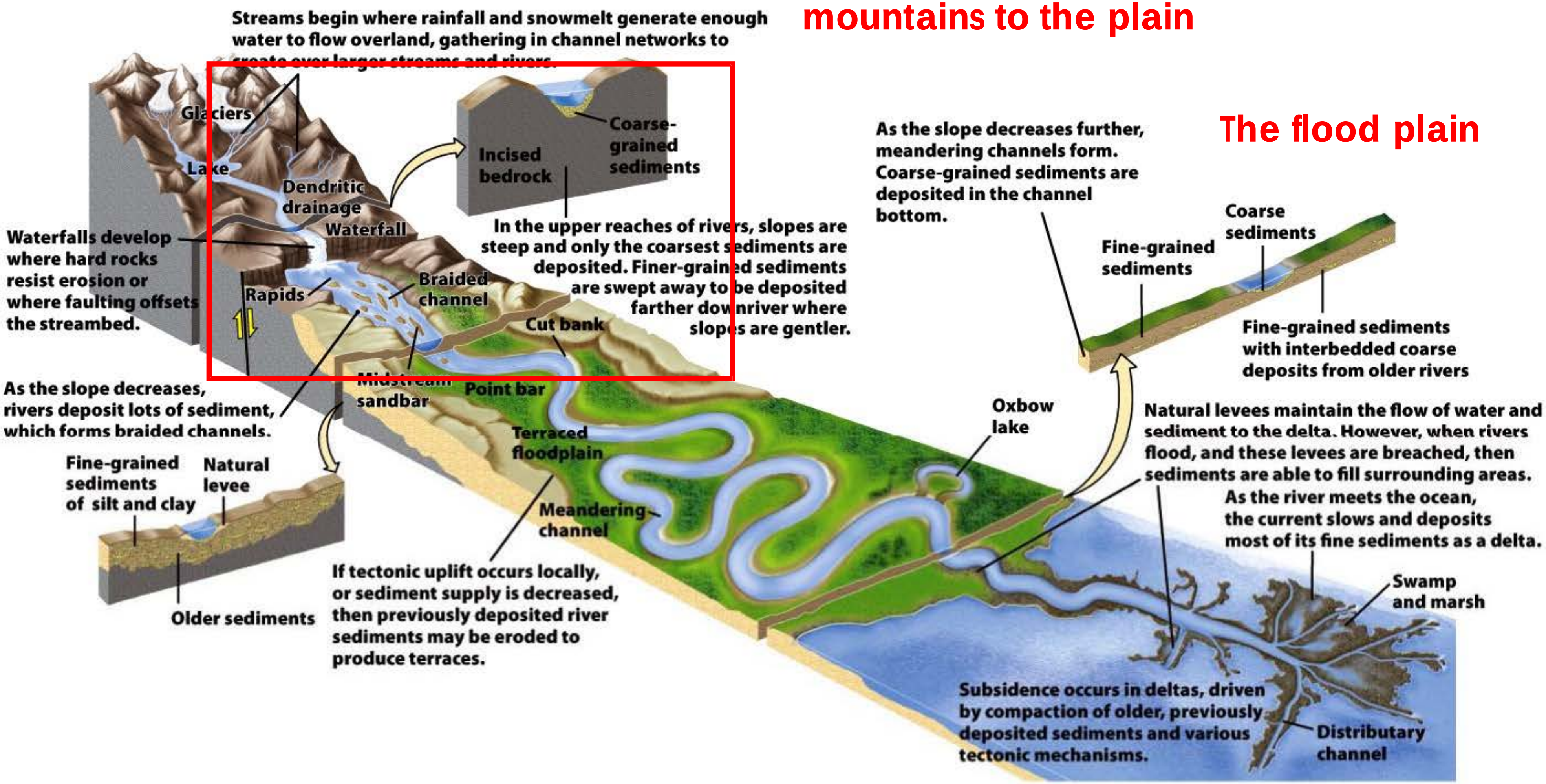


Figure 18.20
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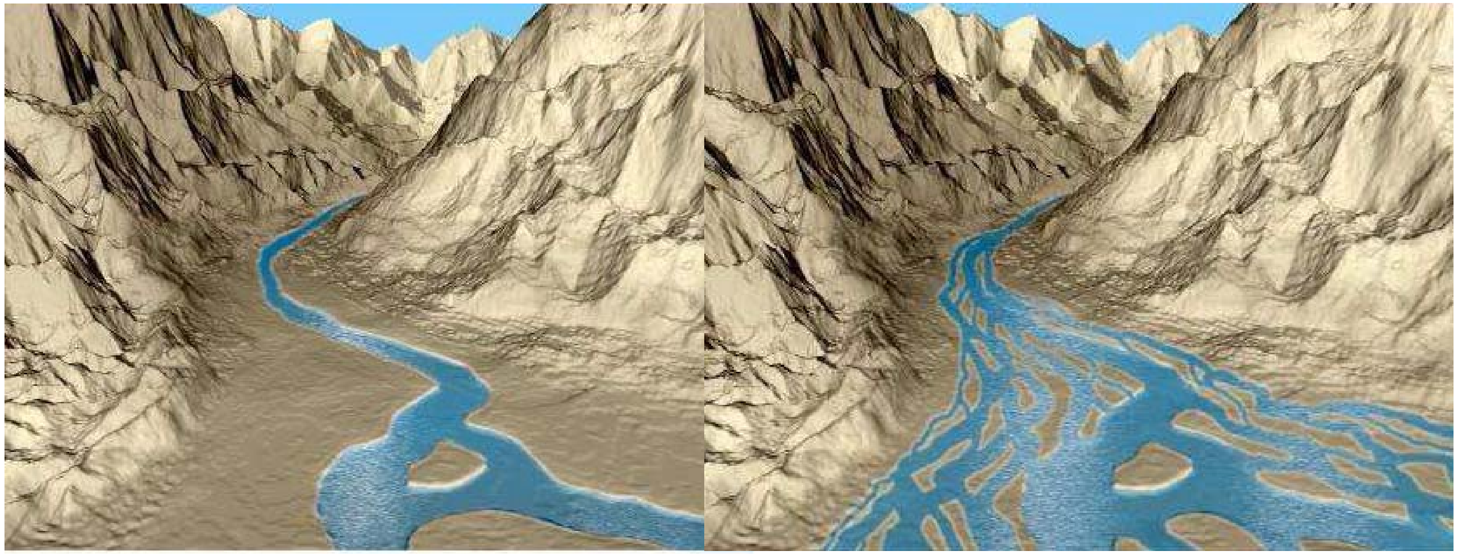
The mountain domain:

- **Large amounts of very heterogeneous sediments ready for transport (mostly coarse-grained)**
- **Variable precipitations and water discharges**

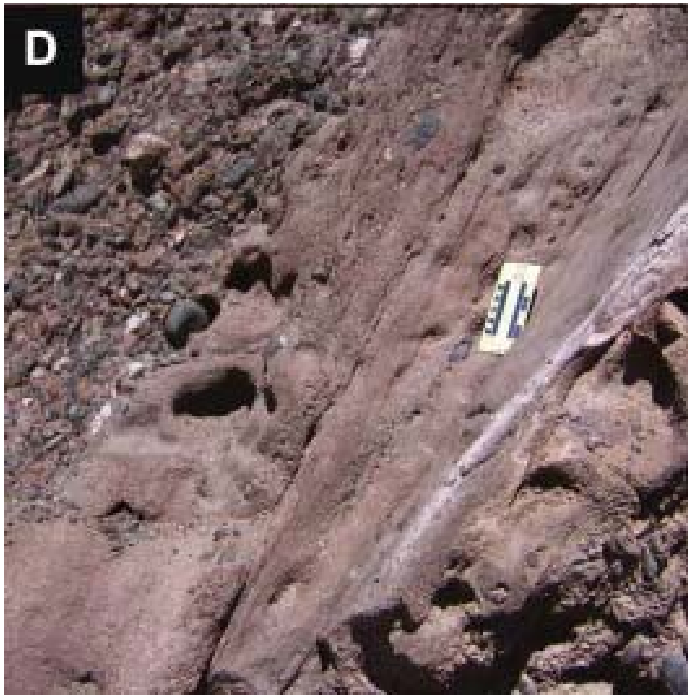


Braided rivers consists of a network of small channels separated by small and often temporary islands called braid bars

Favoured by

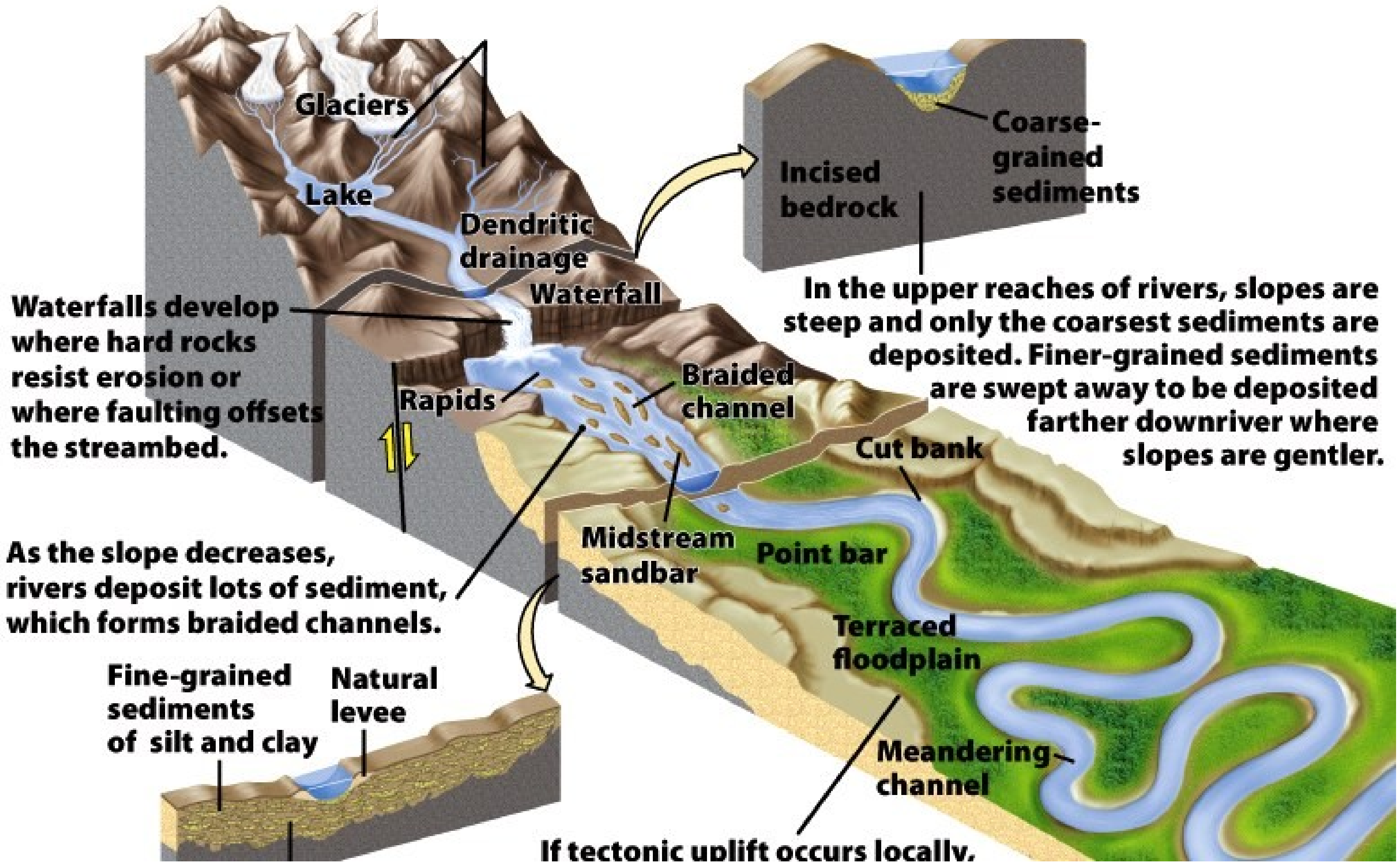
- abundant sediment supply
- high slope gradient (changes)
- erodible banks
- rapid and frequent variations in water discharge

Produce coarse-grained, **poorly organized** sediments



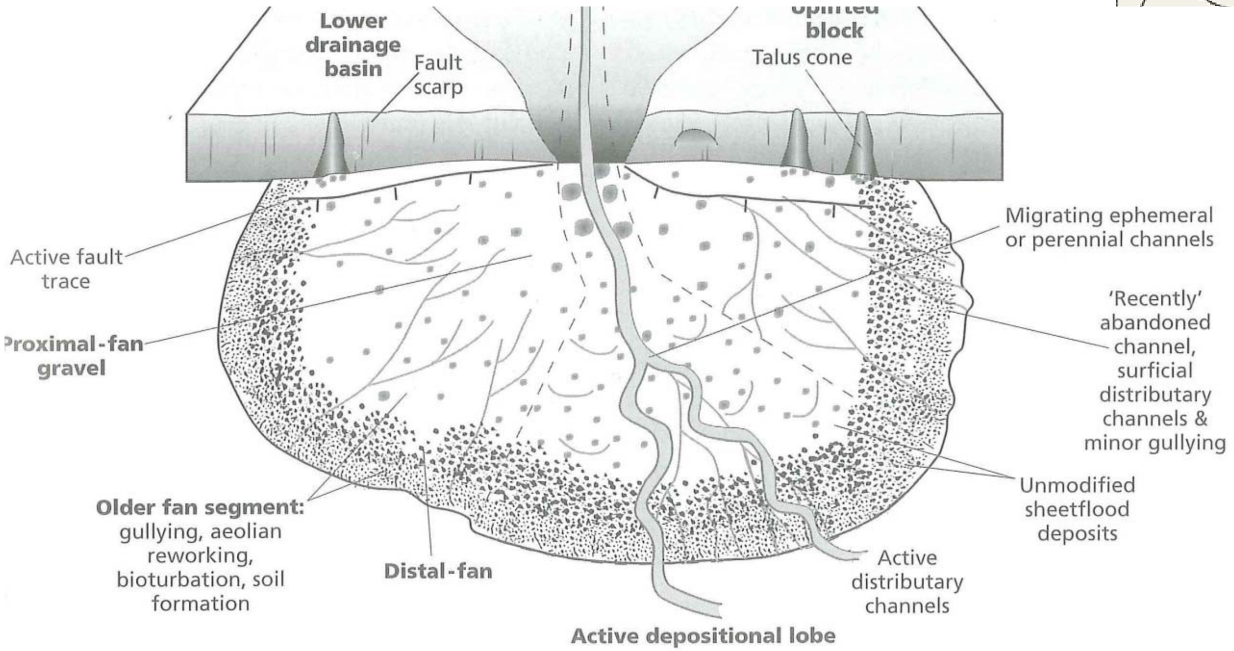
Excellent reservoirs

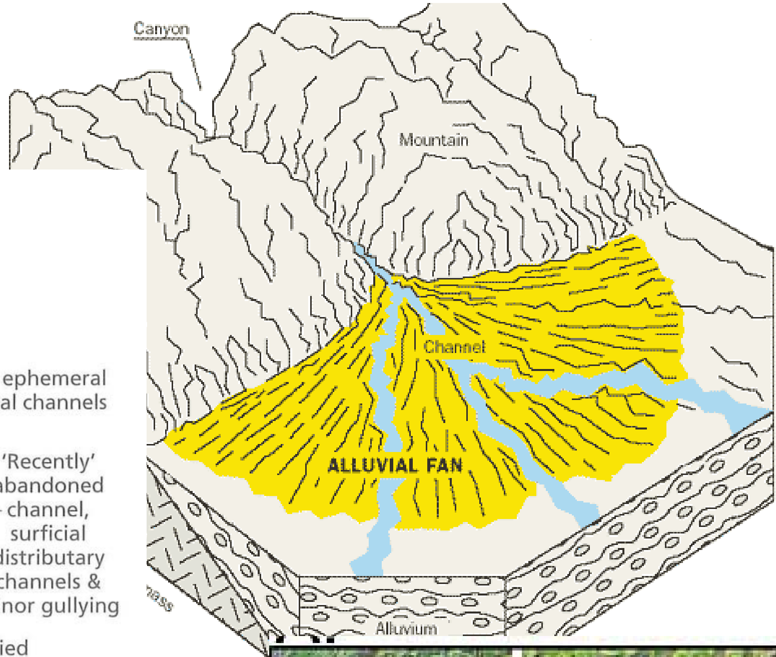
Entering the domains with low slope



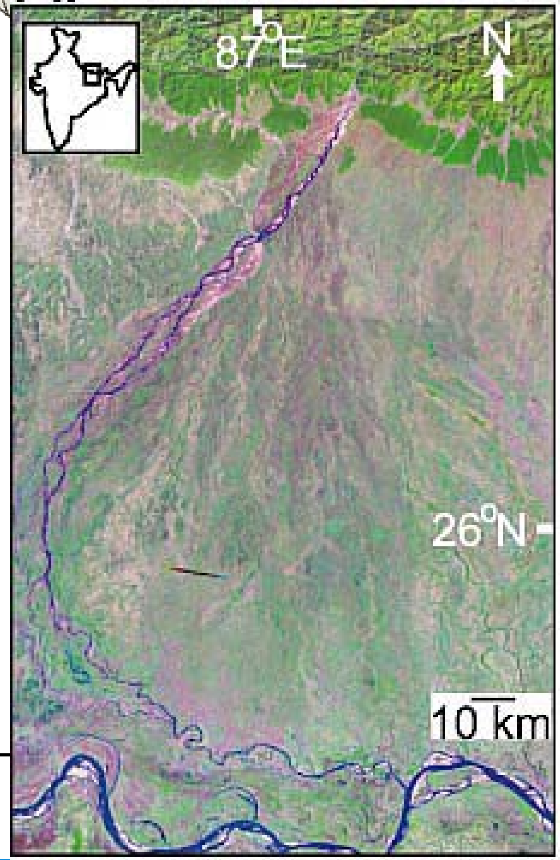
Major decrease in channel area => major drop in velocity => sediments are dumped

Alluvial fans form

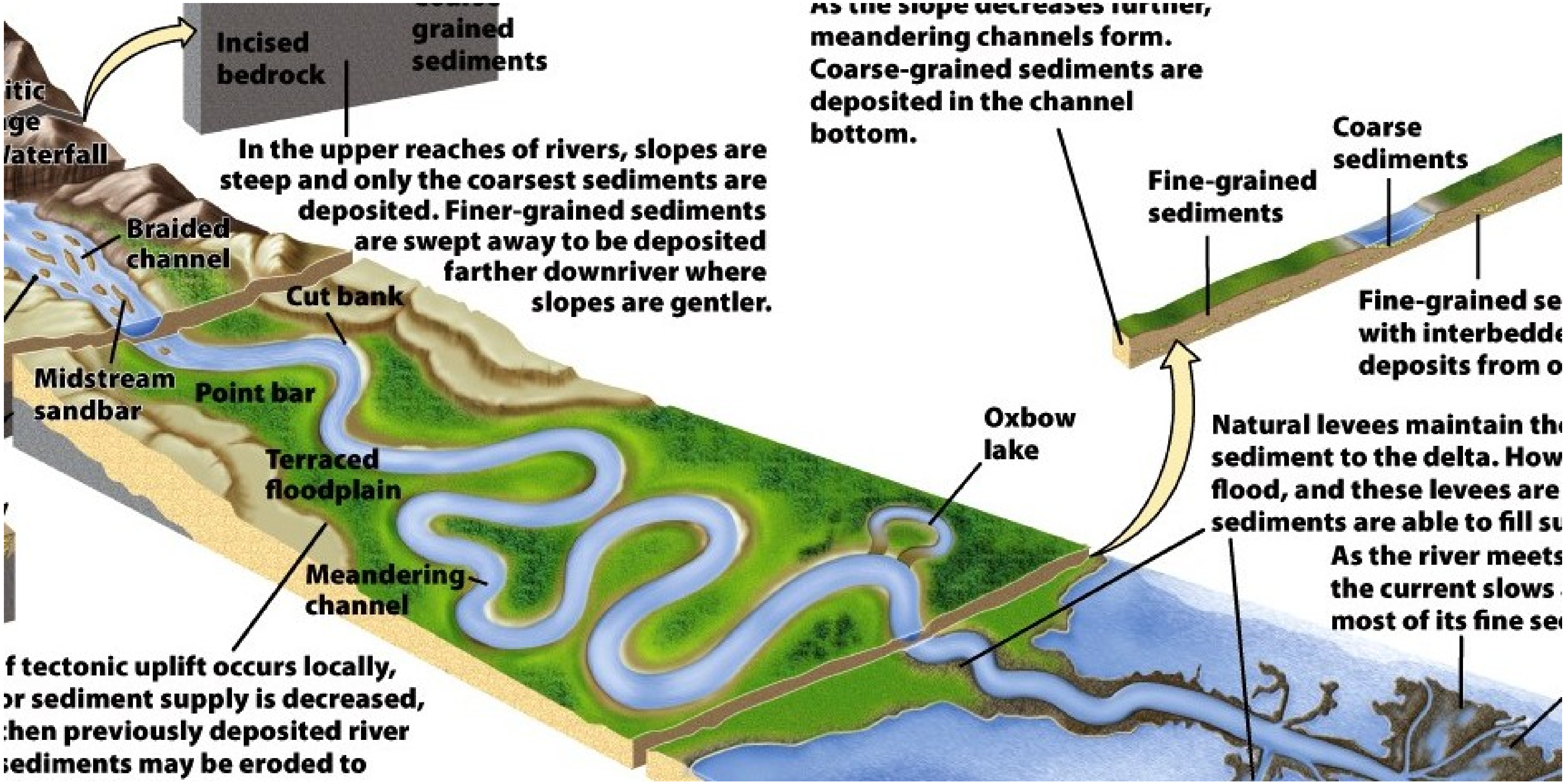




Can be huge
And form in short amount of time



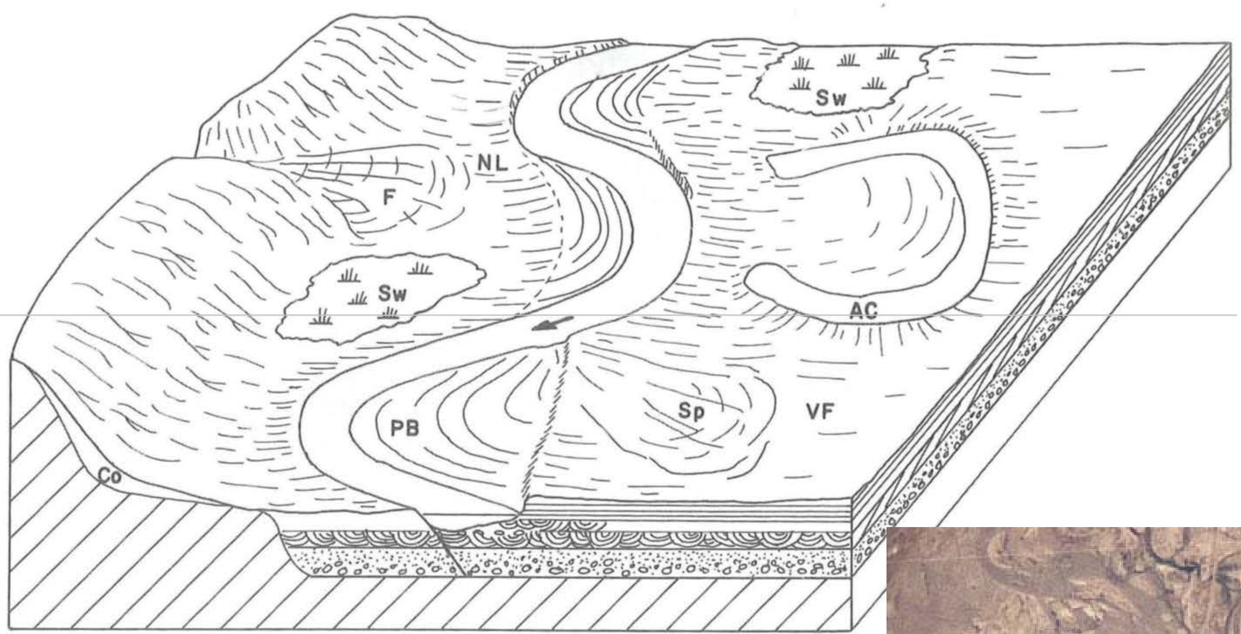
We then enter the flood plains



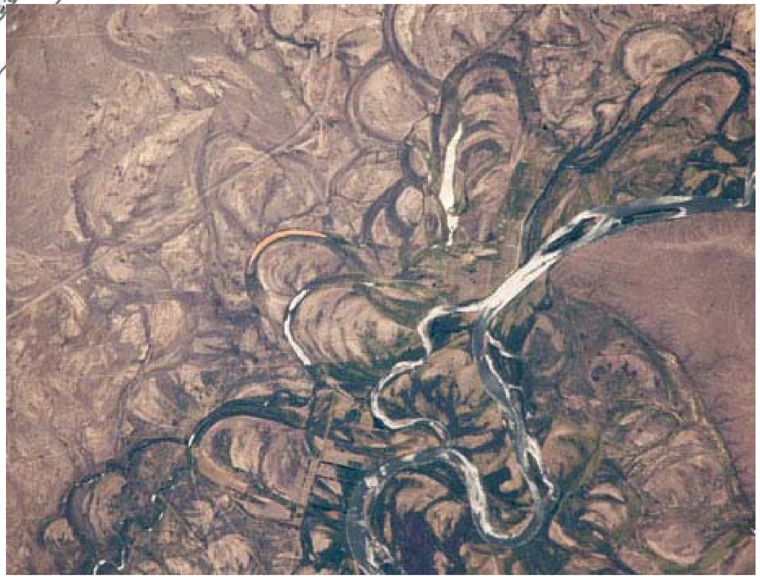
Flood plains are very important because many of the largest human agglomerations are on flood plains.

These offered access to fresh water, fertile soil, easy transportation, etc

Characterized by rivers meandering in (huge) flood plains



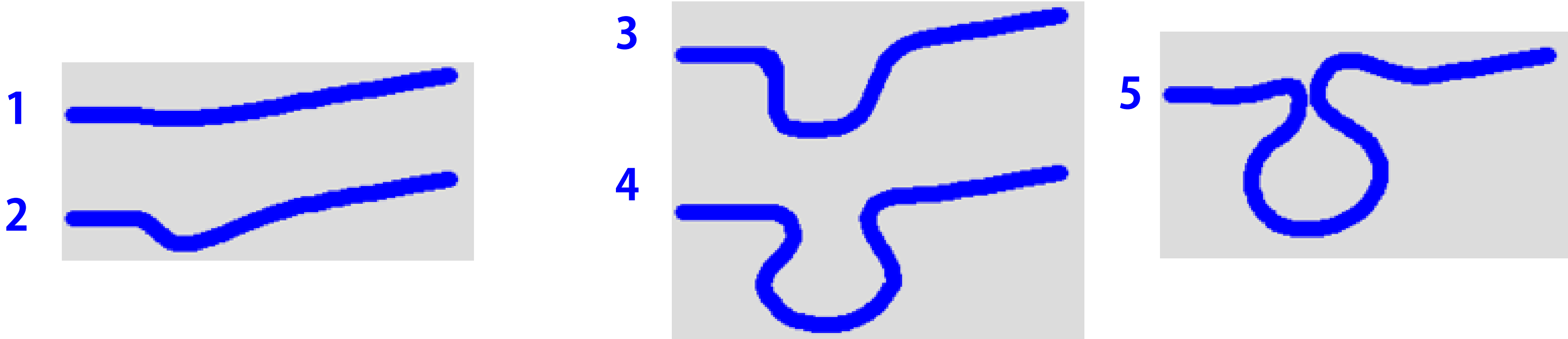
NL=natural levee, PB=point bar, Sp=splay deposit, Sw=swamp, AC=abandoned channel, VF=valley floor



Meanders continuously migrate and are associated with complex structures

Meanders

Meanders form because of the amplification of small, random, irregularities. There is a feed back driven by the differences in water speed in the internal and external parts of the curve

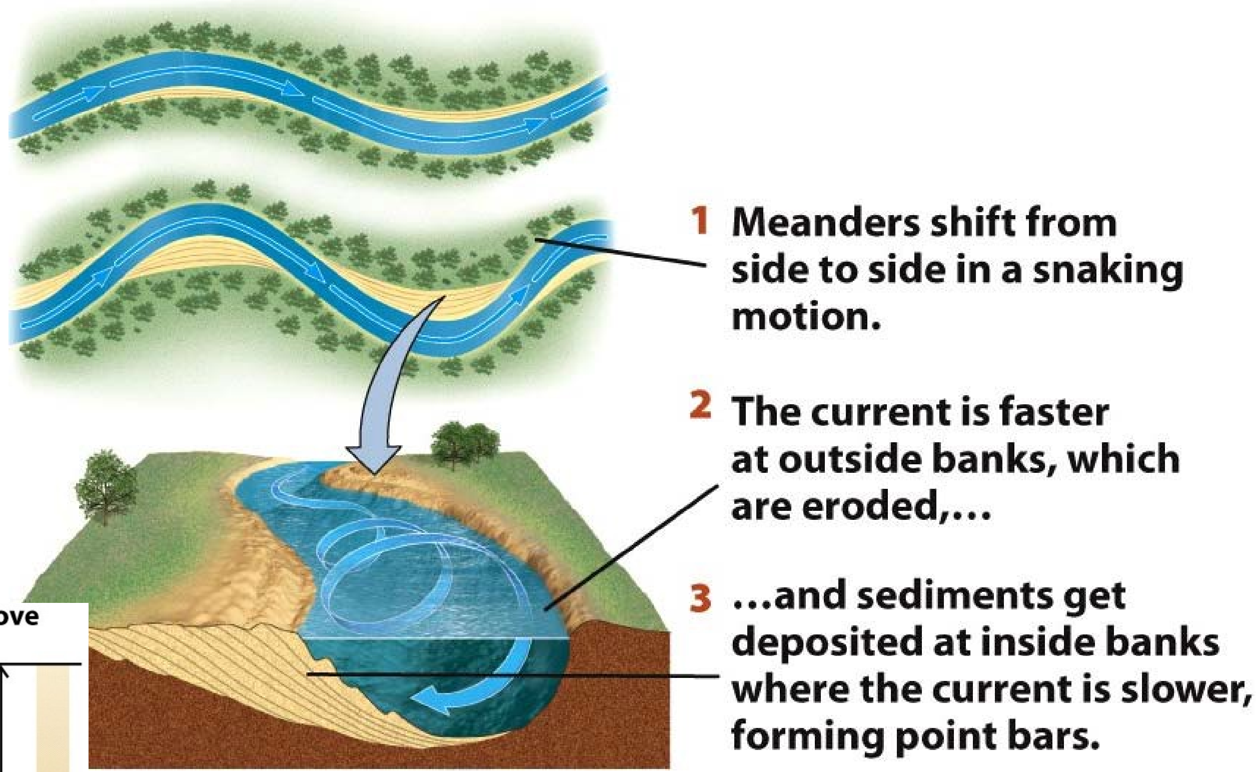


With respect to the straight, max slope line, meanders produce a larger length and, therefore, a lower slope.
This decreases the energy

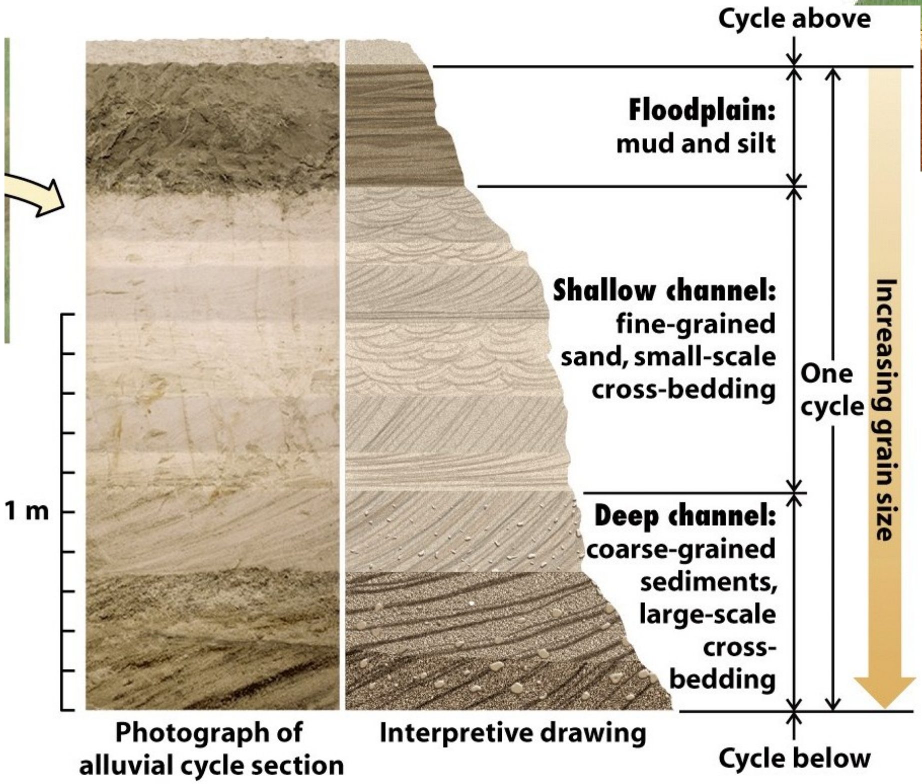
$$u \,\square\, C \sqrt{d\, s}$$

Meandering rivers like the Mississippi, carry a huge amount of very fine grained material (high capacity, low competence)

The meandering river typically flows in his channel creating different sedimentological structures



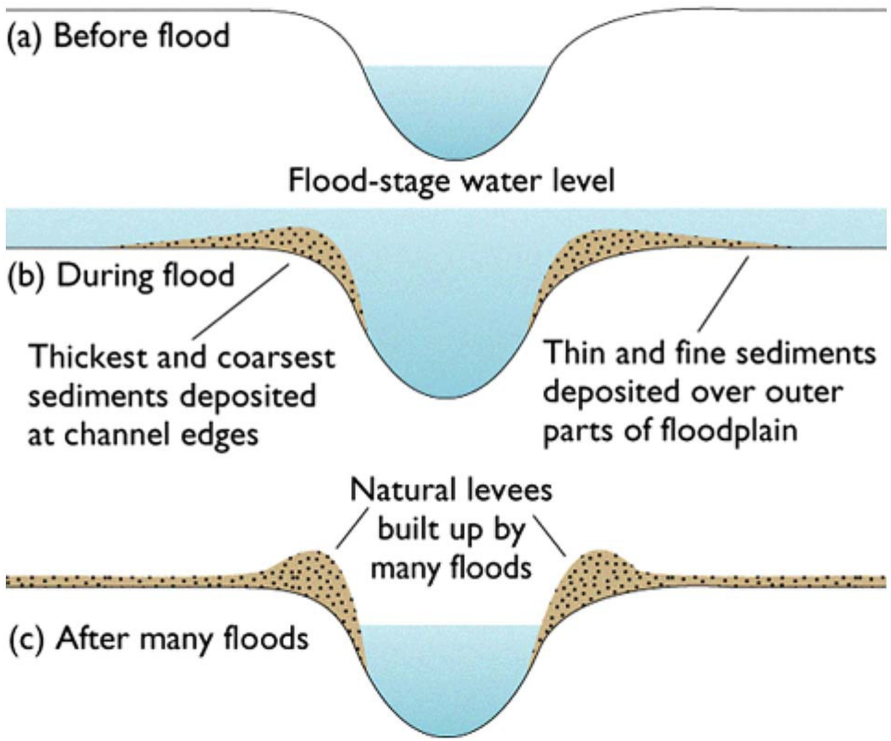
The geological record

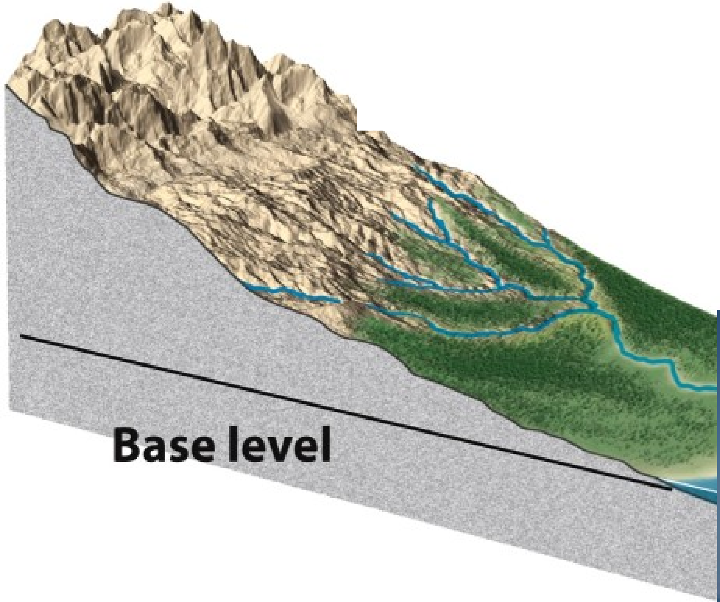


In times of flodding

Water spreads over the flood plain, looses velocity and drops sediments mostly immediately close to the borders of the channel

All sediments which were transported as suspended load in the river are now deposited





We are now ready for the biggest water body, the sea

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