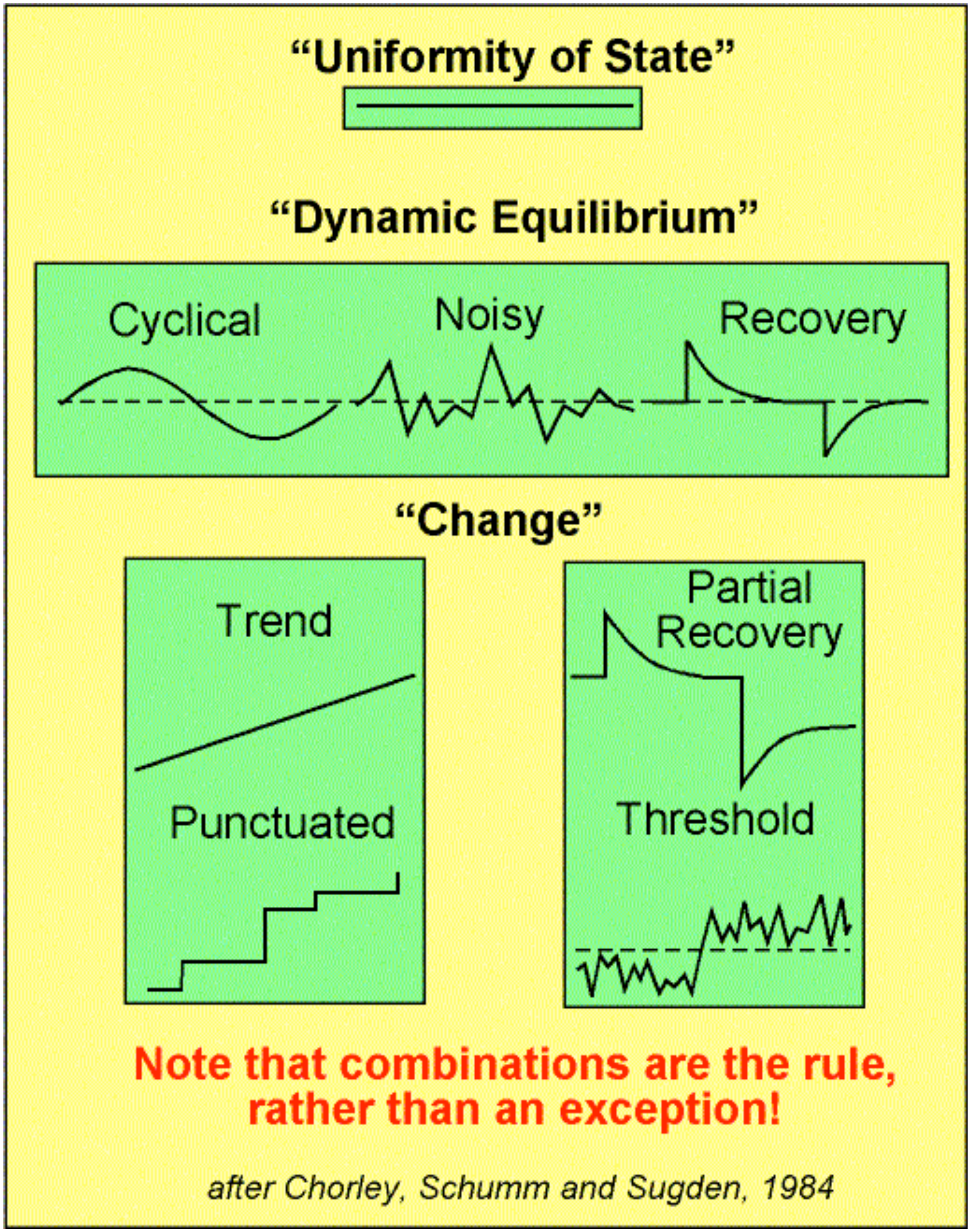
Geomorphological Methods

Systems Terminology

- Steady State
  - A time-invariant condition
- Equilibrium
  - A balance between form and process
- Dynamic Equilibrium
  - State changes around a central point

Examples

- Steady-state
- Dynamic equilibrium
- Change



Note that combinations are the rule, rather than an exception!

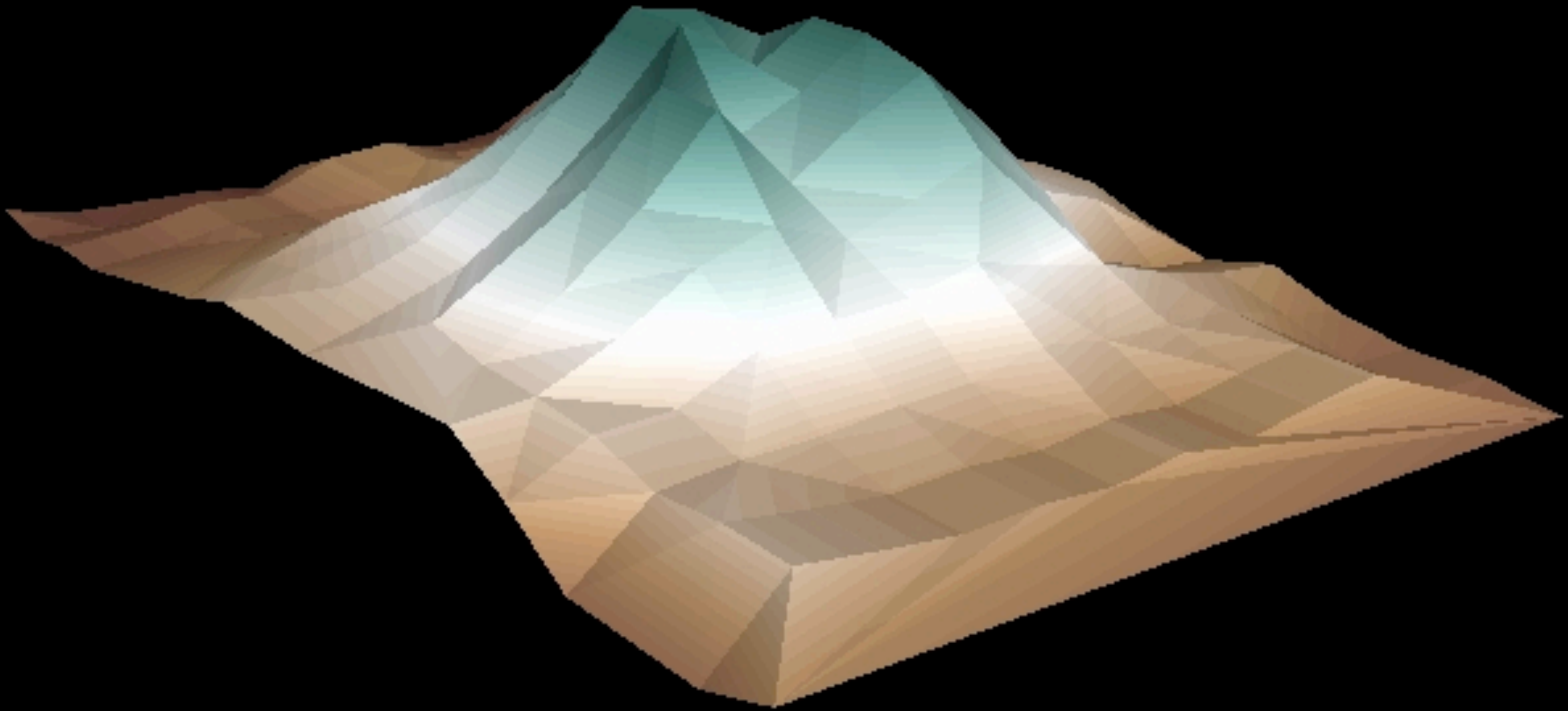
after Chorley, Schumm and Sugden, 1984

Systems Terminology

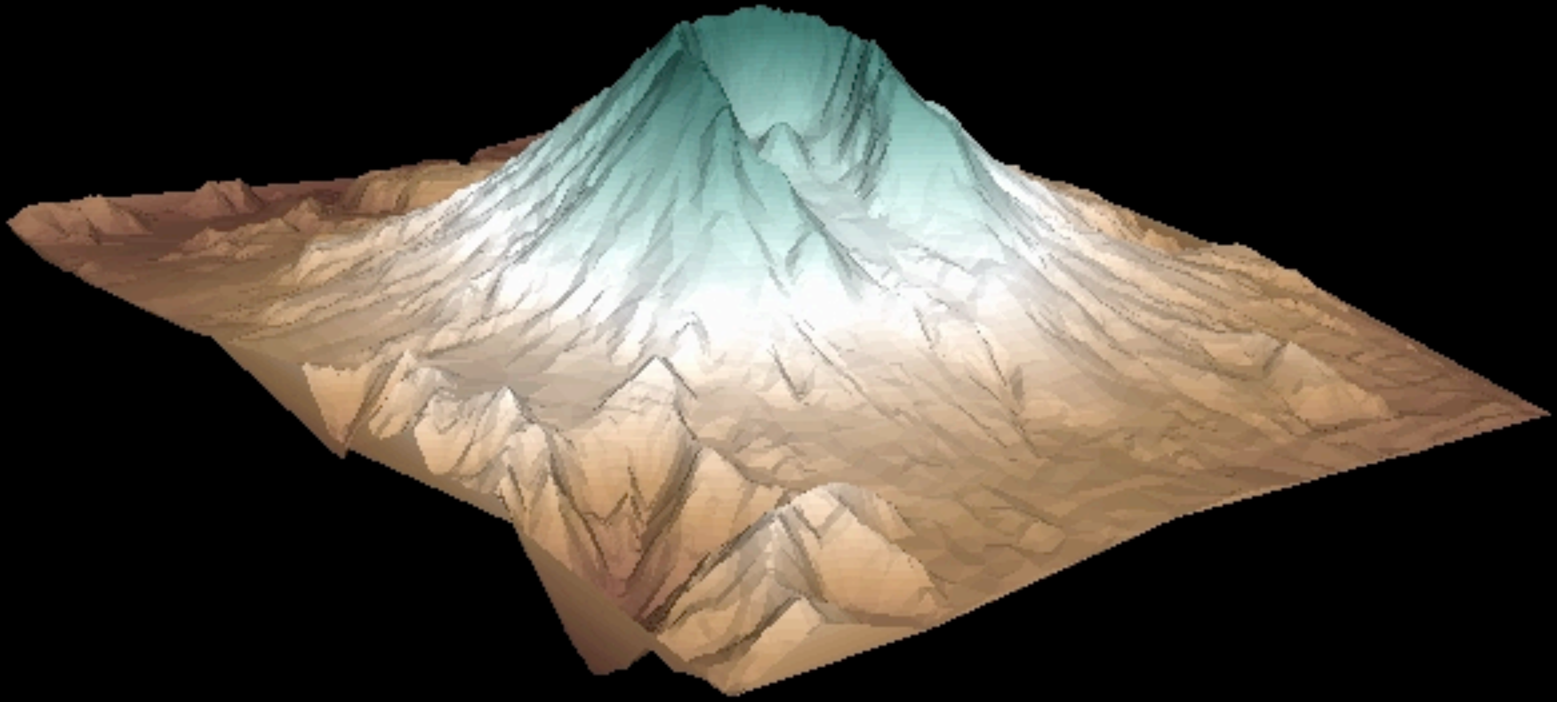
- **Threshold**
  - A condition that must be exceeded in order for state to change within the system
- **Feedback**
  - Positive – self-reinforcing; accelerating
  - Negative – self-regulating; damping
- **Equifinality**
  - Similar final states achieved through different mechanisms

Scale matters…

GTOPO30



USGS 30m: Mount St. Helens



Time and Space in Geomorphology

Figure 1. EARTH SYSTEM PROCESSES:
CHARACTERISTIC SPACE AND TIME SCALES

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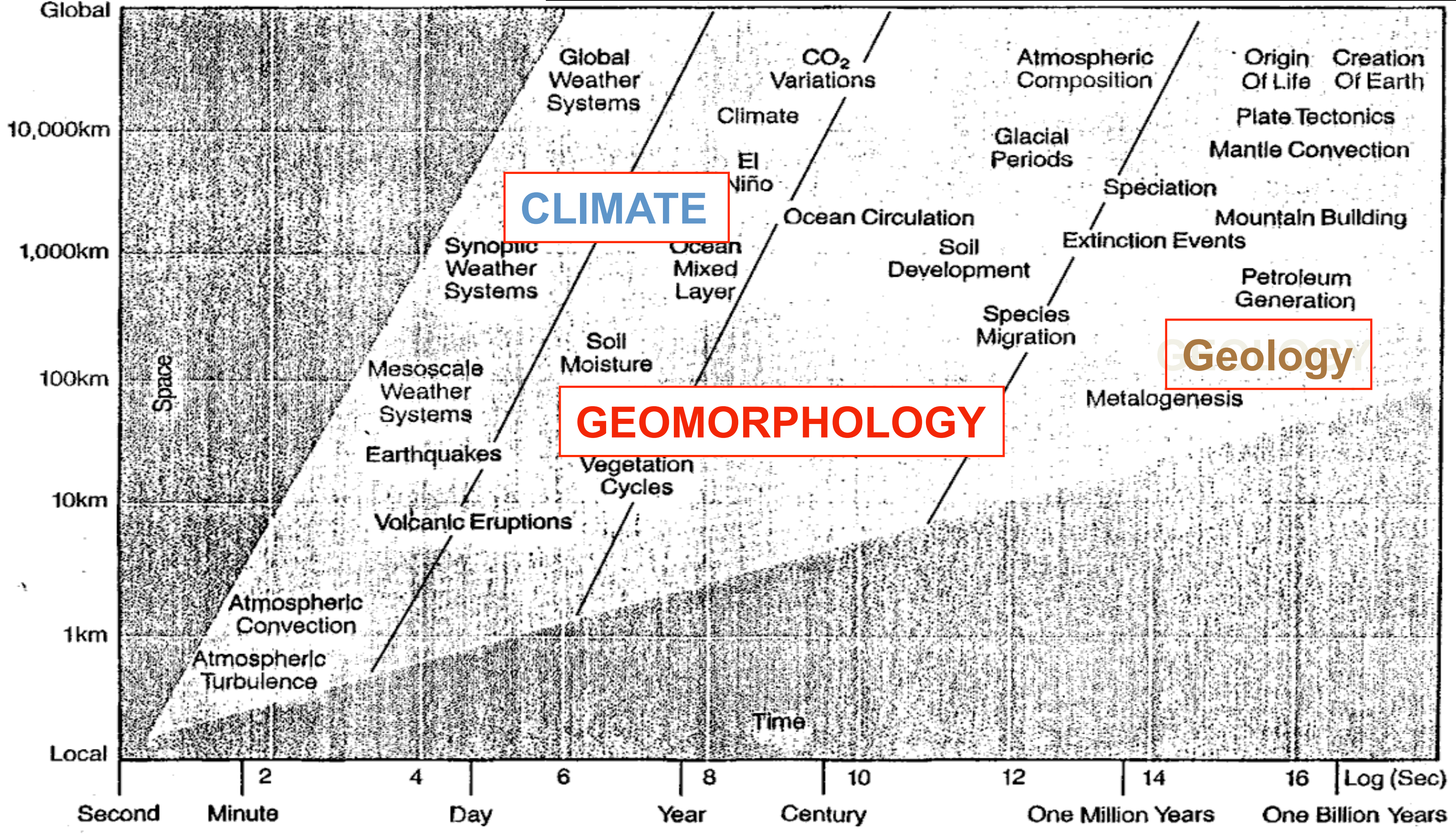
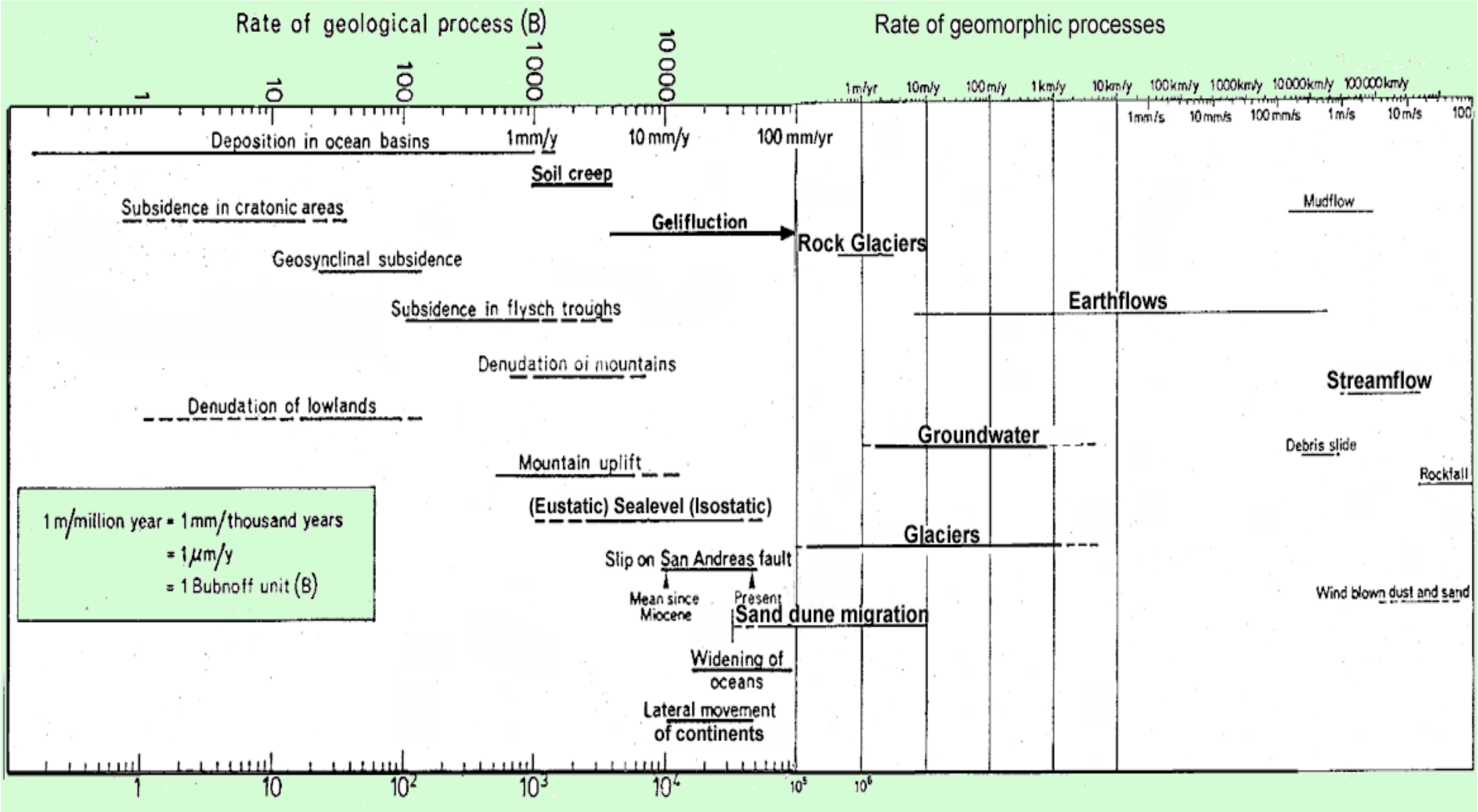
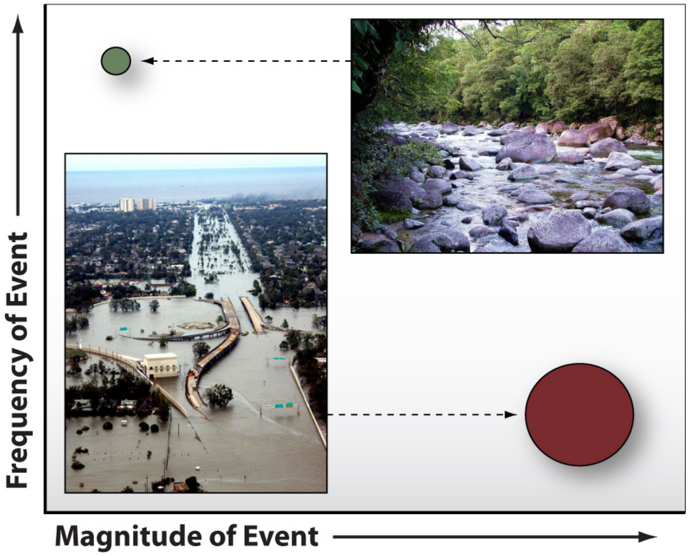


Rates of Processes

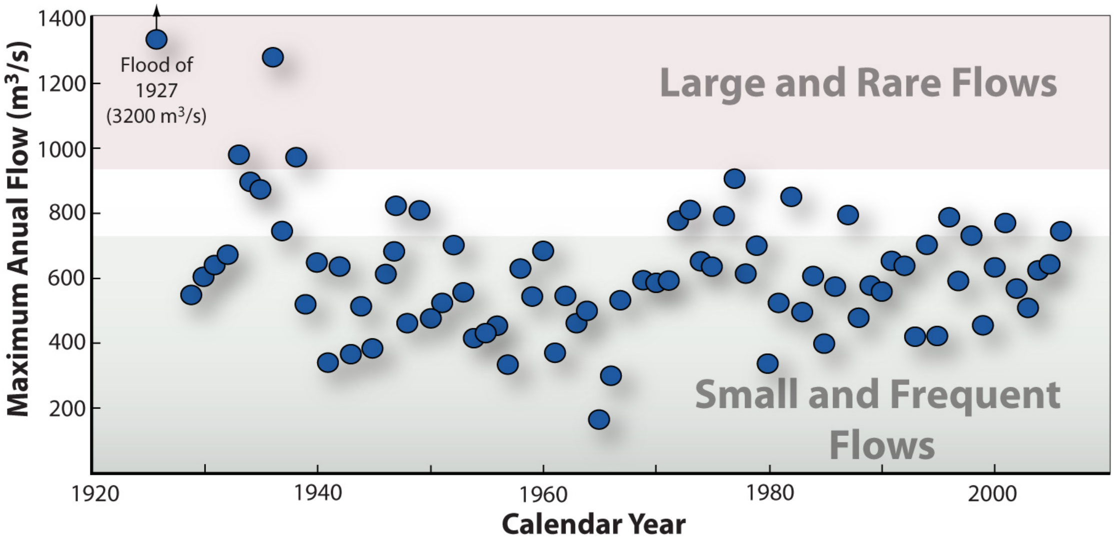


Magnitude vs. Frequency



Small events are common, occurring with great **frequency** they may have little individual effect on the landscape.

Large events are rare; they might occur only once in person's lifetime. Yet, such large events can dramatically **change** the form of the landscape.

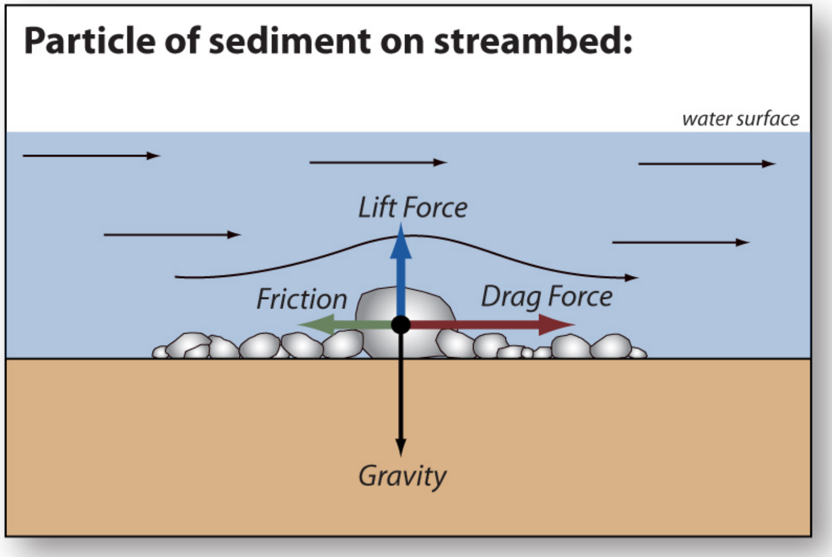


Even in humid, well-watered northeastern North America, there is great variability in annual flood flows. The largest annual flood (1927, immense damage and channel change) is almost 20 times greater than the smallest annual flood.

How do geomorphic processes work?

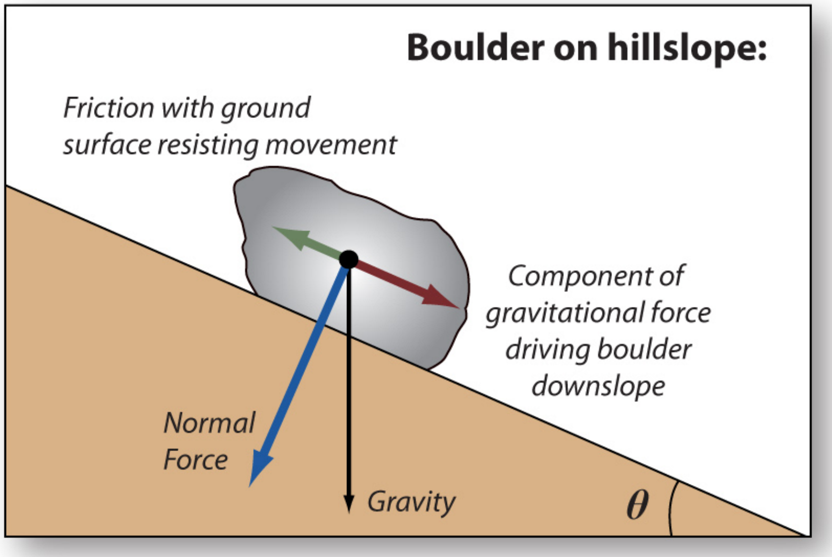
Process studies…

Force balances



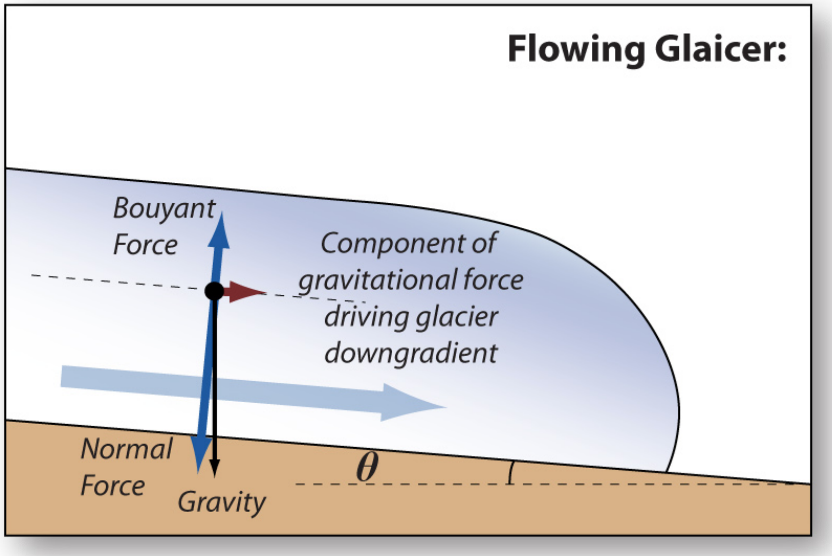
Sediment on a stream bed is subject to a variety of forces. The **gravity force** holds the grain on the bed opposing the **lift force** generated by the current. The current also applies a drag force to the grain. The drag force is resisted both by **frictional forces** and by the resistance offered 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.

Force balances



A **boulder** on a hillslope remains stable as long as the **frictional force**, holding the boulder in place, exceeds the **driving force**. Once the driving force exceeds the frictional force, down goes the boulder. Earthquakes, tectonic tilting, and slope erosion can all increase the driving force.

Force balances



Ice flows by deforming and sliding along its bed. The **driving force is gravity**, modulated by the slope of the ice surface. The **resisting forces** include the ability of ice to resist internal deformation and the frictional resistance to sliding of material at the bed of the ice.

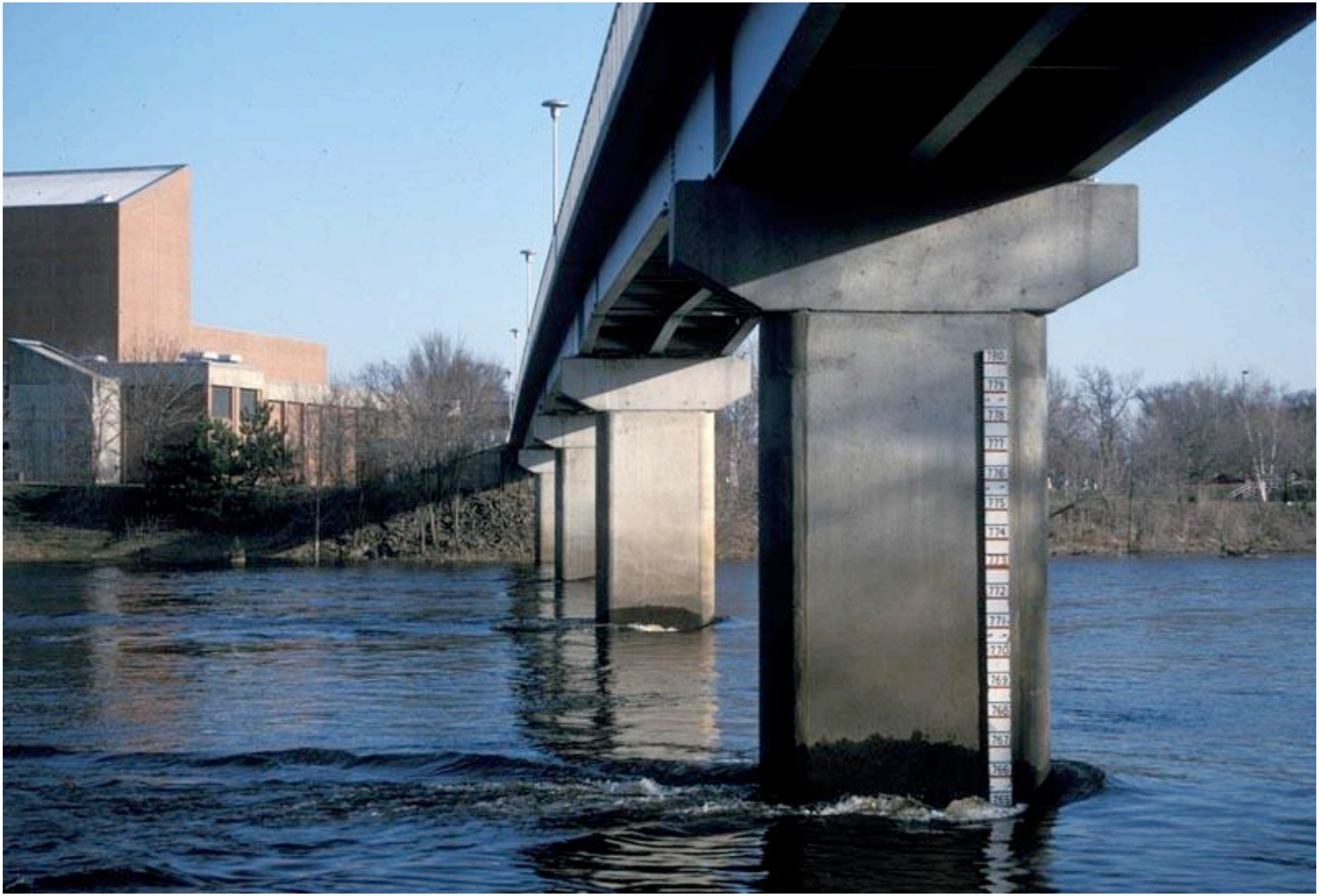
Landscape
Lith
Lith
Lith
Landscape
Landscape
SES.

How fast does this happen?

Process studies and field measurements…

USGS suspended sediment sampling apparatus, Cowlitz River, Washington (1982)

Stream gauge on bridge support, Chippewa River, Wisconsin



GPS Surveying in the Mojave Desert, California

Repeated high-resolution surveys can document landscape change and characterize landform.

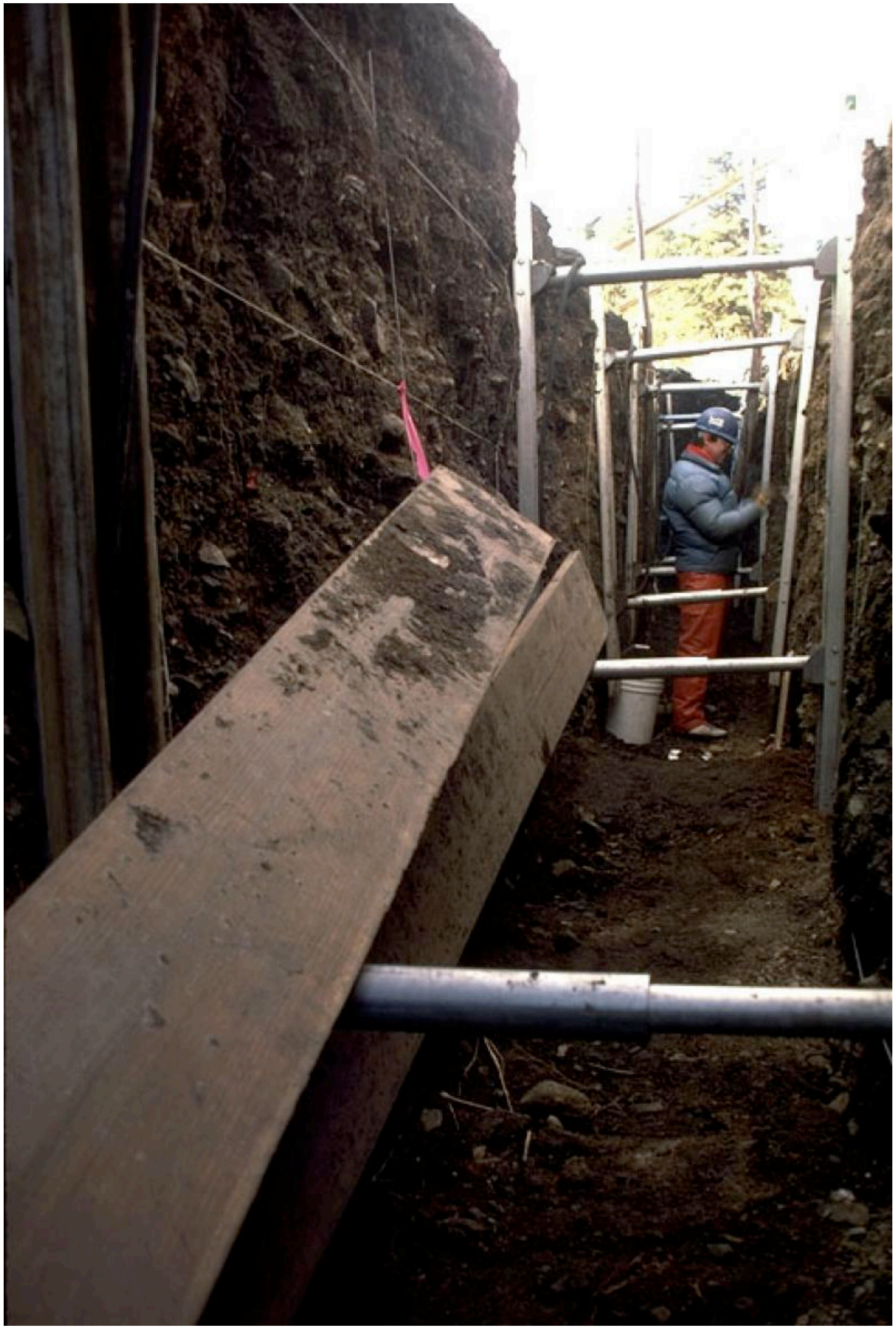
What is this landform made of?

Field studies…

Trench in floodplain sediments, Richmond, Virginia

Drilling into floodplain sediments, Williamstown, Massachusetts

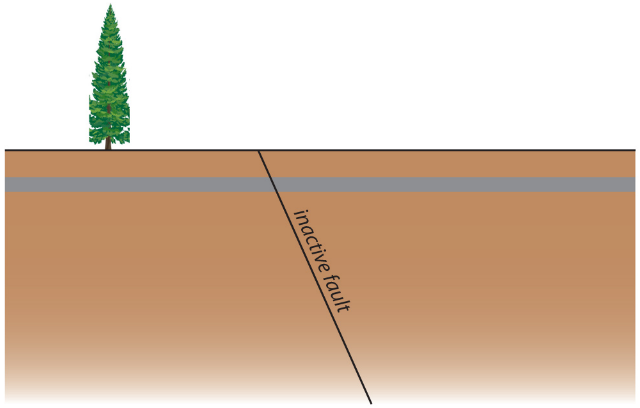
Logging the wall of a trench across the San Andreas Fault, California



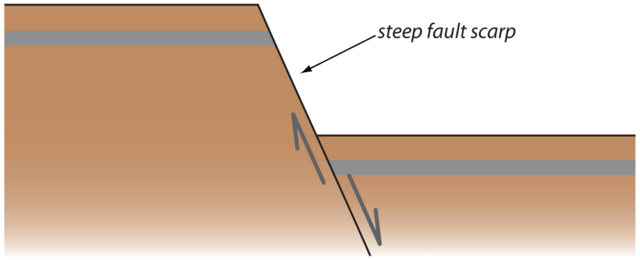
How old is this rock, surface, or landform?

Geomorphological dating techniques…

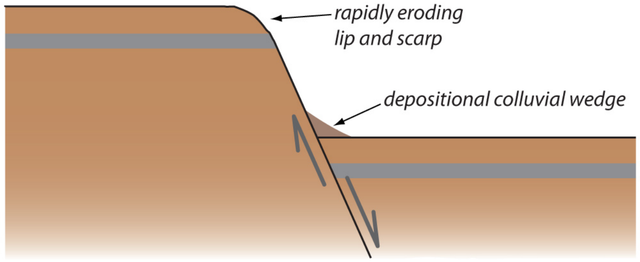
Scarp degradation



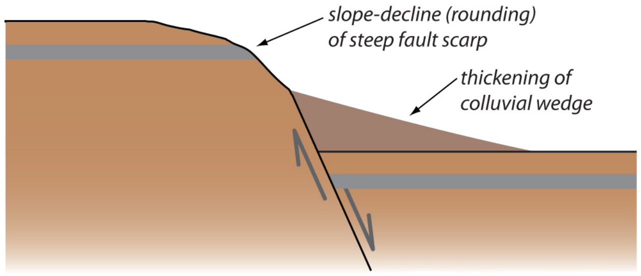
Time 1: The landsurface is smooth and undisplaced.



Time 2: The fault ruptures, creating a steep **fault scarp** that offsets the two relatively flat lying portions of landscape.

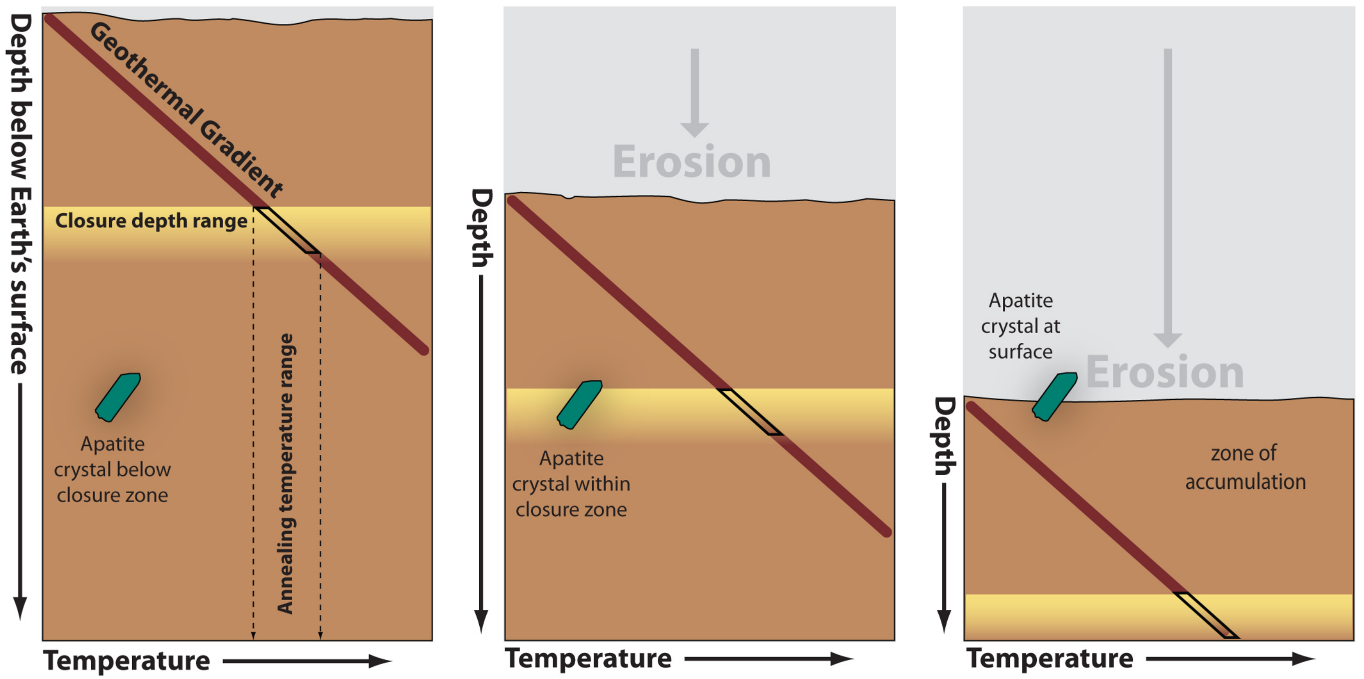


Time 3: The steep scarp quickly begins to erode. Eroded material piles up on the downthrown block creating a **colluvial wedge**.



Time 4: Over time, the colluvial wedge thickens and extends. It preserves a record of the timing of erosion and the volume of material shed from the scarp.

Thermochronometry



The apatite crystal is deep below the surface, where the temperature is warm enough that nuclides **diffuse** out of the crystal, or fission tracks produced by radiodecay rapidly **anneal** (fade away).

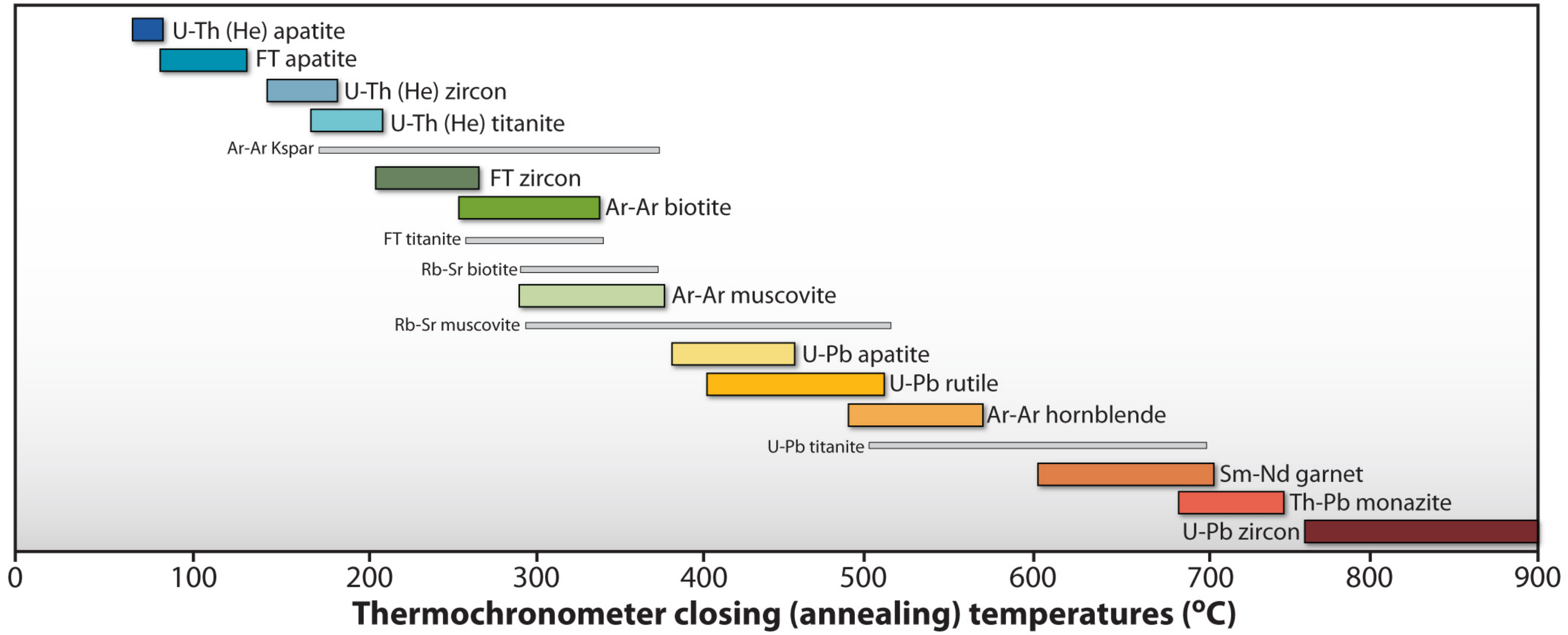
As erosion brings the crystal closer to the surface and the rock cools, the crystal enters the **closure zone** where radionuclides diffuse and fission tracks anneal more slowly than at depth.

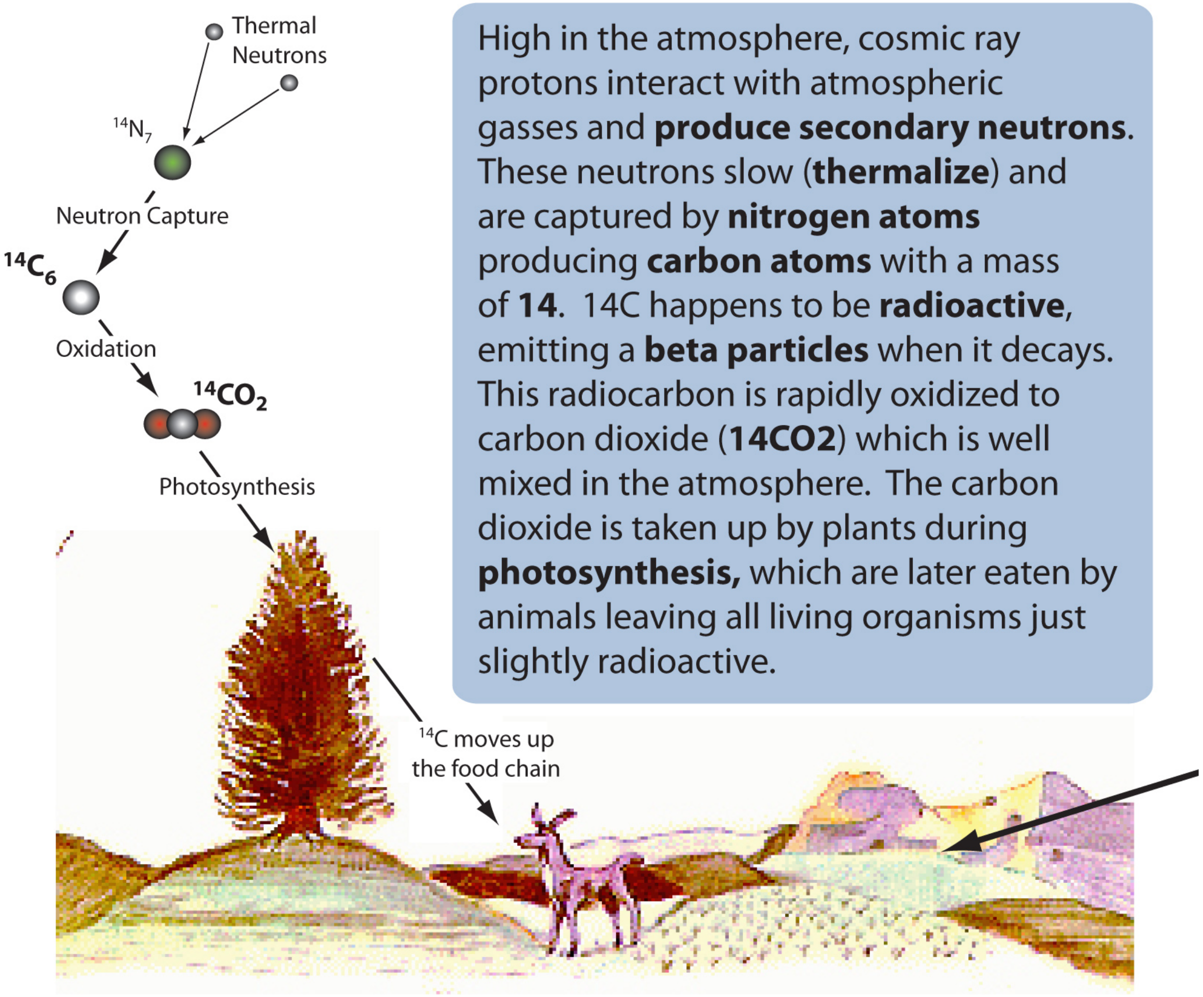
Once the crystal moves above the closure depth, fission tracks cease to anneal and radionuclides are **retained**. The fission track or radiometric age of the crystal reflects the time it took erosion to **remove the depth of rock** overlying the closure depth. This depth/time relationship can be interpreted as a **long-term erosion rate**.

Source Notes:

Thermochronometry

Different minerals have different cooling temperatures and thus reveal erosion rates over different time scales





Thermal Neutrons

$^{14}N_7$

Neutron Capture

$^{14}C_6$

Oxidation

$^{14}CO_2$

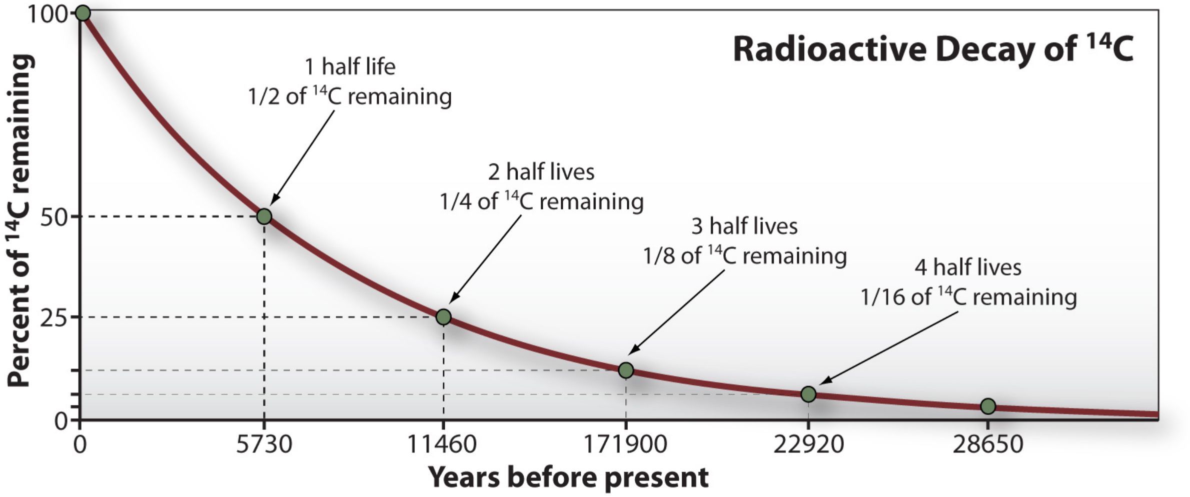
Photosynthesis

^{14}C moves up the food chain

High in the atmosphere, cosmic ray protons interact with atmospheric gasses and **produce secondary neutrons**. These neutrons slow (**thermalize**) and are captured by **nitrogen atoms** producing **carbon atoms** with a mass of **14**. 14C happens to be **radioactive**, emitting a **beta particles** when it decays. This radiocarbon is rapidly oxidized to carbon dioxide (**14CO2**) which is well mixed in the atmosphere. The carbon dioxide is taken up by plants during **photosynthesis,** which are later eaten by animals leaving all living organisms just slightly radioactive.

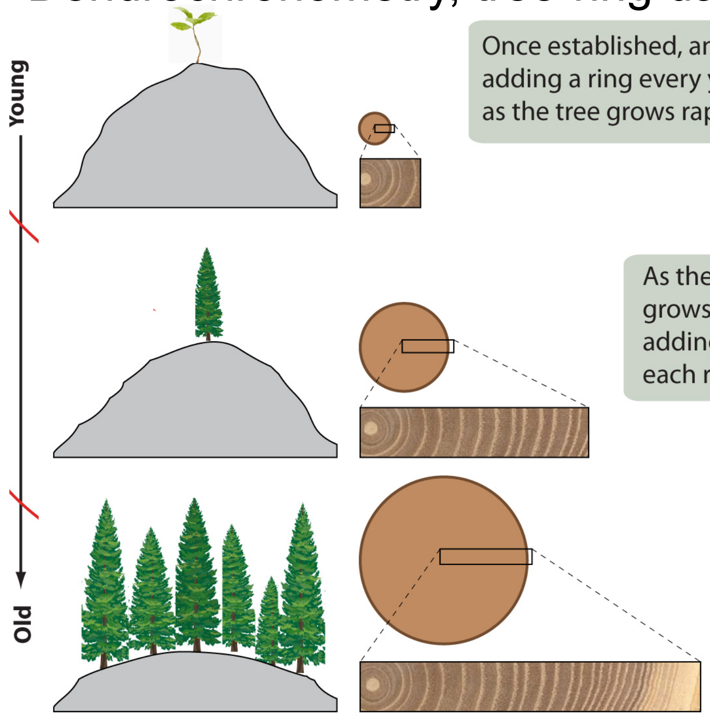
Radio carbon dating

Radio carbon dating



The **time of death** of organic material can be **dated** using the concentration of **radiocarbon** (14C) remaining in the material. As the object ages, radiocarbon atoms decay back to nitrogen at a steady rate; thus, the concentration is reduced over time. Because the half life (decay rate) of radiocarbon is well known, we can estimate an age from a radiocarbon concentration. In practice, radiocarbon dating is useful back perhaps 7 or 8 halflives, about **40,000 years**.

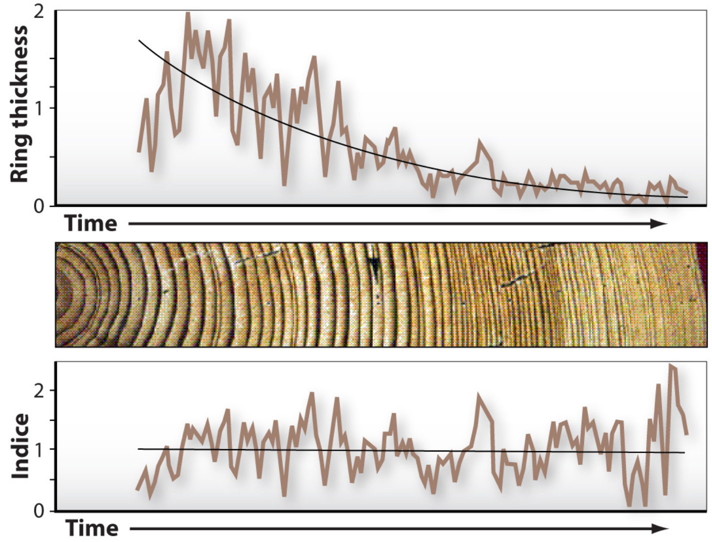
Dendrochronometry, tree-ring dating



Once established, and if in the open, a tree grows easily, adding a ring every year. These early rings tend to be thick as the tree grows rapidly.

As the tree matures, the diameter of the trunk grows larger and thus even if the tree is adding the same amount of mass every year, each ring grows thinner.

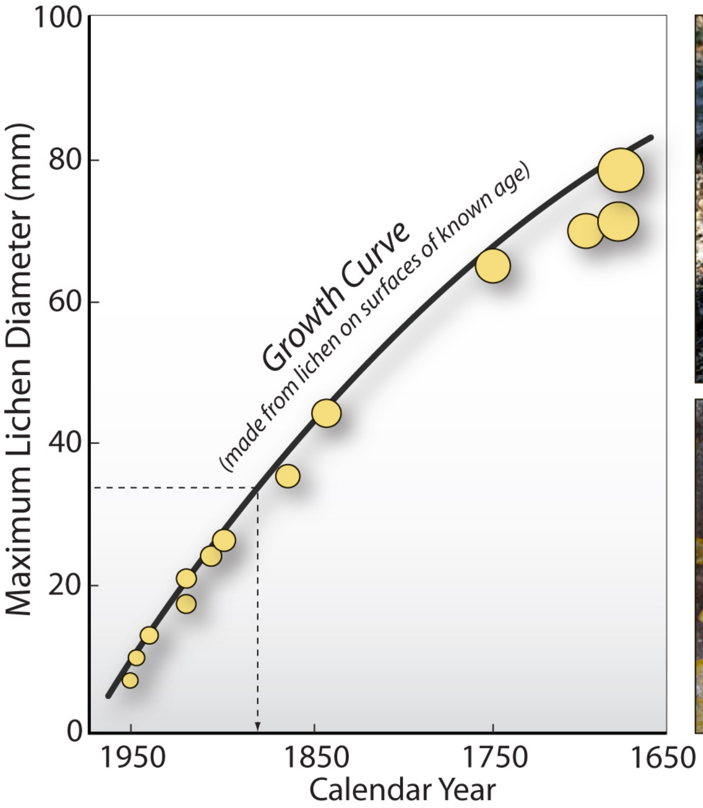
As the forest matures, the tree may be crowded by others competing for sunlight, nutrients, and water. This competition can further slow growth resulting in thinner rings.

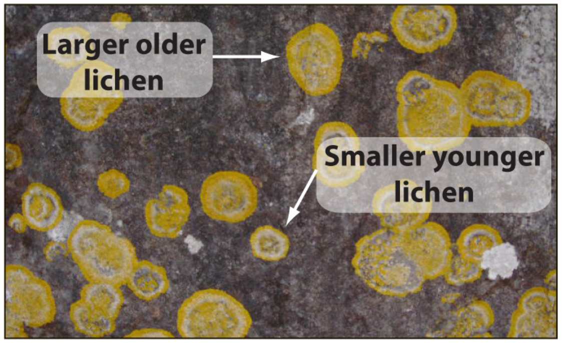


As a tree grows, rings added later tend to be thinner than rings added earlier. If the goal of tree ring analysis is to decipher changes in ring width related to climate (temperature, water and cold stress) then this secular trend, the thinning of rings over time needs to be filtered out usually by detrending the data using a curve fit. The resulting deviation from the curve is considered a "rign width index" and used for paleoclimate interpretation.

It's actually only half of the figure. Don't know if that matters though. As per the copyright below, there may be some permission issues. Could just make up a hypothetical curve if need be.

Lichenometry

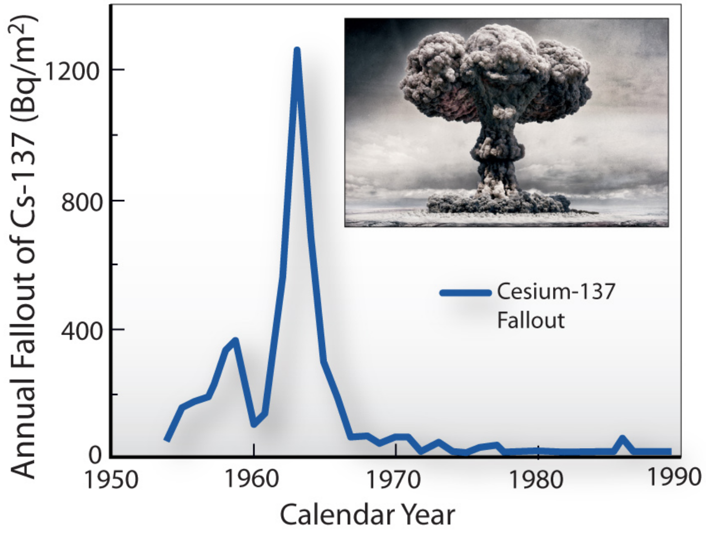


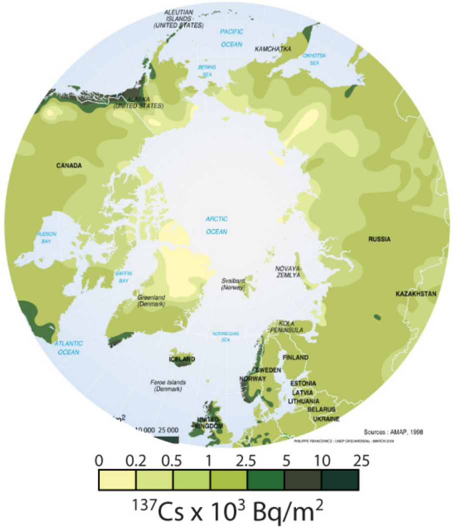


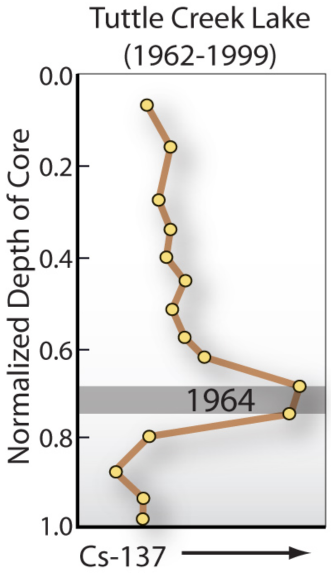
Lichenometry is a calibrated relative dating method which relies on the observation that lichens of a single species have similar growth rates. Thus, by calibrating a **growth curve** on surfaces of known age, such as buildings and tombstones, the maximum width of a lichen found on a surface of unknown age (such as a glacial moraine) can be used for dating.

masses would make it easier for students to recognize what they are looking at.

Cesium 137 dating



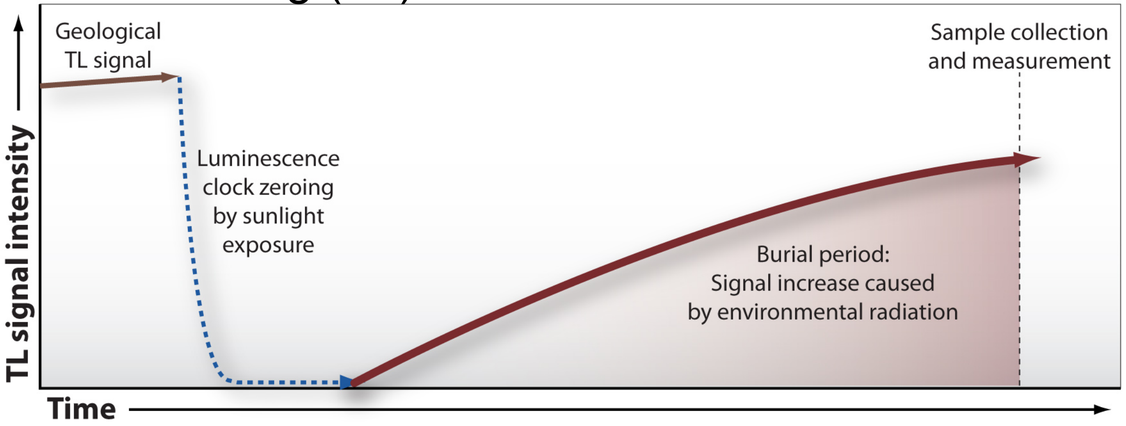

Cesium-137 Fallout
From Nuclear Weapon's Testing

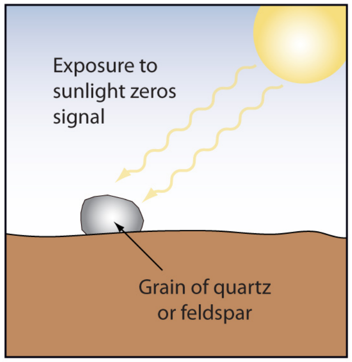

Tuttle Creek Lake (1962-1999)

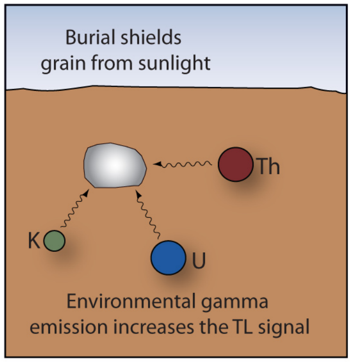
Cesium-137 was released into the environment primarily by the explosion of **nuclear weapons** in the atmosphere. This radionuclide is the product of fission, or the splitting of heavy elements such as uranium. The detonation of powerful hydrogen bombs (which have fission bombs as their core) starting in the 1950s released large amounts of Cesium-137, with the peak release in **1964**. After atmospheric testing of nuclear weapons was curtailed, the release of Cesium-137 quickly decreased.

Cesium-137, which decays with a half-life of about 30 years, emits gamma particles, which are easily detected by sensitive decay counters. In **sediment cores**, the peak Cesium-137 concentration is assigned to 1964 - defining the **age** of the core at this horizon.

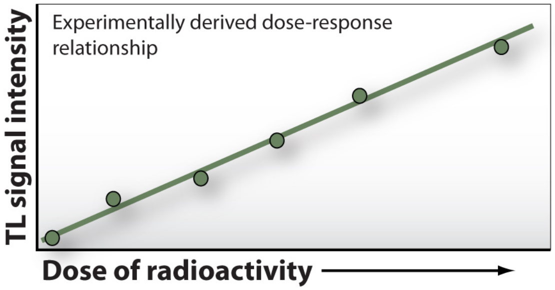
Thermoluminescence dating (TL)

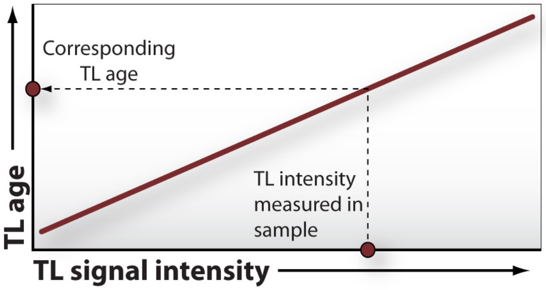






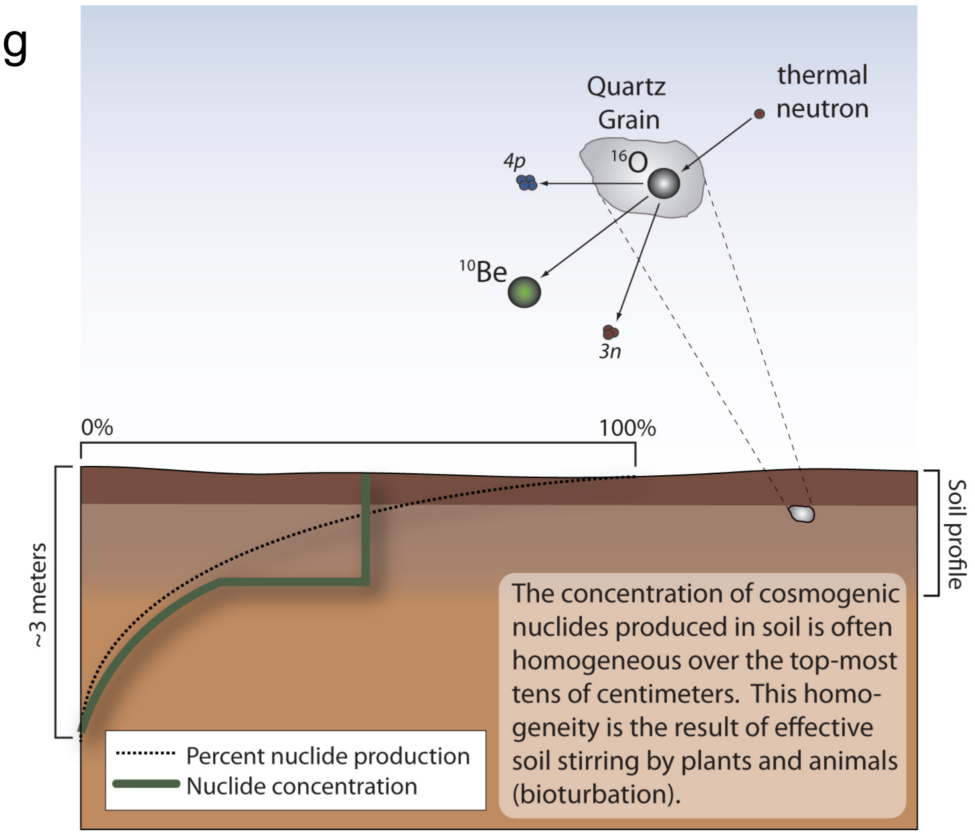
Luminescence dating relies on releasing energy stored in the crystal lattice (this energy is stored as **radioactivity**), damages the lattice and fills "traps" that empty on exposure to light or heat. The **environmental radiation** dose must be measured or estimated before an **age** can be calculated.



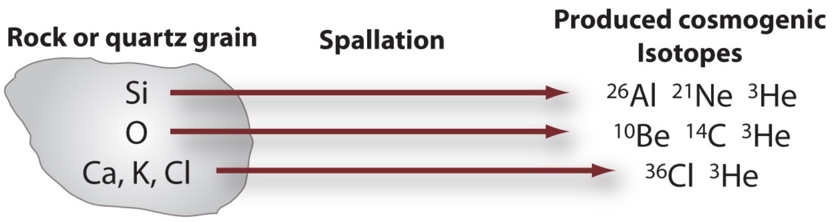


Every sample behaves somewhat differently and has a different sensitivity to radiation. This additive dosing is done to test how much luminescence is generated from a unit dose of radiation. Once the radiation sensitivity (the level of environmental radiation) and the luminesence of the sample have all been determined, an age can be calculated.

Cosmogenic dating



The concentration of cosmogenic nuclides produced in soil is often homogeneous over the top-most tens of centimeters. This homogeneity is the result of effective soil stirring by plants and animals (bioturbation).



^{10}Be, one of several commonly measured **cosmogenic nuclides**, is produced in and near Earth's surface by the bombardment of **cosmic rays**, primarily neutrons. These fast neutrons are rapidly attenuated by soil and rock so that by a depth of several meters, few remain to create cosmogenic nuclides.

Landscape 3 🟫 ☐ 🟫

Lith 1 🟫 ☐ 🟫