

Uplift is a tectonic process

Three types of uplift:

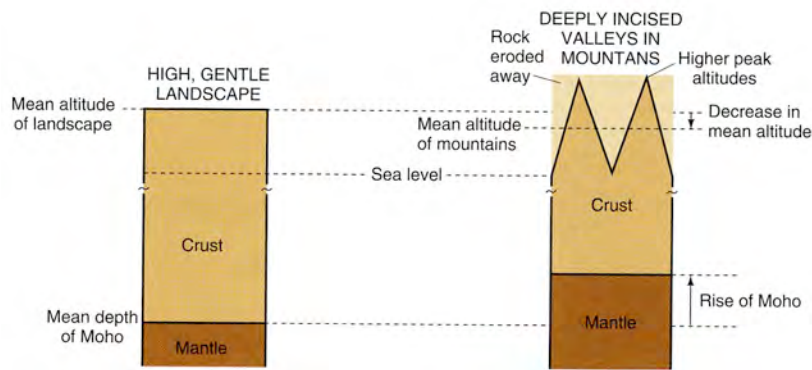
1. Collisional uplift
2. isostatic uplift
3. Extensional uplift.

A physical experiment in isostasy:

[crust density/mantle density = root thickness/total crust thickness]

So can use this equation to estimate how high mountains should be for a given thickness of crust and crust and mantle densities.

Denudation controlled by Climate, lithology (& structure) and relief

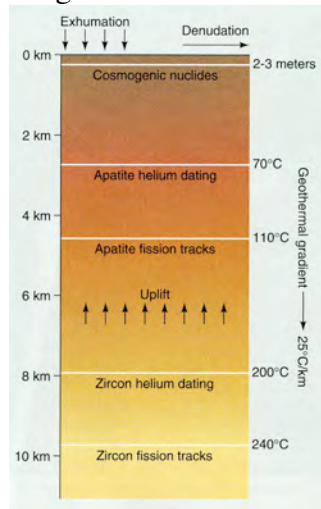


Uplift Rate

1. extrapolation
2. tie points to known elevations.

Estimating Denudation rate

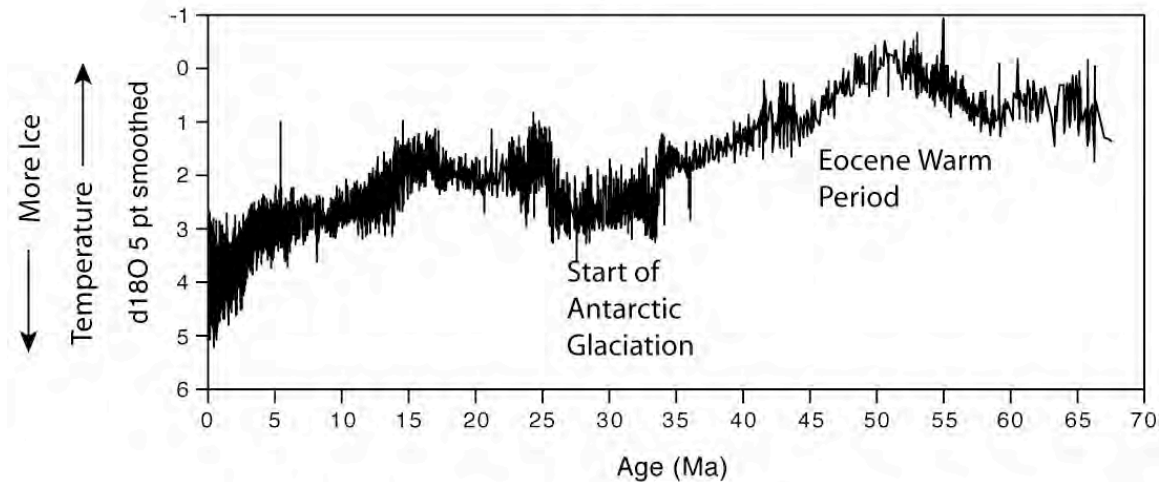
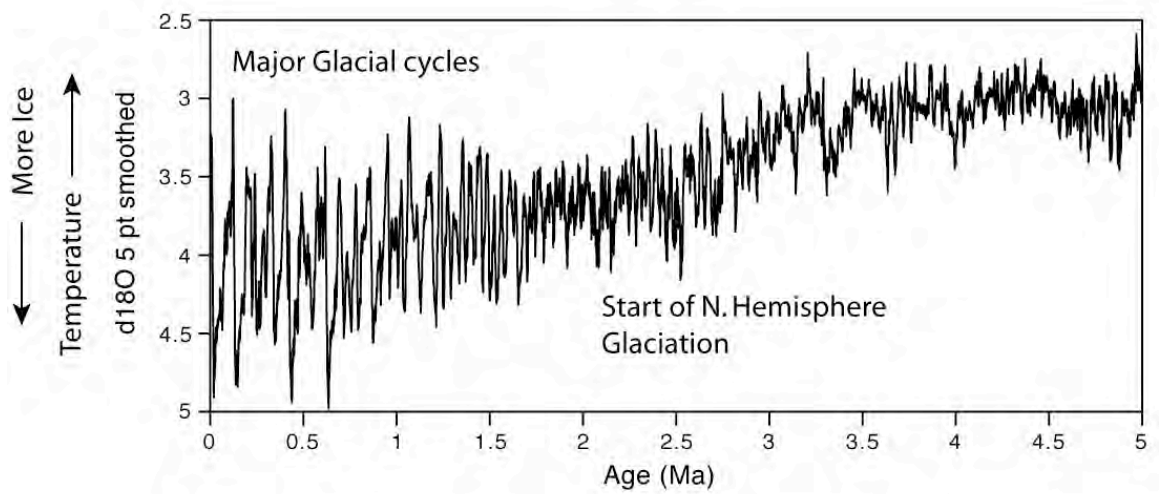
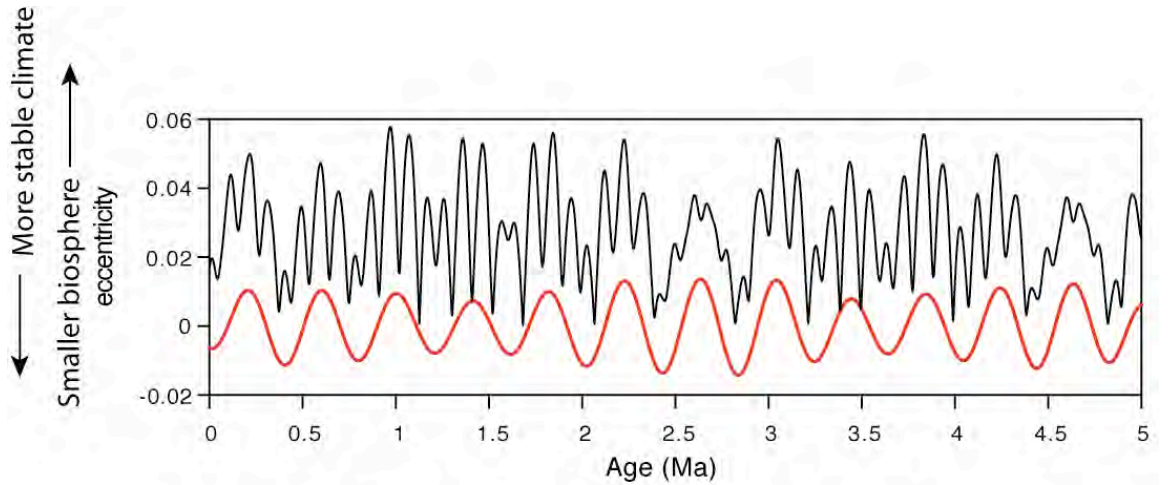
1. minerals or radioactive systems with different closure temperatures
2. radiogenic helium concentration and cosmogenic isotope concentration.)



How is material removed from elevated areas?

Mass Wasting—the downslope movement of regolith and rock under gravity.
Effect of gravity, slope angle and water.

Some Left-overs from last Lecture: [TOP]: Cycle in the size of the biosphere (smooth line) compared to cycle of eccentricity of Earth's orbit. Lower eccentricity reflects more circular orbit and less seasonal change in solar energy as well as a more productive biosphere ; [MIDDLE and BOTTOM]: History of global deep sea temperature and polar ice volume.



Mass Wasting and Landscape Evolution

11-8-06

The process ultimately responsible for many surface features on the Earth is uplift.

Uplift is a tectonic process

Uplift fundamentally owes much to isostasy, which as you will remember, is due to the relative buoyancy rocks of different density .

A physical experiment in isostasy: Measure the relative height of the surface of an ice cube in a glass as it loses volume.

We can also do this mathematically:

Assume the crust has an average density of 2.8 g/cm³ and the mantle has a density of 3.3 g/cm³. If the crust is 40 km thick, we can calculate the thickness of the root of the crust as:

$$40(2.8/3.3) = 34 \text{ km root thickness}$$

[since crust density/mantle density = root thickness/total crust thickness]

So the total height of the crust above baselevel is 40 km – 34 km = 6 km

Now, the magic of isostasy is that we can remove large amounts of the crust by erosion and still have mountains only slightly shorter than they were originally.

Say we erode **6 km off our 6 km mountains**-are they now flat?

Do the math and discover the mountains **are now 5.15 km high**—they have been reduced by about 850 m (not even a kilometer!)

Say we **erode 10 km** of rock off the continent, the new elevation of the mountains is:

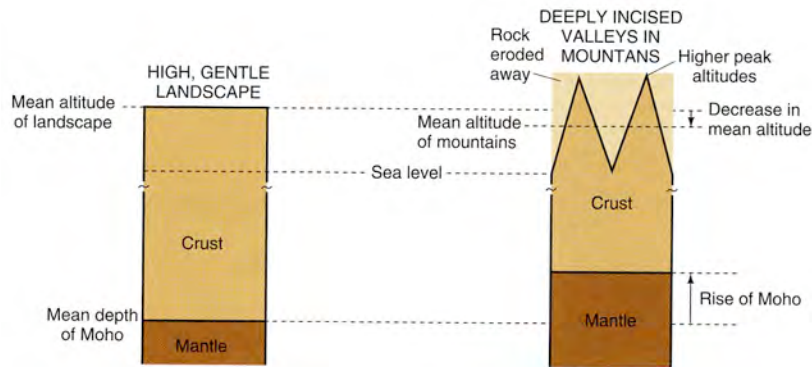
$$30 (2.8/3.3) = 25.5 \text{ km [root thickness],}$$
$$\text{So the new mountain height is: } 30 \text{ km} - 25.5 \text{ km} = 4.5 \text{ km}$$

Compared to the original 6 km high mountains, we have only lost about 1.5 km of height despite eroding 10 km of crust.

Mountain elevation:

A high plateau reflects a deeper crustal root (or warmer lithosphere) than high peaks on a deeply incised surface.

The figure reflecting average and maximum elevation of the Himalaya and Tibetan Plateau reflects the relative effects of denudation rate.



Three types of uplift:

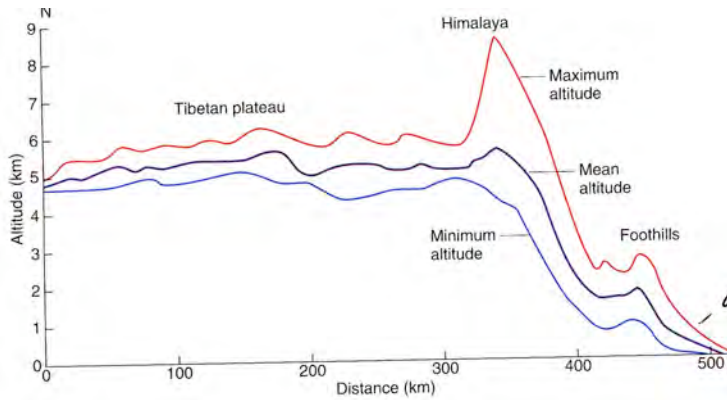
4. **Collisional uplift** created by thrust faulting as in a subduction zone—effectively the crumpling and piling up of rock in a collision belt—eg active deformation of sediments in subduction zones
5. **isostatic uplift**—when cool lithosphere is heated or replaced with hotter lithosphere—examples include buoyant heating by mantle plumes or by peeling off the base of the lithosphere in collision zones and its replacement by hot mantle
6. **Extensional uplift**—rifting is associated with upwelling and heating of the mantle by thermal expansion during unloading. Heat may also accumulate under large plates contributing to continental rifting. Extension of the crust contributes to basin-and-range style uplift. Extension also can create uplifted rift shoulders owing to heating of the young rift.

Denudation (erosion) of rocks is controlled by:

Climate--vegetative cover, rainfall, and glacial activity

Lithology—not just rock type, but also rock structure—highly fractured rocks may be much easier to erode than undeformed rocks.

Relief—Erosion is much faster in high relief areas than in adjacent low lands; changes in ‘baselevel’ by sea level and uplift can also lead to changes in erosion rate.

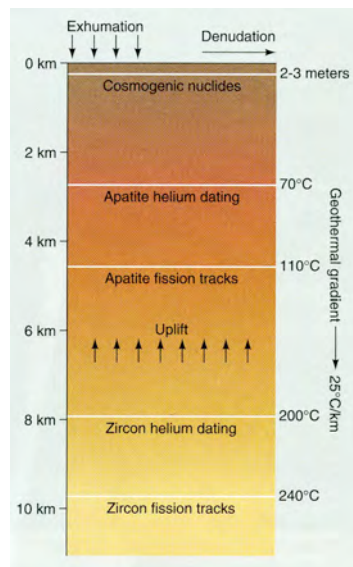


Uplift Rate determined by:

3. extrapolation from rate of movement during earthquakes
4. tie points to known elevations—eg. Marine strata exposed on high mountains, coral reefs exposed above sea level, marine terraces.

Estimating Denudation rate

3. look at **minerals or radioactive systems with different closure temperatures**—e.g. fission tracks in apatite (closure temp of $\sim 110^{\circ}\text{C}$) and zircon (closure temp of 240°C)
4. **radiogenic helium concentration and cosmogenic isotope concentration.**
In the case of cosmogenic nuclides, cosmic rays from the sun bombard minerals in surface rocks and convert some atoms to cosmogenic isotopes such as ^{10}Be , ^{26}Al , and ^{36}Cl . Hence the abundance of these isotopes reflects exposure time.



5. Both provide a means of estimating exhumation (exposure of rocks by removal of overburden)

How is material removed from elevated areas?

Mass Wasting—the downslope movement of regolith and rock under gravity.

Effect of gravity, slope angle and water. Slope angle affected by the ratio of shear strength (strength of rock) to shear stress (the down slope stress imparted by gravity on a rock) when the former is less than the latter, the rock will move downslope.

Water is important because it can reduce shear strength, particularly as saturation is reached and grains are forced apart of fluid pressure. Fluid pressure can allow rocks to move on a cushion of vapor or liquid and can contribute to 'hydroplaning' large masses of rock on a cushion of air or water.

Types of Slope Failures

1. **slumps**—rotational sliding of rock downslope so that the material remains mostly intact
2. **Rock falls**—free fall of large masses of rock—can run out over considerable distances if sufficiently massive to hydroplane on air or water as a rock slide.
3. **Granular flows** which mostly are slow moving **creep** of soil downslope or **earthflows** (like slumps but involving regolith)—most granular flows are mediated by water, but may not be the sediment is not completely saturated.
4. **Slurry flows-- Debris flows** (fast moving)—sliding of regolith and collapse into disordered material, usually due to saturation with water. And **solifluction** (slow moving downslope movement of saturated soil).
5. **Slurry flows** can vary from 80% water to 80% sediment; in marine and lake settings, slurry flows can convert into **turbidity currents** (density currents) as fluid concentration goes up and reduces grain-to-grain contact.

In polar areas, get:

1. **frost heaving** due to freeze-thaw cycles of the ground that lift up rocks and set them down again, and
2. **gelifluction** (the ice-mediated variety of solifluction caused by melting and freezing of soil above permafrost).

In Volcanic terrains:

Slurry flows are common as mud slides or debris flows fueled by

1. earthquakes associated with eruptions
2. melting snow or ice on volcanic peaks or eruptions through lakes inside volcanic calderas.

These types of mass movement can be controlled by underlying geology.

1. In the Bay Area, the highly fractured rocks of the Franciscan Formation are much more prone to slurry flows and earth flows than younger, less fractured rock.
2. Volcanic islands often evolve from shield volcanoes to islands with steep flanks by massive slumping and debris flows.

3. KT Mass wasting of the Western Atlantic by impact shock—created mass flows off the eastern margin of N. America that cover ~ 3.9 million km^2 ; smaller scale slides are common along continental margins triggered by earthquakes or low sea level stands.

Uplift-Climate linkage through the carbon cycle

The carbon cycle is the movement of carbon through the Earth and atmosphere; important in climate through regulation of atmospheric pressure of CO_2 —an important greenhouse gas.

Major sources of CO_2 are (1) **volcanic outgassing** (2) **production of carbonates**, and (3) **metamorphism of carbonates + silicates**

Major sinks for CO_2 are (1) **weathering of carbonates**, (2) **formation of organic carbon** (coal, oil, gas, , plant remains buried in soils), (3) **weathering of silicate rocks**

These reactions are governed by the general relationship that:

$\text{CO}_2 + \text{water} = \text{Carbonic Acid } (\text{H}_2\text{CO}_3)$;

Carbonic acid + silicate minerals produce Carbonates + SiO_2 and Water

Uplift comes into play since exposure of fresh silicates increases weathering and takes up CO_2 from the atmosphere. Therefore, times of extensive mountain building should take up CO_2 and reduce the greenhouse effect, whereas times of little weathering (when the Earth is relatively flat) should allow CO_2 to build up in the atmosphere.

Another feedback is that uplift also creates high sedimentation rates (high weathering) which can help bury organic carbon, further reducing CO_2 .

Other potent greenhouse gases (like methane) are implicitly imbedded in these cycles since methane breaks down quickly in the atmosphere to form CO_2