Shaping the earth surface:

The energy that drives landscape evolution comes from three sources: internal energy, the heat within the Earth, which drives the plate motions and mantle plumes that cause displacement of the crust's surface; external energy, energy coming to the Earth from the Sun, which warms the atmosphere and ocean; and gravitational energy, which pulls rock down slopes at the surface and, along with external energy, causes convection (as currents and winds). Landscape evolution, in fact, reflects a "battle" between tectonic processes such as collision, convergence, and rifting, which build relief, an elevation difference between two locations (*Figure 1 a, b, c, d*); and processes such as downslope movement, erosion, and deposition, which destroy relief by removing material from high areas and depositing it in low ones. If, in a particular region, the rate of uplift exceeds the rate of erosion, the land surface rises. But if the rate of subsidence exceeds the rate of deposition, the land surface sinks. Without erosion and deposition, high and low areas would have lasted for the entirety of Earth history.

(a) A rock and sand seascape along the coast of Brazil.

(b) The peaks of the Grand Tetons in Wyoming.

(c) Buttes of sandstone in Monument Valley, Arizona.

(d) Steep cliffs in Australia's Blue Mountains.

Figure 1: Examples of the great variety of landscapes on Earth.

How rapidly do uplift, subsidence, erosion, and deposition take place? The Earth's surface can rise or sink by as much as 3 m during a single major earthquake. But averaged over time, the rates of uplift and subsidence range between 0.01 and 10 mm per year (*Fig. 2a*). Similarly, erosion can carve out several meters of substrate, the material at and just below the ground surface, during a single flood, storm, or landslide (*Fig. 2b*).

(a) Uplifted beach terraces form where the coast is rising relative to sea level. Present-day wave erosion is forming a new terrace and cutting a cliff on the edge of the old one.

(b) So much erosion can take place during a single hurricane that houses built along the beach become undermined.

Figure 2: The processes of uplift, subsidence, erosion, and deposition can be slow or rapid.

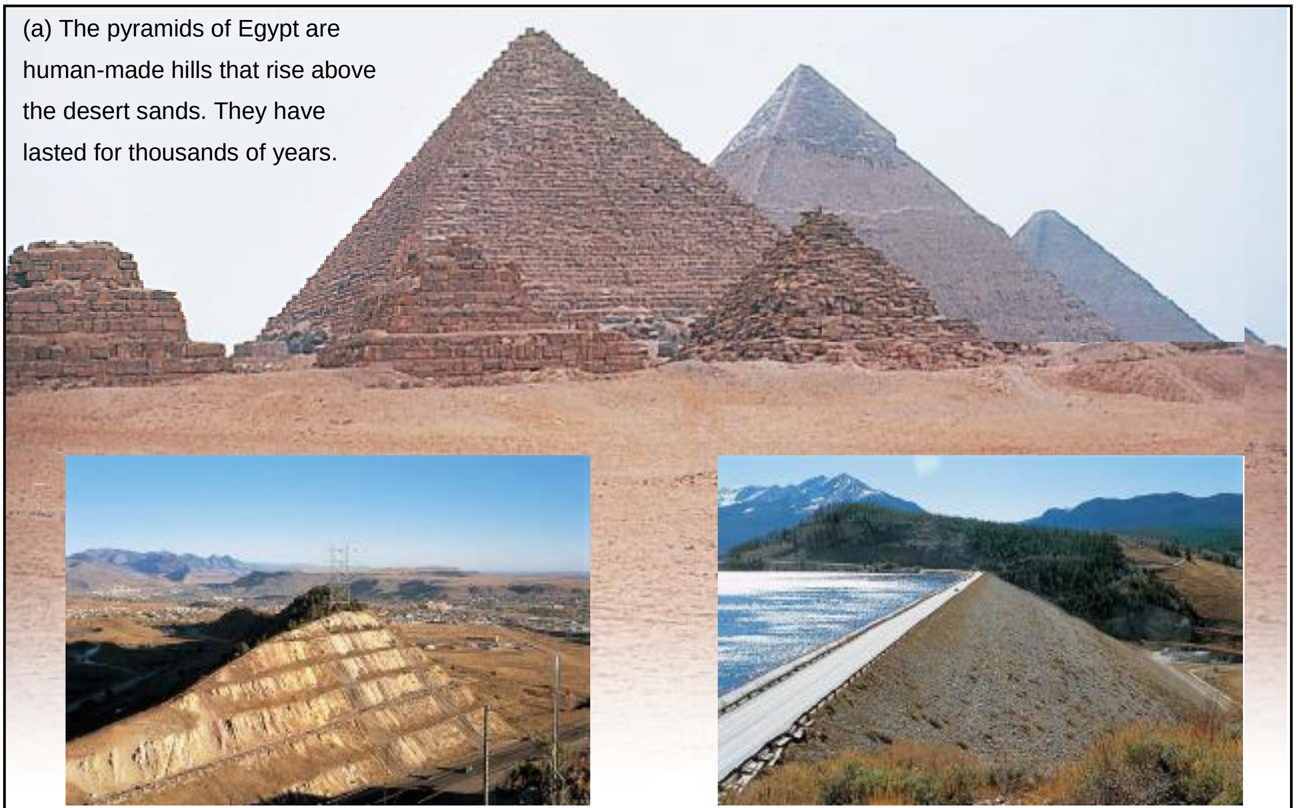
Factors controlling landscape developments:

The specific landforms that develop at a given locality and that together make up the landscape, reflect several factors.

- **Eroding or transporting agent:** Water, ice, and wind all cause erosion and transport sediment. But the shapes of landforms formed by each are different, because of differences in the abilities of these agents to carve into the substrate and to carry debris.

- **Relief:** The elevation difference, or relief, between adjacent places in a landscape determines the height and steepness of slopes. Steepness, in turn, controls the velocity of ice or water flow and determines whether rock or soil stays in place or tumbles downslope.
- **Climate:** The average mean temperature and the volume of precipitation in a region determine whether running water, flowing ice, or wind serves as the main agent of erosion or deposition.
- **Substrate composition:** The material comprising the substrate determines how the substrate responds to erosion. For ex-ample, strong rocks can stand up to form steep cliffs, while soft sediment collapses to generate gentle slopes.
- **Life activity:** Some life activity weakens the substrate (by burrowing, wedging, or digesting), while some holds it together (by binding it with roots).
- **Time:** Landscapes evolve through time, in response to continued erosion and/or deposition. For instance, a gully that has just started to form in response to the flow of a stream does not look the same as a deep canyon that develops after the same stream has existed for a long time.

Although water, wind, and ice are responsible for the development of most landscapes, human activities have had an increasingly important impact on the Earth’s surface. We have dug pits (mines) where once there were mountains, have built hills (tailings piles and landfills) where once there were valleys, and have made steep slopes gentle and gentle slopes steep (*Fig. 3a–c*). By constructing concrete walls, we modify the shapes of coast lines, change the courses of rivers, and fill new lakes (reservoirs).



(a) The pyramids of Egypt are human-made hills that rise above the desert sands. They have lasted for thousands of years.

(b) In the process of making highway cuts, engineers cut deep valleys through high ridges. This example borders a highway near Denver.

(c) This stone dam holds back a reservoir in Colorado. Think about how long it would take a glacier to pile up so much sediment.

Figure 3: Human influence on a geologic scale.

Much of the Earth’s surface is unstable and capable of moving downslope, due to the pull of gravity, in seconds to weeks. Geologists refer to the downslope transport of rock, regolith (soil, sediment, and debris), snow, and ice as mass movement, or mass wasting. Like earthquakes, volcanic eruptions, storms, and floods, mass movements are a type of natural hazard, meaning a natural feature of the environment that can cause damage to living organisms and to buildings. Unfortunately, mass movement becomes more of a threat every year, because as the world’s population grows, cities expand into areas of unsafe ground. Mass movement also plays a critical role in the rock cycle, as the first step in the transportation of sediment, and in the evolution of landscapes, as the most rapid means of modifying the shapes of slopes.

Types of Mass Movement

Most people refer to any mass movement of rock and/or regolith down a slope as a landslide. Geologists and engineers, however, find it useful to distinguish among different kinds of landslides based on four features:

1. The type of material involved (rock or regolith).

2. The velocity of movement (slow, intermediate, or fast).

3. The character of the moving mass (coherent, chaotic, or slurry).

4. The environment in which the movement takes place (subaerial or submarine).

Rock or regolith on unstable slopes has the potential to move downslope under the influence of gravity. This process, called ***mass movement***, or mass wasting, plays an important role in the erosion of hills and mountains.

What is the slow and large mass movements ?

- **Slow mass movement, caused by the freezing and thawing of regolith, is called creep**. In places where slopes are underlain with permafrost, solifluction causes a melted layer of regolith to flow down slopes. During slumping, a semi-coherent mass of material moves down a spoon-shaped failure surface. Mudflows and debris flows occur where regolith has become saturated with water and moves downslope as a slurry.
- **Large mass movements can take place on underwater slopes. Some generate tsunamis**.

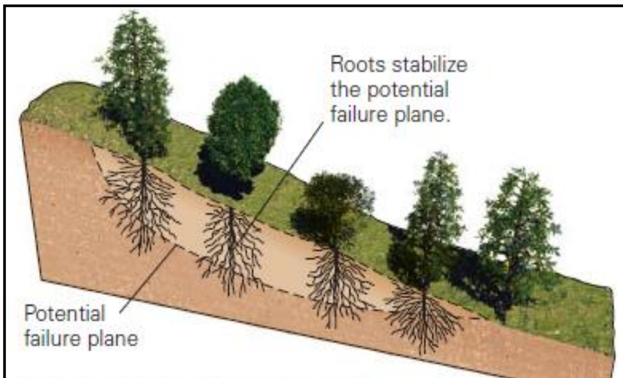
Preventing Mass Movements

In areas where a hazard exists, people can take certain steps to remedy the problem and stabilize the slope (*Fig. 4 a-h*).

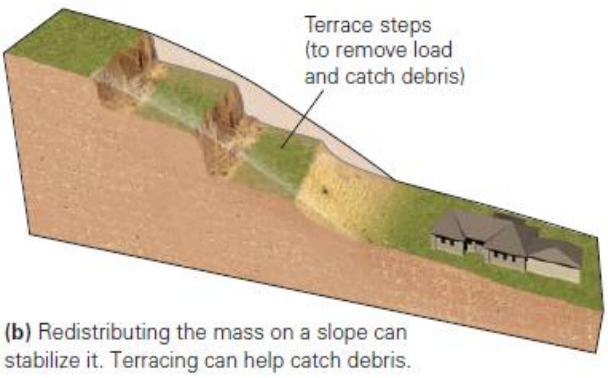
1. **Revegetation:** Stability in deforested areas will be greatly enhanced if land owners replant the region with vegetation that sends down deep roots and binds regolith together.
2. **Regrading:** An over steepened slope can be regraded or terraced so that it does not exceed the angle of repose.
3. **Reducing subsurface water:** Because water weakens material beneath a slope and adds weight to the slope, an unstable situation may be remedied either by improving drainage so

that water does not enter the subsurface in the first place, or by removing water from the ground.

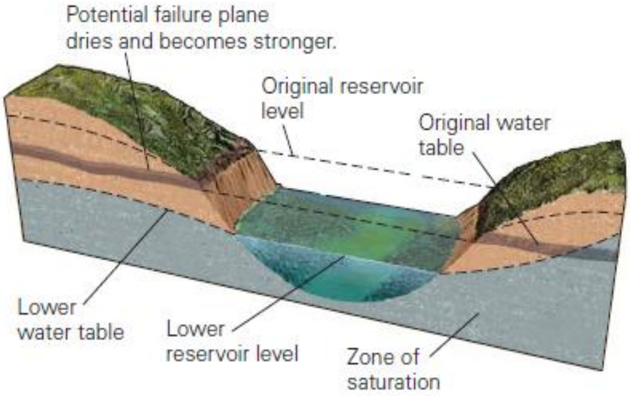
4. **Preventing undercutting:** In places where a river undercuts a cliff face, engineers can divert the river. Similarly, along coastal regions they may build an offshore break-water or pile riprap (loose boulders or concrete) along the beach to absorb wave energy before it strikes the cliff face.
5. **Constructing safety structures:** In some cases, the best way to prevent mass wasting is to build a structure that stabilizes a potentially unstable slope or protects a region downslope from debris if a mass movement does occur. For example, civil engineers can build retaining walls or bolt loose slabs of rock to more coherent masses in the substrate in order to stabilize highway embankments. The danger from rock-falls can be decreased by covering a roadcut with chain link fencing or by spraying roadcuts with concrete. Highways at the base of an avalanche-prone slope can be covered by an avalanche shed, whose roof keeps debris off the road.
6. **Controlled blasting of unstable slopes:** When it is clear that unstable ground or snow threatens a particular region, the best solution may be to blast the unstable ground or snow loose at a time when its movement can do no harm.



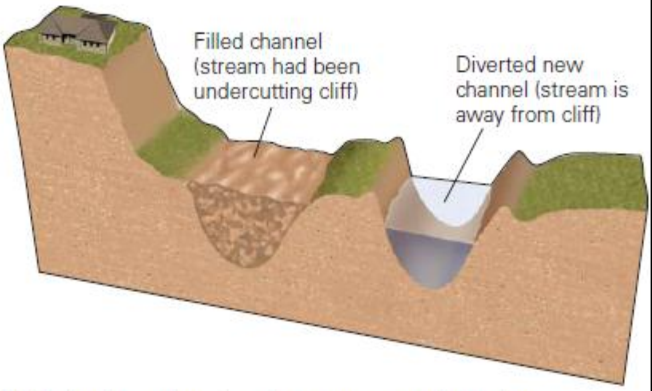
(a) Revegetating a slope results in the growth of roots that can hold a slope together.



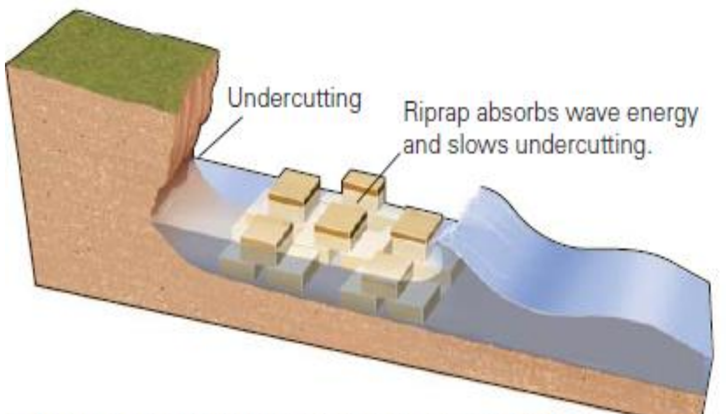
(b) Redistributing the mass on a slope can stabilize it. Terracing can help catch debris.



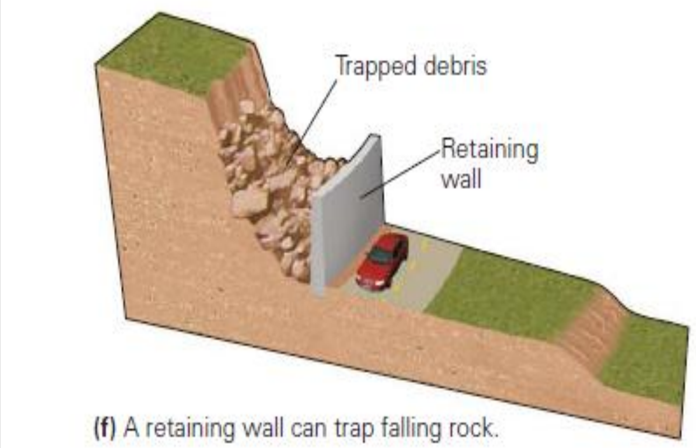
(c) Lowering the level of the water table can strengthen a potential failure surface.



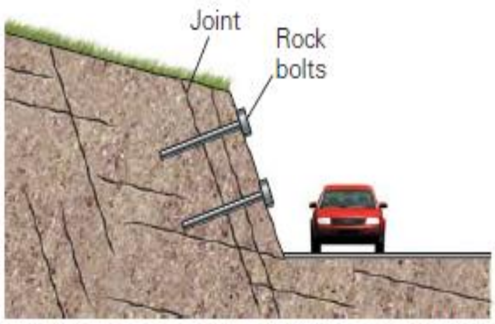
(d) Relocating a river channel can prevent undercutting.



(e) Adding riprap can slow undercutting of coastal cliffs.



(f) A retaining wall can trap falling rock.



(g) Bolting or screening a cliff face can hold loose rocks in place.

(h) An avalanche shed diverts debris or snow over a roadway.

Figure 4 a-h : A variety of remedial steps can stabilize unstable ground.