The farm fields shown here are no longer viable. Years of irrigation in this arid region (California’s Imperial Valley) have caused salinization - soils too salty to support crops. Salinization occurs as irrigation water evaporates. Trace amounts of salt are left behind, and over the years salt levels in the soil gradually build up.
Summary of Important Concepts

• **Soil** is a layer of weathered rock, minerals, and organic matter at the earth’s surface that supports plant life.

• The main factors that determine the characteristics of a soil are **climate** (mainly temperature and rainfall), **topography**, type of **parent rock material**, **organic activity**, and the **amount of time** that the soil has been forming.

• Soil forms from **regolith** - broken up rock material at the earth’s surface. Soil forms as regolith undergoes **weathering** - the **physical** and chemical breakdown of rock.
  - **Physical weathering** is breakdown of rock by physical forces. *Example*: rock wedged apart by freezing water or by plant roots.
  - **Chemical weathering** is breakdown of rock by chemical reactions. *Examples*: solution, oxidation, and hydrolysis reactions.
Summary of Important Concepts, continued

• A soil profile is a set of distinct layers, or soil horizons, that occur in a soil. These horizons have different features in different types of soil.

• The main types of soil on earth are:

  - **Loess** (pronounced “luss”): fertile soils developed on wind-blown glacial silt deposited during the Ice Ages.

  - **Laterites**: red, iron oxide-rich soils of wet, hot tropical areas, created by intense chemical weathering of parent rock material.

  - **Pedalfers**: rich soils with brown color, high in aluminum and iron; typical of cooler, wet temperate climates world-wide.

  - **Pedocals**: soils typical of warm, arid regions; high in calcium and commonly contain *caliche* (white deposits of calcium carbonate)

  - **Tundra soils**: soils forming in polar climates of permafrost (permanently frozen ground).
Summary of Important Concepts, continued

• The main environmental problems associated with soils, and the principle methods used to mitigate them, are the following:

  1. Soil erosion by water and wind. Occurs by sheet erosion, rill erosion, and gully erosion, and when wind blows away exposed soil.
     Water erosion is mitigated by terracing, strip cropping, crop rotation, and tillage practices. Wind erosion is mitigated by windbreaks, strip crops, and cover crops.

  2. Soil expansion. Occurs in soils containing certain clay minerals that expand when wet, causing damage to structures.
     Mitigated by removal of the soil, by soil additives that reduce expansion behavior, or by regulating soil moisture.

  3. Permafrost. Structures built where permanently frozen soil exists below the surface will shift and settle if the permafrost melts.
     Mitigated by preventing melting of the permafrost zone.
Summary of Important Concepts, continued

4. **Salinization.** Occurs in irrigated farmlands in arid areas; soils become salty due to evaporation of irrigation water. Salinization is mitigated by creating adequate drainage in irrigated fields, and by flushing away accumulated salt.

5. **Contamination.** Pollutants such as petroleum and various chemicals may contaminate soils. Mitigated by:
   - **bioremediation** (bacterial activity breaks down pollutants)
   - **phytoremediation** (plants that absorb pollutants)
   - **vapor extraction** (blowing air through the soil to remove volatile (easily evaporated) pollutants)
What is SOIL?

It has been said that soil represents “a few inches between humanity and starvation”. This phrase puts the importance of soil in perspective. **Soil** is a layer of weathered rock, minerals, and organic matter at the earth’s surface that supports plant life. Without soil, human life would not be possible.

This figure illustrates the composition of a typical soil. Soil is composed of **mineral matter** from weathered rock; **water**, **gases**, and **organic matter** (the remains of plant and animal material and bacteria).
Soil’s main important uses for humanity are summarized here.
The fate of the Sahel region of Africa sadly illustrates what happens when soils are not managed well. The Sahel is the semi-arid region lying between the Sahara Desert to the north and wetter tropical areas to the south. Frequent years of drought, combined with pressure brought on by over-grazing and farming (both related to population growth), have caused massive soil erosion and converted much of the Sahel into a wasteland incapable of producing much food. As a result, frequent famines wrack this part of Africa.
Weathering and Soil Formation

Soil forms from **regolith** - the term used for broken up rock material at the earth’s surface.

Rock (regolith) exposed at the earth’s surface undergoes **weathering** - the physical and chemical breakdown of rock at the earth’s surface. Two main types of weathering occur: **physical** weathering and **chemical** weathering.

1. **Physical weathering** is breakdown of rock by physical forces. Rocks may be broken apart along planes of weakness by…
   - **thermal** (hot and cold) **expansion and shrinking**
   - **frost wedging** (water freezing and expanding in cracks)
   - **organic activity** (for example tree roots wedging rock apart, or animals burrowing)
This tree illustrates an example of physical weathering. The tree has grown in a crack in the rock, and as it has grown it has forced the rock apart.
2. Chemical weathering is breakdown of rock by chemical reactions that occur when rock and mineral matter interact with water and air. The main types of chemical weathering are:

- **Solution**: rock dissolves by the action of carbonic acid in water; this is a particularly effective way to weather carbonate rocks like limestone and marble.

- **Oxidation**: rock breaks down when oxygen atoms carried by water combine with iron in the rock, producing iron oxide minerals, and giving rock and soil an orange-red color.

- **Hydrolysis**: rock breaks down when H+ atoms carried by water substitute for other atoms in the rock; this reaction produces clay minerals - the most important minerals in soil.

*Important: nearly all chemical weathering proceeds faster under wetter conditions.*
An example of **solution**: This limestone has been gradually dissolved by water from breaking waves, as shown by the pitted, honeycomb texture.
The importance of water in chemical weathering is dramatically illustrated here. The granite obelisk at the left was carved about 3500 years ago in Egypt. In the dry climate of Egypt the rock surface remains fresh even after all those years.

A “twin” obelisk carved at the same time was moved to New York City about 100 years ago. After surviving unscathed for 3400 years in arid Egypt, the wetter climate of New York quickly broke down the rock surface by chemical weathering!
Soil Profiles

Digging down into a soil, you would notice that the soil zone has a layered appearance. This layering is called a soil profile. Each layer of a soil profile is called a horizon.

Soil profiles vary between different types of soils, but one can often recognize the “O”, “A”, “B”, and “C” horizons in many soils.
O horizon: a thin layer of partially decomposed organic matter called humus.

A horizon: called the zone of leaching; in this area mineral matter is dissolved by water percolating down.

B horizon: called the zone of accumulation; in this area particles and dissolved materials from the A horizon are deposited.

C horizon: a zone of transition from soil to rock, consisting of weathered parent bedrock.
Types of Soils

Many schemes have been proposed for classifying soils. Four our purposes, we can recognize FIVE great soil types on earth. • Loess • Laterites • Pedalfers • Pedocals • Tundra soils

Loess (pronounced “luss”) covers about 10% of the earth’s land area, and is perhaps the most fertile soil on earth. Vast areas of farmland in the U.S. and in Asia are underlain by loess.

Loess is formed on deposits of wind-blown glacial silt that were laid down over vast areas of the continents during the Ice Ages. As glaciers moved across the high northern latitudes they ground up rock material to a powder. This was washed out from the glaciers by streams, then picked up by winds and blow over great distances.
This map shows the world-wide distribution of loess. Notice the vast areas of the U.S. and Asia that are covered by loess. These areas are some of the world’s most productive farmland.
Loess is tan to yellow in color, and porous and light. The small mineral grains weather readily, producing nutrients that get taken up by plants. The porous soil drains well, and is easily tilled to make fields.

This photo shows an excavated layer of loess in China -- home to the largest loess deposits in the world.
Loess is a soil defined by its *origin* (deposits of wind-blown glacial silt). The four other great soil types we will consider are defined not by their origin, but by the *climate in which they form*. The two climatic factors that are most important here are *precipitation* and *temperature*. As shown in the figure below:

- **Laterites** form in hot, wet climates.
- **Pedalfers** form in cool, wet climates.
- **Pedocals** form in hot, dry climates.
- **Tundra soils** form in cold, dry climates.
- **Laterites**: form in hot, wet climates. These are red, iron oxide-rich soils of tropical areas, created by intense chemical weathering of parent rock material under warm, high-rainfall conditions.

- **Pedalfers**: form in cool, wet climates. These are rich soils with brown color, high in aluminum and iron; typical of cooler, wet temperate climates world-wide.

- **Pedocals**: form in dry, hot climates. These soils occur in desert areas. They are high in calcium and commonly contain *caliche* (white deposits of calcium carbonate).

- **Tundra soils**: form in cold, dry climates. These soils occur in the high northern latitudes, and much of the area covered by these soils is *permafrost* (areas of permanently frozen ground).
Soil Problems and Mitigation

Soil forms slowly. It takes hundreds to thousands of years for a soil to fully develop from parent regolith. But human activities can destroy soil quickly -- much faster than it forms. With the human population - and thus demand for food - increasing, soil degradation is one of the most important issues in environmental geology today.

We will review the following major soil problems, and associated methods of mitigation:

• **Soil Erosion** by water, by wind, and by human activities
• **Soil Expansion**
• **Permafrost**
• **Salinization**
• **Contamination** by pollutants
Soil Erosion

Soils erode by the action of water and wind, and due to human activities.

Erosion by water takes several forms. Sheet erosion occurs when a layer (sheet) of water moves across a sloping soil surface. If the water focuses into small channels, called rills, then rill erosion occurs. Rills can become deeper and form gullies, leading to gully erosion.

Erosion by wind occurs on farm fields that are bare, or in places where plants have been eliminated. With no plants to hold soil in place, wind easily carries it away.

Soil erosion is increased by human activities like:
- overgrazing: cattle remove nearly all plant cover
- deforestation: cutting of forests leaves soils exposed
- recreation: off-road vehicles rip up vegetation and soil
This figure illustrates soil losses due to sheet and rill erosion in the U.S.. Most erosion losses are occurring in the Midwest - on some of the country’s most productive farmland.
This figure illustrates soil losses due to wind erosion in the U.S. Notice most losses due to wind erosion are on the windy Great Plains.
An example of human contribution to soil erosion. The tearing up of this slope by dirt bikes has killed off plant cover, exposed soils, and created ditches along which eroding gullies have begun to form.
This figure shows how total U.S. cropland has been reduced over the past two decades. The main reasons for the loss of cropland area:

- soil erosion
- urban development
- conversion of cropland to other uses
**Mitigation of soil erosion** can be effectively accomplished by several approaches.

1. **Terracing** - a method for making all fields flat in sloping area. One of the oldest and most effective methods for reducing water erosion.

The photograph shows how terracing makes the fields all flat even though the land slopes steeply.
Mitigation of soil erosion, continued….

2. **Strip-cropping** - rows or strips of close-growing plants alternate with strips of widely-spaced ones. The close-growing plants trap eroding soil, and help create a wind break.

3. **Crop rotation** - regular (yearly) alternation of crops that deplete soil with crops that protect and enrich soil. For example, *groundcover crops* (clover, alfalfa, grasses) tend to conserve soil by protecting it from water and wind erosion, while *row crops* (corn, soybeans) tend to make soil more vulnerable to erosion.

4. **Tillage practices** - ways of tilling fields that reduce erosion. For example, plowing rows perpendicular to a field’s slope helps reduce water erosion because the rows trap water as it runs down slope. Also reducing the amount of tilling, or eliminating tilling completely by using “no-till” planting methods, are highly effective at reducing erosion.
Soil Expansion

Some soils contain high amounts of certain clay minerals that expand greatly when wet. Soils that are rich in these clay minerals are called **expansive soils**. These can also be “expensive soils”, because of the damage they cause!

This wall has cracked due to expansive soil underneath. By swelling and heaving the ground, expansive soils cause about 6 billion dollars in property damage in the U.S. each year.
Mitigation of expansive soils can be effectively accomplished by:
- removing the soil prior to building
- mixing non-expansive material into the soil
- keeping the moisture content of the soil constant by controlling the amount of water than enters the soil
- using deeply-sunk and reinforced foundations that can handle the expansion without damaging the structure

This map shows that areas of expansive soils are very common in the U.S. particularly in the Southeast, the Great Plains, and the Rocky Mountain states.
**Permafrost** is ground that is permanently frozen below the surface. In areas of permafrost a permanent zone of frozen soil exists below the surface even if the surface soil thaws in summer. Permafrost covers most of the higher northern land areas of earth, such as Siberia, Canada, and Alaska.
If permafrost melts it can cause subsidence, soil flow, and structural damage. One common problem is that a house built on permafrost may gradually warm up and melt the permafrost, causing the ground to shift and settle, with associated damages. An example is shown in this photograph of a damaged house in Fairbanks, Alaska.
Mitigation of permafrost problems can be accomplished by:
- bulldozing up and removing the permafrost layer before building
- building a structure with open space between floor and ground, so heat from the structure does not warm the ground (shown in the photograph here)
Mitigation of permafrost, continued….

- using heat-radiating piers to hold up a house, so house heat is not conducted into the ground (an example is shown here)
- building roads on thick beds of coarse gravel, to allow cold air to go under the roadway
Permafrost was a major concern in the construction of the 800 mile Alaska oil pipeline. The oil is pumped through hot to make it flow more easily through the four-foot pipe. To avoid melting the permafrost the pipeline was elevated 6 feet above the ground. This has the added benefit of not blocking the migration of animals like caribou!
The zigzag pattern of the pipeline allows the pipe to expand and contract with temperature changes, and also allows the ground to move somewhat without causing damage.
Salinization

Salinization of soils occurs in irrigated farmlands in arid areas. The soil becomes salty due to evaporation of irrigation water. This photo shows a salinized field in California’s Imperial Valley. This field will no longer grow crops.

Salinization has plagued humanity ever since irrigation agriculture was first developed in the “Fertile Crescent” area of Middle East 1000’s of years ago.
Salinization occurs because flooding fields with irrigation water raises underground water up close to the surface. As water at the surface evaporates, it leaves salt behind. Capillary action in the soil pulls more water up from below, which in turn evaporates and leaves salt. Over time salt builds up in the soil, eventually rendering the soil incapable of supporting crops. Badly salinized fields actually have white crusts of salt covering the surface.

*Mitigation of salinization* can be accomplished by the following expensive and time-consuming procedures:
- lowering the level of underground water by pumping, and then flushing the salt out of the soil with large amounts of irrigation water
- installing underground drains in the soil to take away excess irrigation water, thus keeping the water table from rising up to the surface
Contamination

Pollutants have contaminated soils in many areas. The most common contaminants are petroleum products, pesticides, heavy metals, cleaning agents, and other hazardous chemicals.

*Mitigation of soil contamination* can be accomplished by:

1. **Bioresmediation** - makes use of *microorganisms* (bacteria and fungi) that break down contaminants which have an organic chemical structure, such as petroleum products.

2. **Phytoremediation** - makes use of *plants* that absorb contaminants into their tissues. This can be used to remove salts and certain types of heavy metals.

3. **Vapor extraction** - a technique that involves blowing air through the soil to remove volatile (easily evaporated) contaminants, such as cleaning agents.