# SOIL FORMATION AND LANDSCAPE STABILITY

## Smith and Pun, Chapter 14

## WHAT IS SOIL?

**"Soils are natural three-dimensional bodies used for many purposes, the most important of which is to produce food and fiber for humankind."**

**(United States Dept. of Agriculture, Soil Conservation Service)**

**"Soil is that portion of the earth's surface located in the vertical space between air above and geologic substratum below, with horizontal limits bounded by materials such as deep water, ice, and rock outcrop that are not considered soil."**

**(Buol, S.W., R.J. Southard, R.C. Graham, and P.A. McDaniel. 2003. Soil Genesis and Classification, 5th ed. Iowa State Press).**

## SOIL FORMATION

**Soil is formed from <u>parent</u> <u>material</u> (see Figure 14.2, page 387). Geologic materials at the surface of the Earth are either solid rock or loosed unconsolidated material that typically overlies solid rock.**

**The term <u>bedrock</u> is used to describe continuous occurrences of solid rock.**

**The unconsolidated deposits that overly bedrock are called <u>regolith</u>. This term is derived from the Greek "rhegos," meaning "blanket," and "lithos," meaning "stone."**

## SOIL HORIZONS

**Soils consist of one or more naturally occurring <u>horizons</u> (see Figure 14.3, page 387). These horizons are designated as:**

**O Horizons dominated by organic material; O horizons have been formed from organic litter derived from plants and animals and deposited on an organic or a mineral surface. O horizons, when present, usually occur at the soil surface, although they may comprise the entire thickness of soil in organic soils or may be buried beneath mineral soil.**

## SOIL HORIZONS (3)

**B** **Mineral horizons formed below O, A, and/or E horizons in which parent material has been significantly altered by concentrations of silicate clay, iron, aluminum, carbonates, gypsum, or humus, or by removal of the more soluble components. There are many types of B horizons, but the primary factor in identifying a B horizon is that it formed as subsoil, below one or more horizons, and is significantly different from the material in which it was formed as a result of pedogenic (i.e., soil forming) processes.**

## SOIL HORIZONS (2)

**A** **Mineral horizons at the soil surface or below an O horizon. A horizons contain humified organic matter mixed with mineral material and result from decomposition of roots or from cultivation that has physically disturbed the soil.**

**E** **Mineral horizons in which loss of clay, iron, or aluminum has concentrated sand and silt particles of quartz or other resistant minerals. E horizons have lighter colors than overlying A horizons and underlying B horizons. E horizons are not present in many soils.**

## SOIL HORIZONS (4)

**C** Mineral horizons or layers, other than bedrock, with little or no alteration be soil forming processes. C horizons lack the properties of O, A, E, or B horizons. Plant roots such as taproots of trees or a few fine roots that leave only trace amounts of organic carbon upon death may be present in some C horizons.

**R** Layers of hard bedrock that underlie one or more of the above horizons. Rock of sufficient hardness that hand digging with a spade is impractical even when the material is moist is designated R. Small cracks, partially or totally filled with soil material and occupied by roots, are often present in R horizons.

## SOIL FORMING PROCESSES

Soil forming processes responsible for the development of different horizons include:

- Additions – to the surface and subsurface
- Transformations
- Transfers – vertical and/or horizontal
- Removals – leaching

See Figures 14.6 through 14.8 on pages 390 and 391.

## SOIL FORMING PROCESSES (2)

**Specific soil forming processes include:**

- **Accumulation of organic matter**
- **Weathering**
- **Eluviation – the removal of soil material in suspension or in solution from one or more horizons within a soil**
- **Illuviation – the deposition of soil material removed from one horizon to another in the soil**
- **Leaching – the removal of soluble materials from one horizon or zone to another via water movement in the profile**
- **Accumulation of salts**
- **Aggregation of primary soil particles (sand, silt, and clay)**

## SOIL FORMING FACTORS

**Five factors are responsible for the differences that we ultimately observe in different soils on the landscape. These factors are:**

1. **Parent Material**
2. **Climate**
3. **Vegetation**
4. **Topography**
5. **Time**

**See Figure 14.10 on page 393.**

## SOIL FORMING FACTORS (2)

**Parent Material**

**Soils result from the weathering of parent materials, and different rocks, sediments, and unconsolidated deposits weather to produce soils with different characteristics.**

**For example, soils formed on basalt parent materials tend to be much more fertile than those derived from granite.**

**Why? Basalt parent materials are rich in iron, magnesium and other cations such as $K^+$ and $Na^+$. The concentration of these cations in granites is low, since granites are Si-rich rocks.**

## SOIL FORMING FACTORS (3)

**Climate**

**Temperature and the quantity of precipitation are key variables in soil formation.**

**Moisture is essential for weathering reactions to occur, and the volume of water infiltrating the profile determines whether soil constituents are leached from the profile.**

**Chemical weathering reactions are also facilitated by high temperatures in the tropics. In contrast, the freeze-thaw process in colder regions enhances physical weathering and produces pathways for water flow.**

## SOIL FORMING FACTORS (4)

**<u>Vegetation</u>**

**There is a strong connection between climate and vegetation and the effect of these two factors on soil formation. This relationship occurs because of the influence of climate on the type and abundance of vegetation present (see Figure 14.11 on page 394).**

**Plants play important physical and chemical roles in soil development. Different vegetative communities support different soil organisms and microorganisms which churn the soil. The amount of organic matter and the depth to which it is distributed is also controlled by the type of vegetation present.**

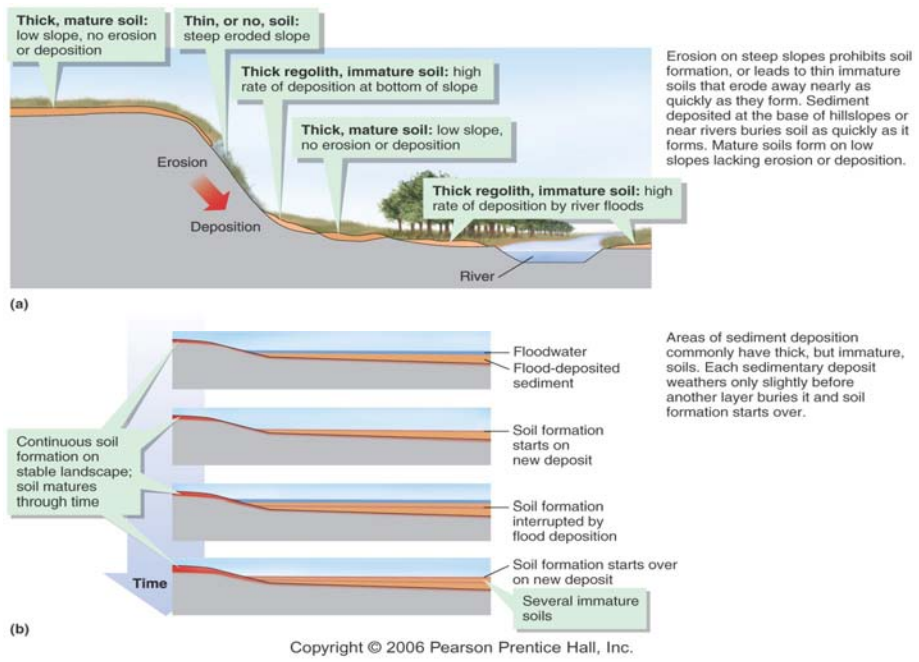
## SOIL FORMING FACTORS (5)

**<u>Topography</u>**

**Topography also plays an important role in soil development. Topography determines the stability of the land surface and whether deposition or erosion processes will be dominant. Remember that each new deposition event sets the soil formation clock back to time = 0 (see Figure 14.13 on page 396).**

**The orientation of the slope (i.e. north-facing or south-facing) plays an important role in soil temperature and moisture.**

**The thickest soils develop on flat surfaces that are stable.**




## SOIL FORMING FACTORS (6)

**Time**

**Time refers to the length of time that the parent materials are subjected to the soil forming processes (see Figure 14.12 on page 395).**

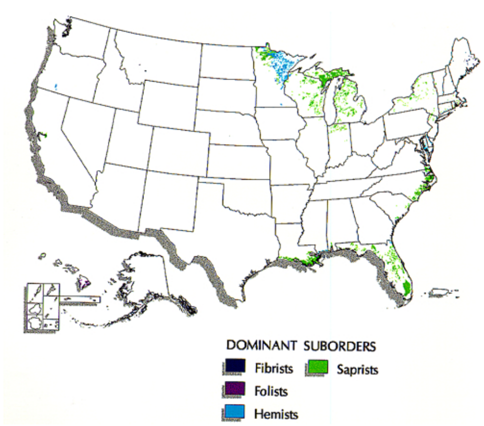
**Soils of different ages differ primarily in thickness and the mineral content of horizons.**

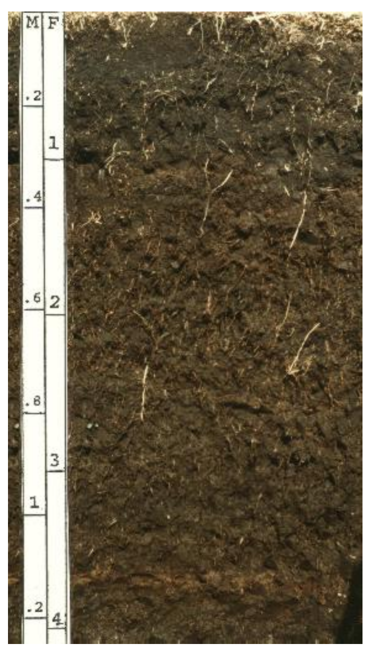
## SOIL CLASSIFICATION

**Soil scientists in the United States classify soils into 12 different orders (see Table 14.1 and Figures 14.14 and 14.15 on pages 398-399).**

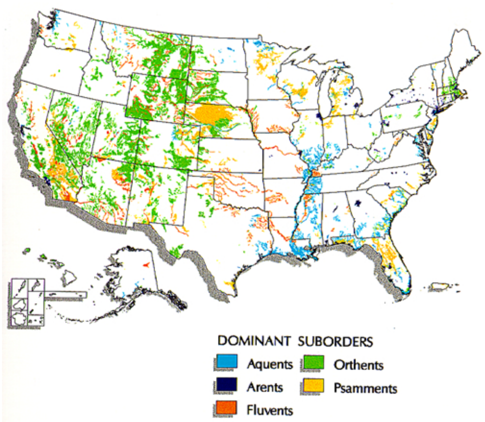
- **Histosols**
- **Entisols**
- **Inceptisols**
- **Andisols**
- **Gelisols**
- **Spodosols**
- **Mollisols**
- **Ultisols**
- **Oxisols**
- **Vertisols**
- **Alfisols**
- **Aridisols**

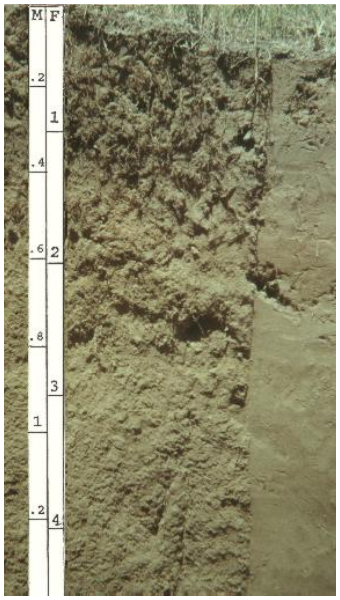
## Histosols



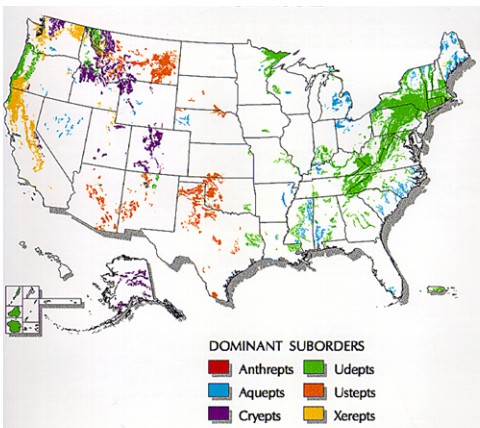



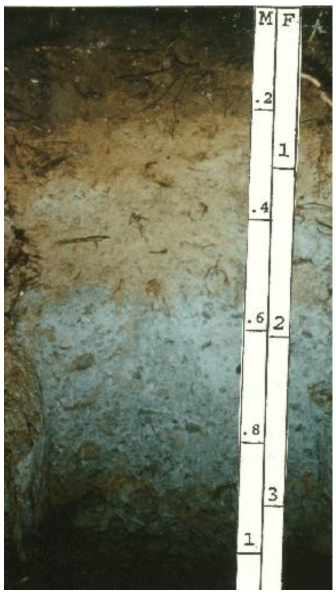
# Entisols



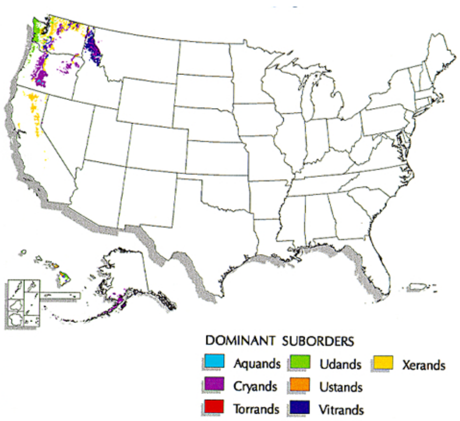



# Inceptisols

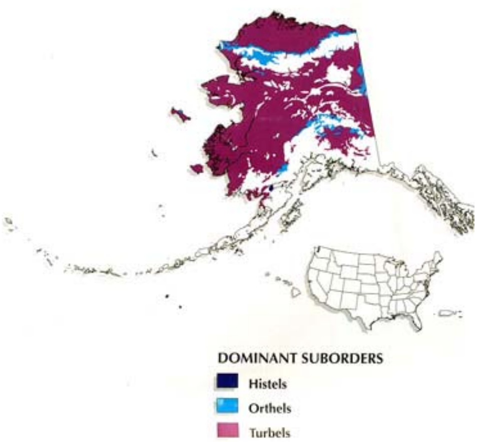


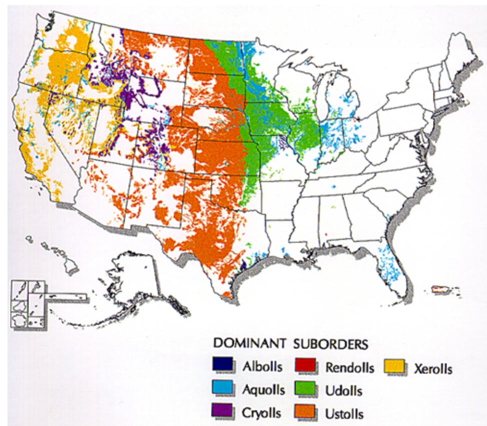
# Andisols



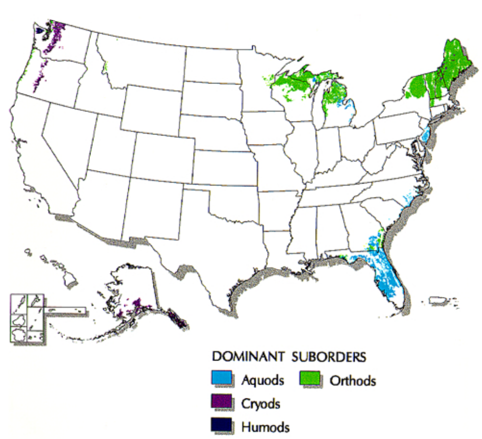

# Gelisols

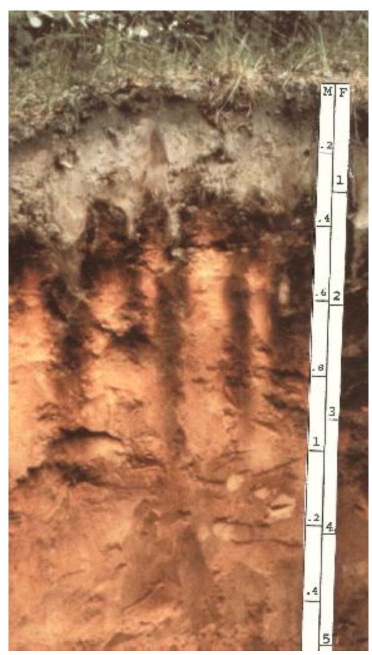


# Mollisols

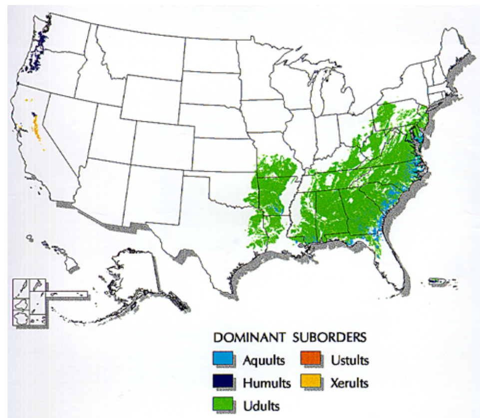



# Spodosols

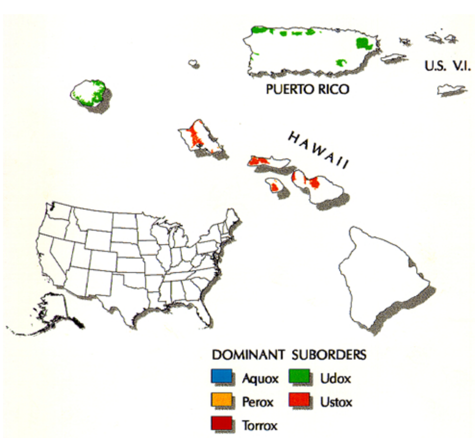


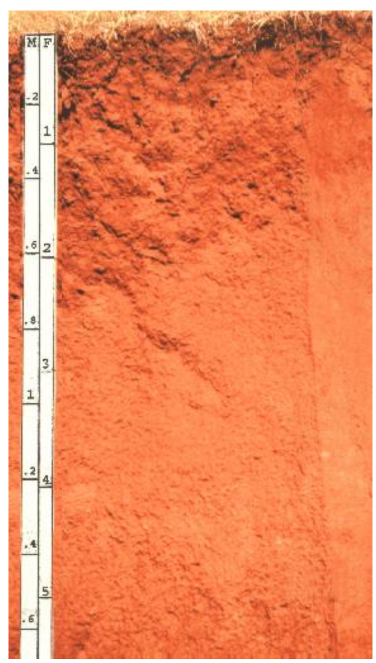



# Ultisols

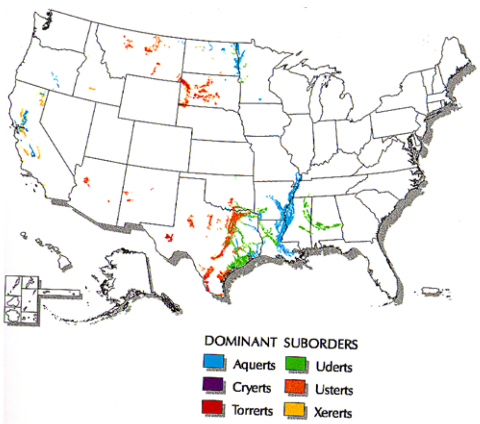



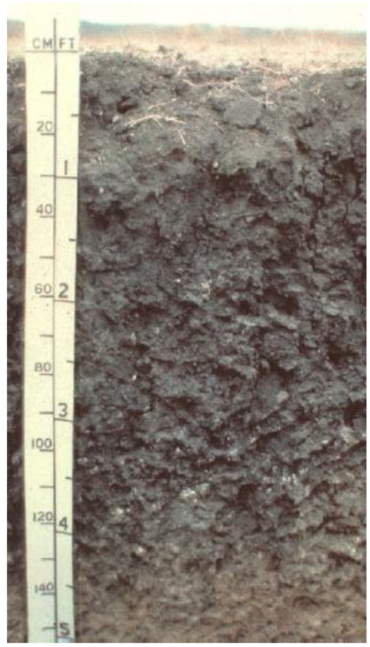

# Oxisols



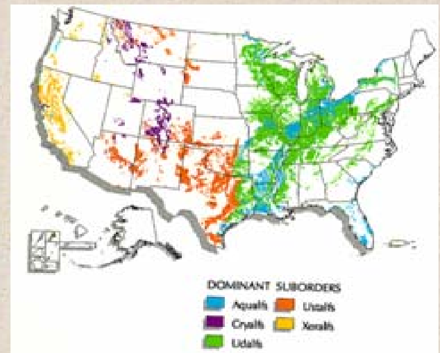
# Vertisols



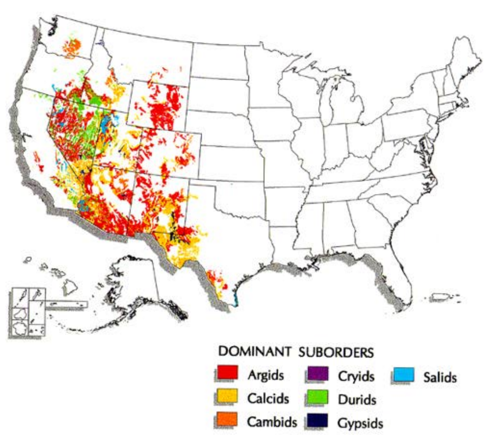



# Vertisols-surface cracks

## Alfisols




## Aridisols



## ATMOSPHERIC ADDITIONS TO SOILS

**How do soil scientists explain calcite-rich soils in the desert?**

**Soils formed in arid desert environments often have accumulations of calcite that cannot be explained by weathering of parent materials alone (see Figures 14.9 and 14.20 on pages 392 and 403).**

**If the calcite is not derived from weathering of parent materials, then it must be derived from atmospheric deposition.**

## ATMOSPHERIC ADDITIONS TO SOILS (2)

**To determine whether atmospheric contributions from dust could account for the calcite-rich soils, Leland Gile and Robert Grossman with the United States Dept. of Agriculture Soil Conservation Service (USDA-SCS; now the Natural Resources Conservation Service [NRCS]) performed dust sampling experiments over a 10-year period during the 1960s.**

**Gile and Grossman set up 8 dust traps mounted no more than 1 meter above the ground surface in the southern New Mexico desert. The collected dust was then analyzed for calcium content.**

## ATMOSPHERIC ADDITIONS TO SOILS (3)

**The results of Gile and Grossman's experiment showed that all of their dust samples contained calcium. To compare the amount of calcium in the dust to calcite contents in the soil, Gile and Grossman calculated the equivalent amount of calcite that could precipitate from the calcium supplied in the dust (see Figure 14.21 on page 404).**

- **Six of the eight traps yielded similar amounts of equivalent calcite, between 0.35 and 0.55 $g/m^2/yr$.**
- **Two dust traps yielded much higher values near 1.3 $g/m^2/yr$.**

## ATMOSPHERIC ADDITIONS TO SOILS (4)

**Gile and Grossman determined that the two traps with very high concentrations were in unusual locations.**

- **One trap was located in close proximity to blowing sand dunes, and accumulated two to 10 times more dust than the other seven traps.**
- **The second outlier trap was located where eroded soil with calcite was exposed at the surface, providing an additional source for calcite.**

**Gile and Grossman excluded the data from these two traps from their subsequent data analysis. At the remaining six sites, approximately 0.5 $g/m^2/yr$ of equivalent calcite accumulates.**

## ATMOSPHERIC ADDITIONS TO SOILS (5)

**Gile and Grossman also considered how much calcite could be formed from calcium derived from rainfall. Rainwater contains ions dissolved from dust in the atmosphere (the primary source of calcium), volcanic gas and air pollution.**

**Based on the rainfall data, Giles and Grossman calculated that rainwater delivers the equivalent of approximately 1.5 grams of calcite to each square meter of the soil.**

**Adding this amount to the dust trap abundances (excluding the two outlier traps) indicated that the total equivalent calcite added by atmospheric dust and precipitation is about 2.0 g/m$^2$/yr (see Figure 4.21).**

## ATMOSPHERIC ADDITIONS TO SOILS (6)

**The final part of Gile and Grossman's experiment was to determine whether the atmospheric addition of calcium was sufficient to account for the observed calcite concentrations in the desert soils (see Figure 4.22 on page 405).**

**To test their hypothesis, Gile and Grossman, excavated all of the soil below a 1 meter by 1 meter square on the surface and measured the total calcite content. The calcite content of the soil was found to be about 12 kg.**

## ATMOSPHERIC ADDITIONS TO SOILS (7)

**Next, Gile and Grossman had to determine the duration of soil formation to evaluate whether atmospheric additions were sufficient to account for the amount of calcite present in the desert soils.**

**Charcoal fragments from the soil and underlying stream sediment (the parent material) were separated and dated using the $^{14}C$ radioactive isotope method.**

**The older charcoal (about 7,000 years old) in the stream sediment was deposited before the soil formed, and the younger charcoal (about 4,000 years old) may have been mixed into the soil while soil formation was ongoing.**

## ATMOSPHERIC ADDITIONS TO SOILS (8)

**The radioactive isotopes dates indicate that the soil formed for at least 4,000 years, but for no more than 7,000 years.**

**To account for the 12 kg of calcite over these time intervals would require the addition of approximately 1.7 to 3.0 g/yr, on average, into the square meter of surface where the soil was excavated.**

**The estimated atmospheric contribution from the dust trap and rainfall data is 2.0 $g/m^2/yr$, and compares closely to the average rate of calcite accumulation in the soil.  Gile and Grossman subsequently made similar measurements on many soils and obtained similar results.**

## ANTHROPOGENIC EFFECTS ON SOILS

**Soil erosion is the greatest threat to future agricultural production both in the United States and abroad. Each year in the United States alone, approximately 4 billion metric tons of soil is eroded.**

- **Flowing water is responsible for about 2/3 of this erosion.**
- **More than ½ of the soil eroded is from croplands. Even where soil remains, the upper horizons (topsoil) that are most rich in nutrients are commonly lost.**

## ANTHROPOGENIC EFFECTS ON SOILS (2)

**Soil Erosion by Flowing Water**

**Agricultural activities destabilize landscapes by increasing water runoff and erosion potential. Erosion in undisturbed forests and grasslands is relatively small compared to soil loss in the same areas after natural vegetation has been removed and the soils converted to crop production.**

**Infiltration of rainfall into natural soils is generally more efficient because the thick vegetative cover acts to slow water down flowing across the surface thus increasing the opportunity for infiltration.**

## ANTHROPOGENIC EFFECTS ON SOILS (3)

**Soil Erosion by Flowing Water**

**Cultivated fields, in contrast, often lie barren and are not utilized for portions of the year, or are only sparsely covered by vegetation. Additionally, utilization of heavy farm implements compacts the soil and decreases its porosity.**

**Infiltration is lower on bare, compacted soil than on loose vegetated soil covered with plant debris (see Figure 14.23 on page 407)!**

## ANTHROPOGENIC EFFECTS ON SOILS (4)

**Soil Erosion by Flowing Water**

**Reduced infiltration translates into greater runoff from rainfall and snowmelt, which results in increased erosion. Water may flow in shallow continuous sheets across the surface, or it may focus into small channels where deeper flow enhances erosion.**

**Rill – A tiny channel that is shallow enough to be removed by tilling the surface with a plow.**

**Gully – A deeper channel that cannot be smoothed by tillage.**

## ANTHROPOGENIC EFFECTS ON SOILS (5)

**Soil Erosion by Blowing Wind**

**Wind erosion is most common in dry regions where agricultural production may already be marginal.**

**Vegetation decreases the effectiveness of wind erosion by binding soil with roots and by acting as an obstacle to reduce the velocity of wind (see Figure 14.25 on page 408).**

**Droughts are naturally occurring events; however, agricultural activities may enhance wind erosion (see Figure 14.24 on page 408). Water-demanding crops may replace native drought tolerant grasses. These species may die when stressed for moisture. Overgrazing may also increase susceptibility of soil to erosion.**

## PREVENTING SOIL EROSION

**Slope is one of the most important factors in soil erosion, because water flows faster down steep slopes increasing erosion. Whenever possible, it is best to leave steep slopes undisturbed.**

**Erosion on steep slopes may be reduced by terracing (see Figure 14.26 on page 409). The flat terrace surfaces slow down the water and also allow the water to soak into the soil.**

## PREVENTING SOIL EROSION (2)

Soil erosion may occur even on gentle slopes and rolling hills. Some crop-planting practices can decrease this erosion (see Figure 14.27 on page 409).

If crop rows run downhill, the water follows the rows and causes erosion. Planting along the contours of the slopes allows the crops to intercept downslope water flow, decrease erosion, and increase infiltration.

Alternating the planting of corn with hay or other natural grasses will also decrease erosion, because grasses form a continuous vegetative cover

## PREVENTING SOIL EROSION (3)

Erosion may also be reduced by instituting “no-till” farming practices. This practice leaves the unutilized crop residues in the field rather than plowing them under. Erosion is decreased because the plant remains slow down runoff. An additional benefit is the return of plant nutrients to the soil.

Windbreaks may also be utilized to reduce erosion. The trees form obstacles to wind that slow down the wind speed and force the blowing air up and away from the land surface (see Figure 14.28 on page 410).