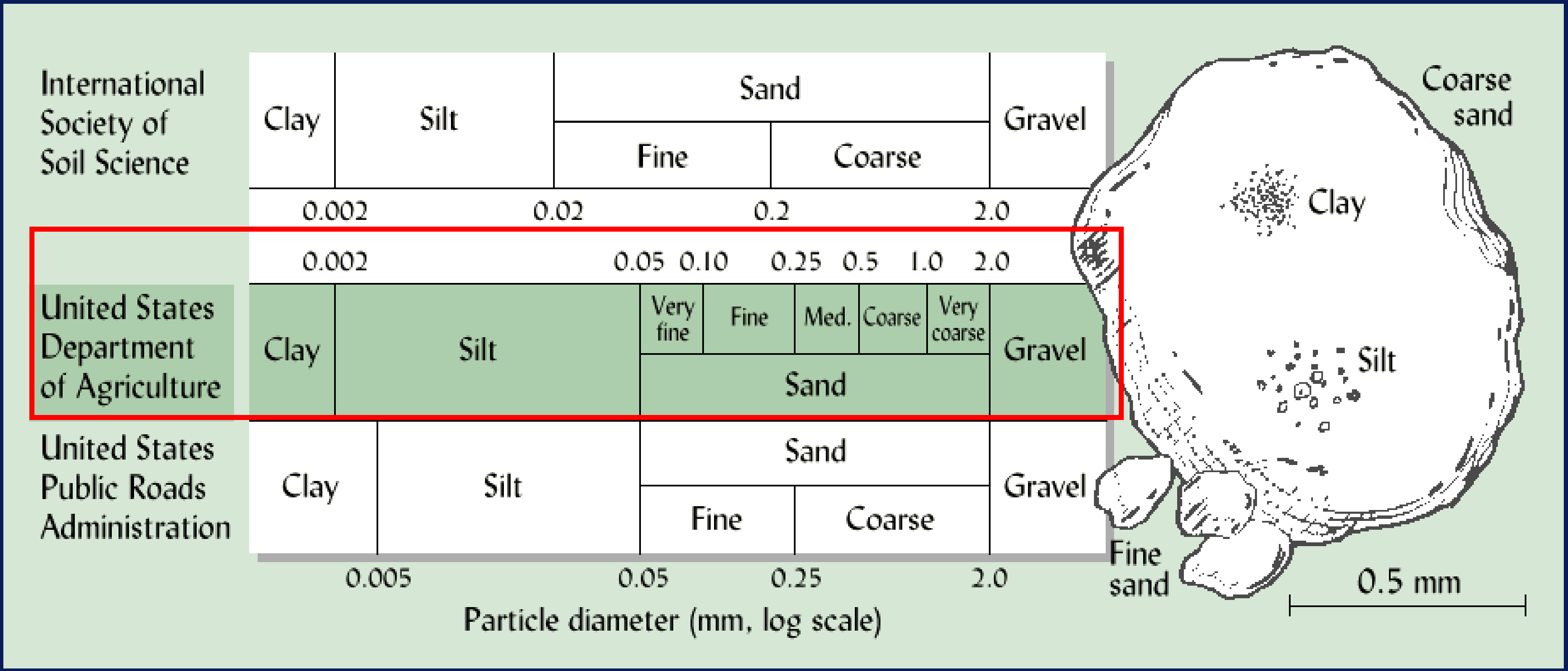
GEOLOGY 408/508

SOIL ARCHITECTURE AND PHYSICAL PROPERTIES

CHAPTER 4

Brady & Weil, Rev. 14th ed.

SIZE CLASSIFICATION OF SOIL PARTICLES



The shaded scale in the center and the names on the drawings of particles follow the United States Department of Agriculture system, which is widely used throughout the world. The USDA system is also used in this book.

The other two systems shown are also widely used by soil scientists and by highway construction engineers. The drawing illustrates the size of soil separates (note scale). (FIGURE 4.1)

NATURE OF SOIL SEPARATES

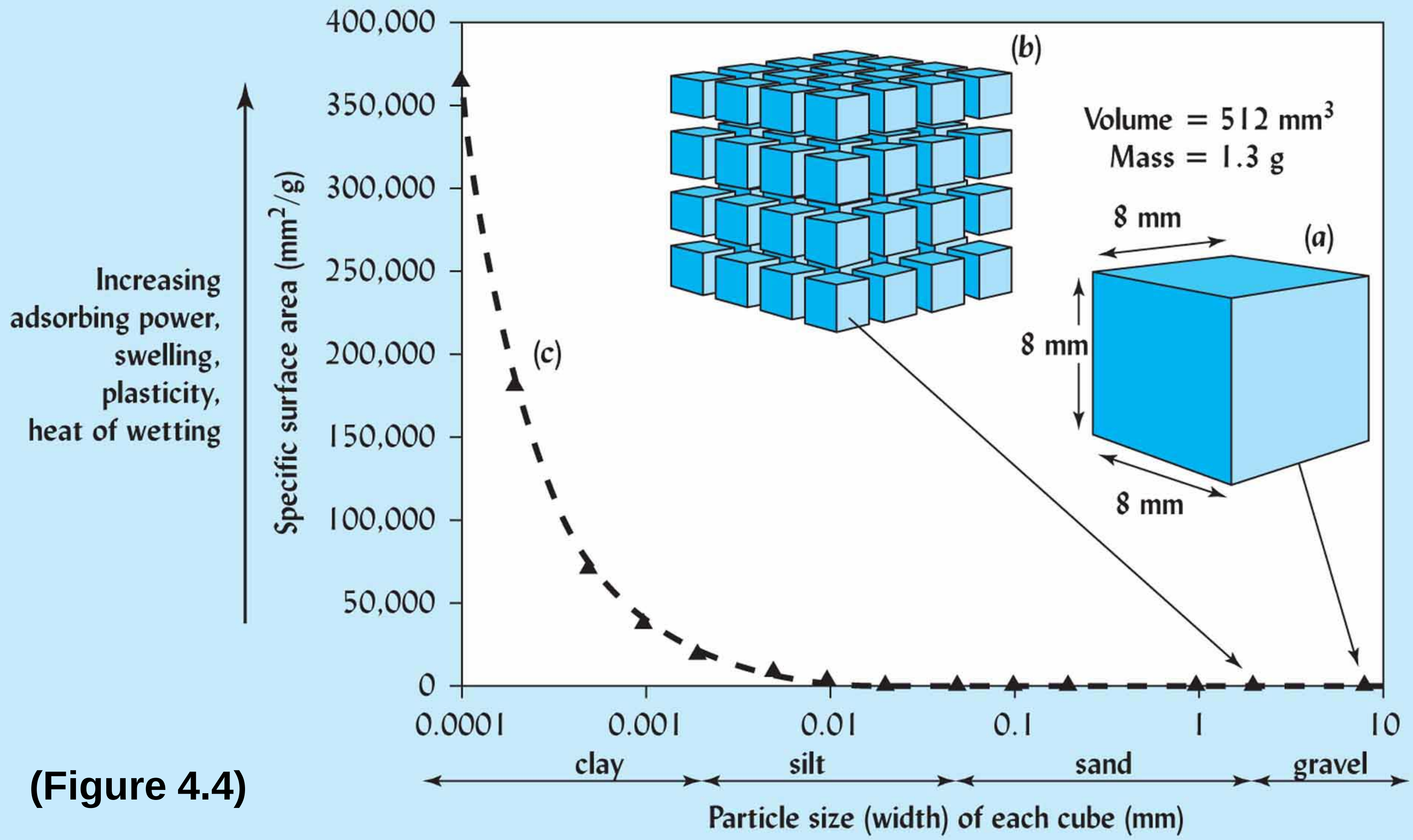
Soil texture - the size grouping of mineral particles; the relative proportion of soil separates.

Soil structure - the arrangement of soil particles into groups or aggregates

Soil separates - various size groups

Mechanical analysis - process of determining sizes of particles in soils

THE RELATIONSHIP BETWEEN THE SURFACE AREA OF A GIVEN MASS OF MATERIAL AND THE SIZE OF ITS PARTICLES.



(Figure 4.4)

NATURE OF SEPARATES

Coarse separates:

- behave as individual particles
- are not sticky when wet
- have low water holding capacity
- well drained and aerated
- have irregular shapes

NATURE OF SEPARATES

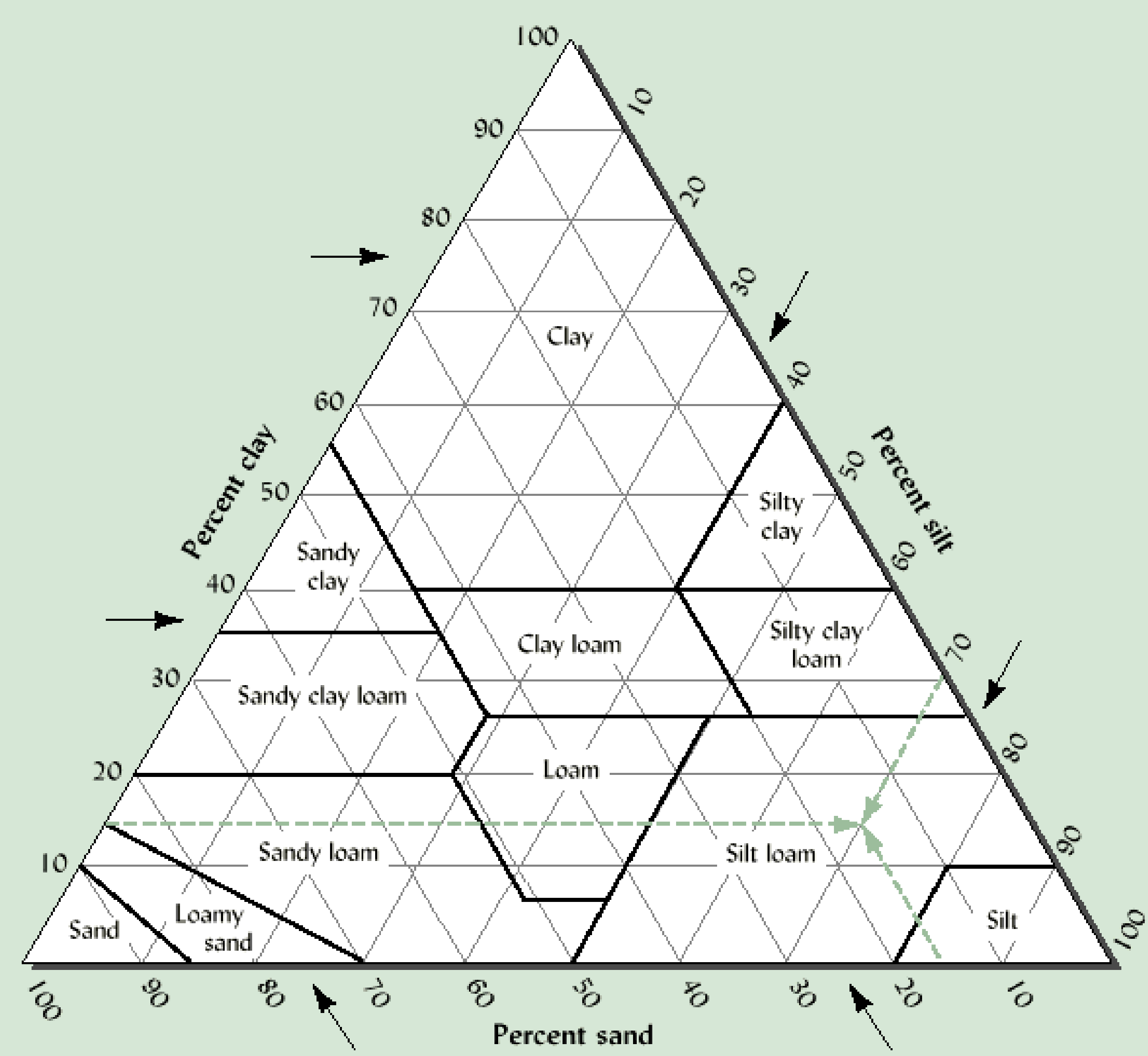
Clay and silt separates:

- have very high surface area
- surface area of fine clay > 10,000 x that of fine sand
- clay particles are mica-like in shape, plastic when wet, hard when dry

- silt particles are "microsand" particles
  - irregular & diverse in shape
  - composed mostly of SiO_2
  - have film of clay on surface which causes some plasticity, cohesion, sorption

SOIL TEXTURAL CLASSES

The major soil textural classes are defined by the percentages of sand, silt, and clay according to the heavy boundary lines shown on the textural triangle. (FIG 4.6)



TEXTURAL DETERMINATION

The “Feel” Method:

Determination of soil texture by properties of particle size, plasticity, stickiness by hand examination [see text, Box 4.2]

TEXTURAL DETERMINATION

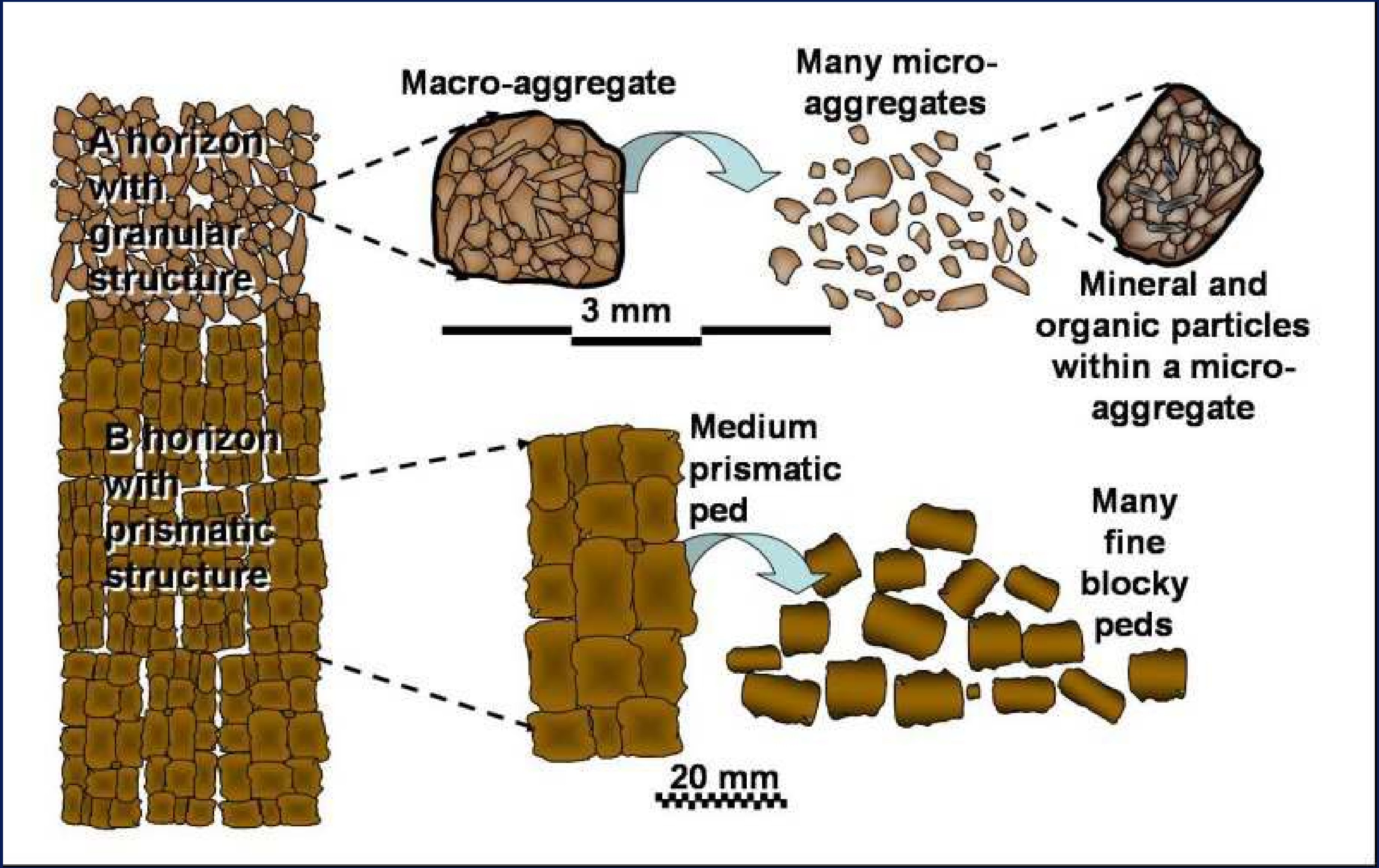
The Laboratory Method:

- completely disperse soil sample
- sieve to remove sand
- allow silt and clay to settle from suspension
- use hydrometer to determine % clay

$V = kd^2$ Stokes' Law

k - related to gravity acceleration and density and viscosity of water

THE HIERARCHICAL ORGANIZATION OF SOIL STRUCTURE. (FIGURE 4.11)



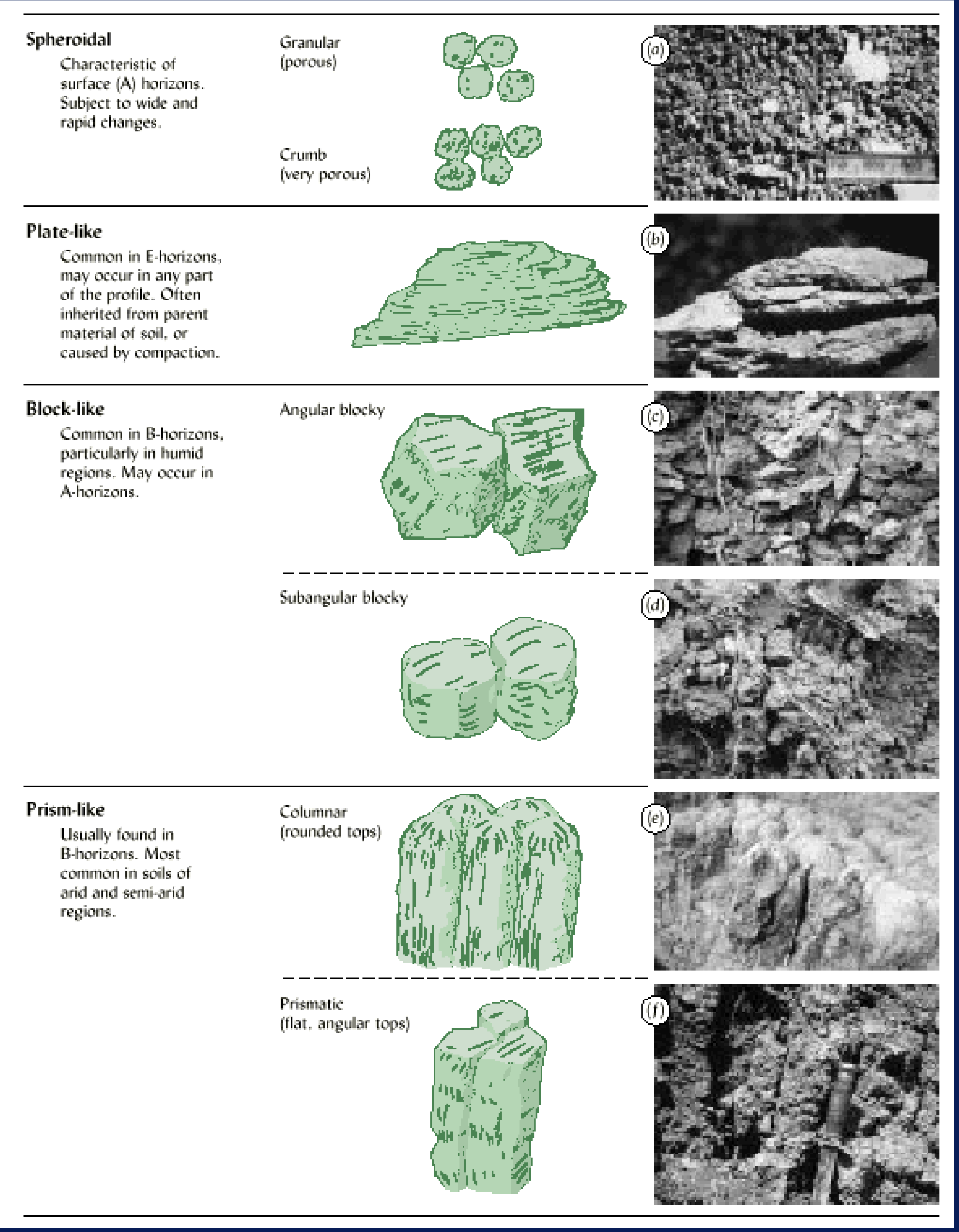
SOIL STRUCTURE

The various structure types (shapes) found in mineral soils.

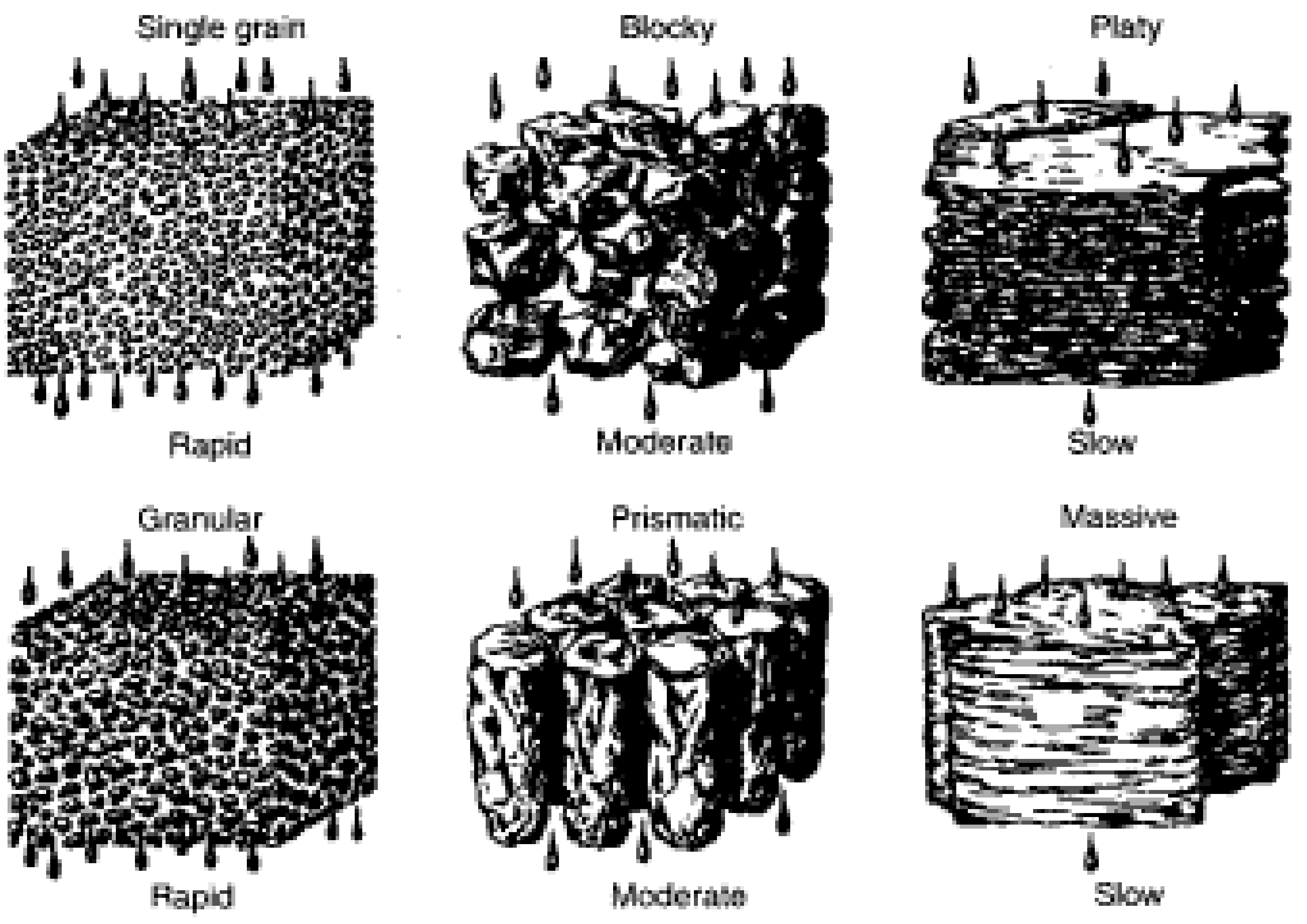
Their typical location is suggested.

The drawings illustrate their essential features and the photos indicate how they look in situ.

For scale, note the 15-cm-long pencil in (e) and the 3-cm-wide knife blade in (d) and (f). (FIG 4.13)

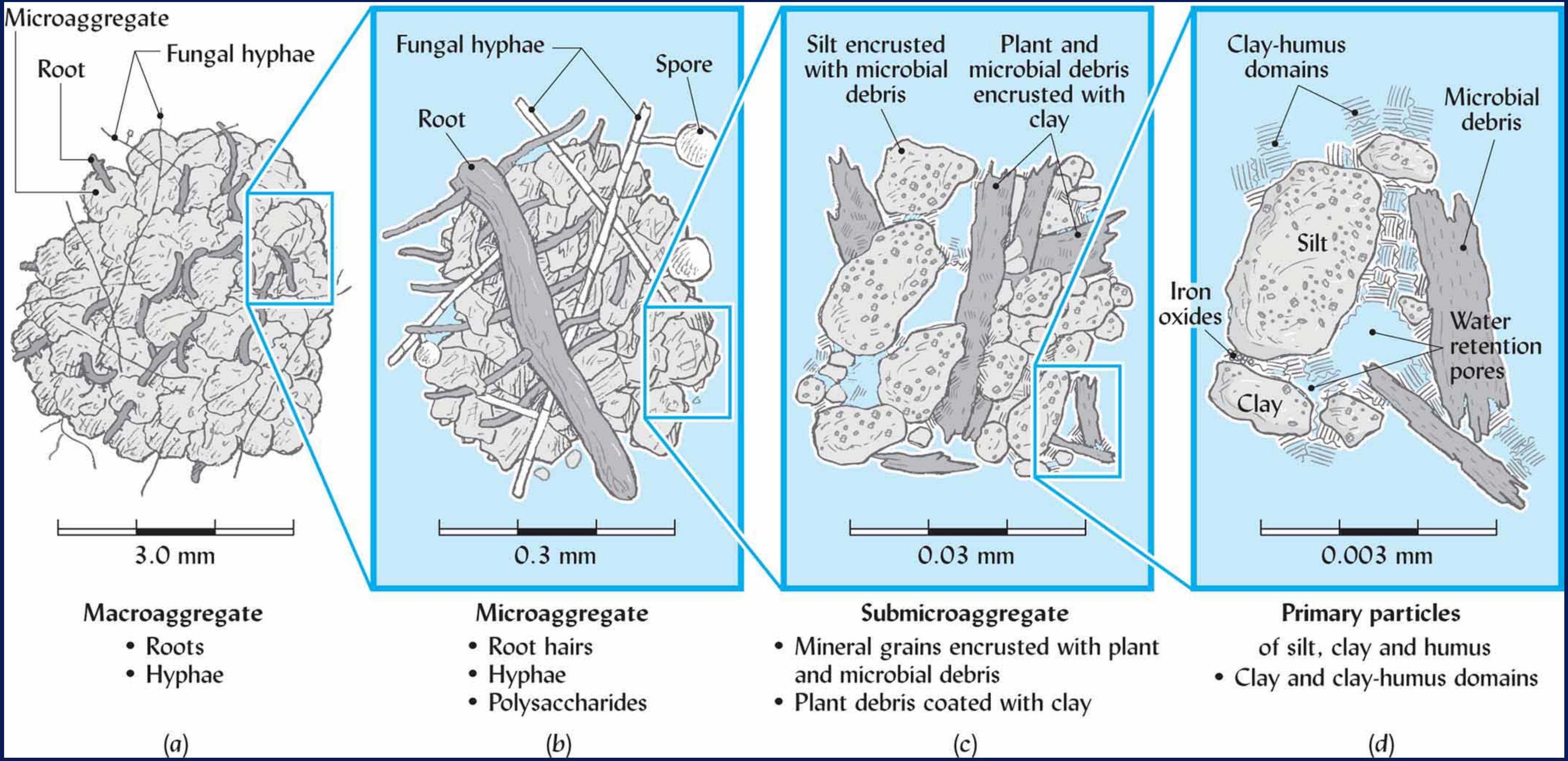


SOIL STRUCTURE AND PERCOLATION OF WATER



Larger aggregates are often composed of an agglomeration of smaller aggregates. FIGURE 4.15

This illustration shows four levels in this hierarchy of soil aggregates.



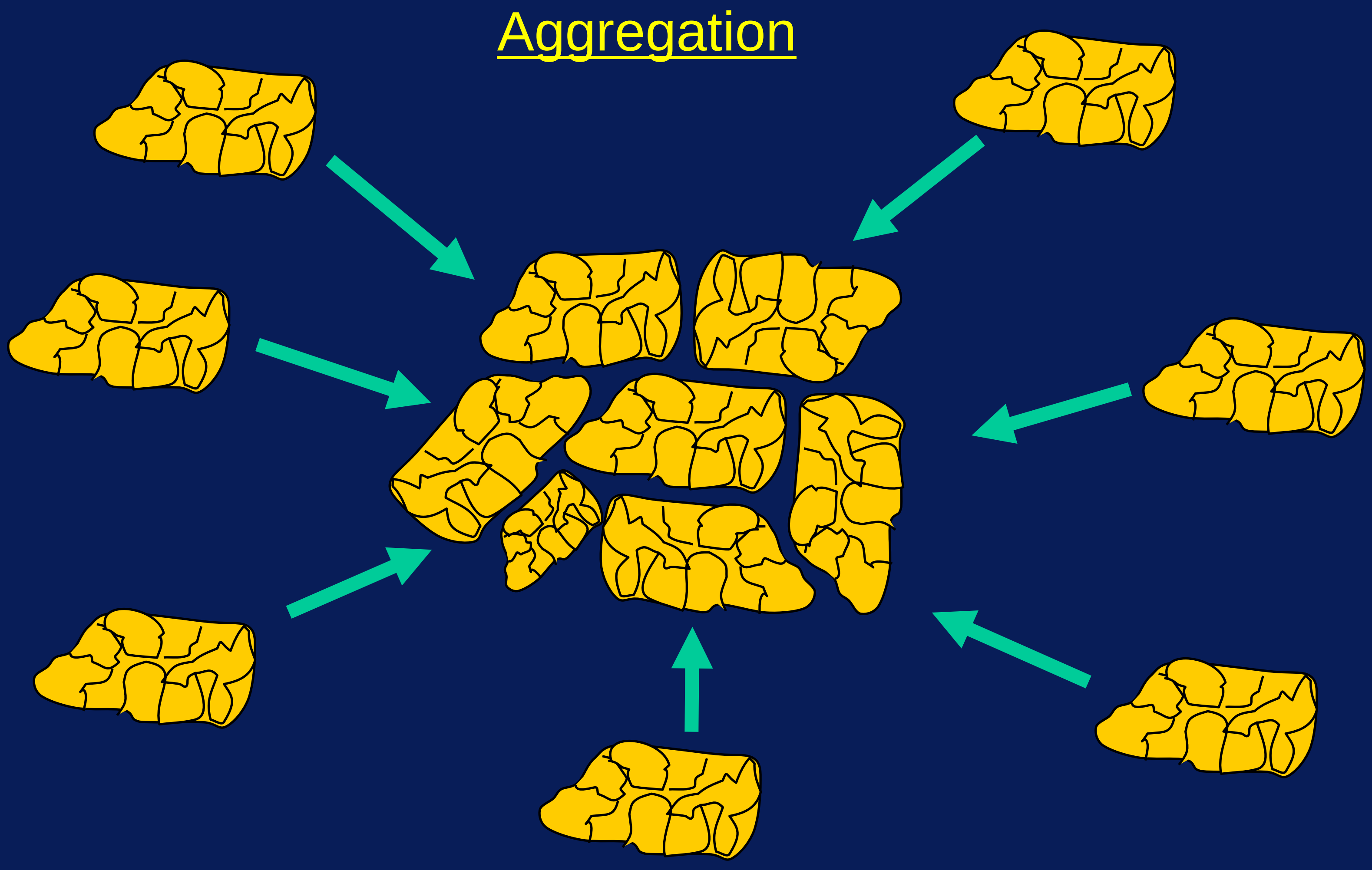
FORMATION AND STABILIZATION OF SOIL AGGREGATES

Physical-Chemical Processes:

- Flocculation of clays by multivalent cations
- Formation of *clay domains* (from flocculation)
- Formation of microaggregates from clay domains and organic colloids (humus)
- Shrink/swell from wetting/drying cause stronger binding of microaggregates
- Freeze/thaw cycles also aid in aggregate binding

CREATING STRUCTURE

- organic and inorganic 'glues'



FORMATION AND STABILIZATION OF SOIL AGGREGATES

Biological Processes:

- Burrowing & molding activities of earthworms
- Enmeshment of particles by sticky networks of roots & fungal hyphae
- Production of organic glues by microorganisms
- Macroaggregates form from these three processes
- Mycorrhizae fungi especially effective

FORMATION AND STABILIZATION OF SOIL AGGREGATES

Biological Processes, continued:

- Organic matter is the major agent relative to formation & stabilization of aggregates
- Organic “glues” from living and decaying macro- and micro-organisms are important
- Organomineral complexes aid in process
- Effects of living organisms (roots, earthworms, etc.) important

FORMATION AND STABILIZATION OF SOIL AGGREGATES

Influence of Tillage:

- Causes favorable effects
  - breaks up large clods
  - incorporates OM
  - loosens compacted soil
- Causes unfavorable effects
  - may crush stable aggregates
  - hastens OM oxidation, especially of interped OM

TILLAGE AND STRUCTURAL MANAGEMENT OF SOILS

Tillage & Soil Tilth:

- **Tilth** is the physical condition of soil in relation to plant growth
- Clay soils need more careful management to prevent destruction of desirable structure
- Clay type is important when considering the “moisture window” for tillage
- Conventional tillage causes compaction
- Conservation tillage minimized soil disturbance

PARTICLE DENSITY

Density:

the mass of a unit volume of (soil) solids, g cm^{-3}

- **particle density of most soils: 2.60 - 2.65**
- **density of quartz = 2.65**
- **Fineness of size has NO B☐EARING on particle density**
- **organic matter has particle density = 1.2 - 1.5**

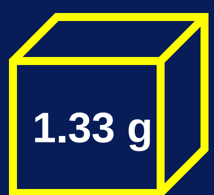
BULK DENSITY

Bulk density, D_B :

the mass of a unit volume of dry soil.

The volume includes both solids and pores

Field:



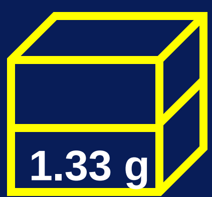
1 cm^3

Undisturbed sample,
solids & pore spaces

$$D_B = \frac{\text{wt. of soil (1.33 g)}}{\text{vol. of soil (1 cm}^3\text{)}}$$

$$= 1.33 \text{ g cm}^{-3}$$

Lab: compress:



≈ 1/2 pores
≈ 1/2 solids

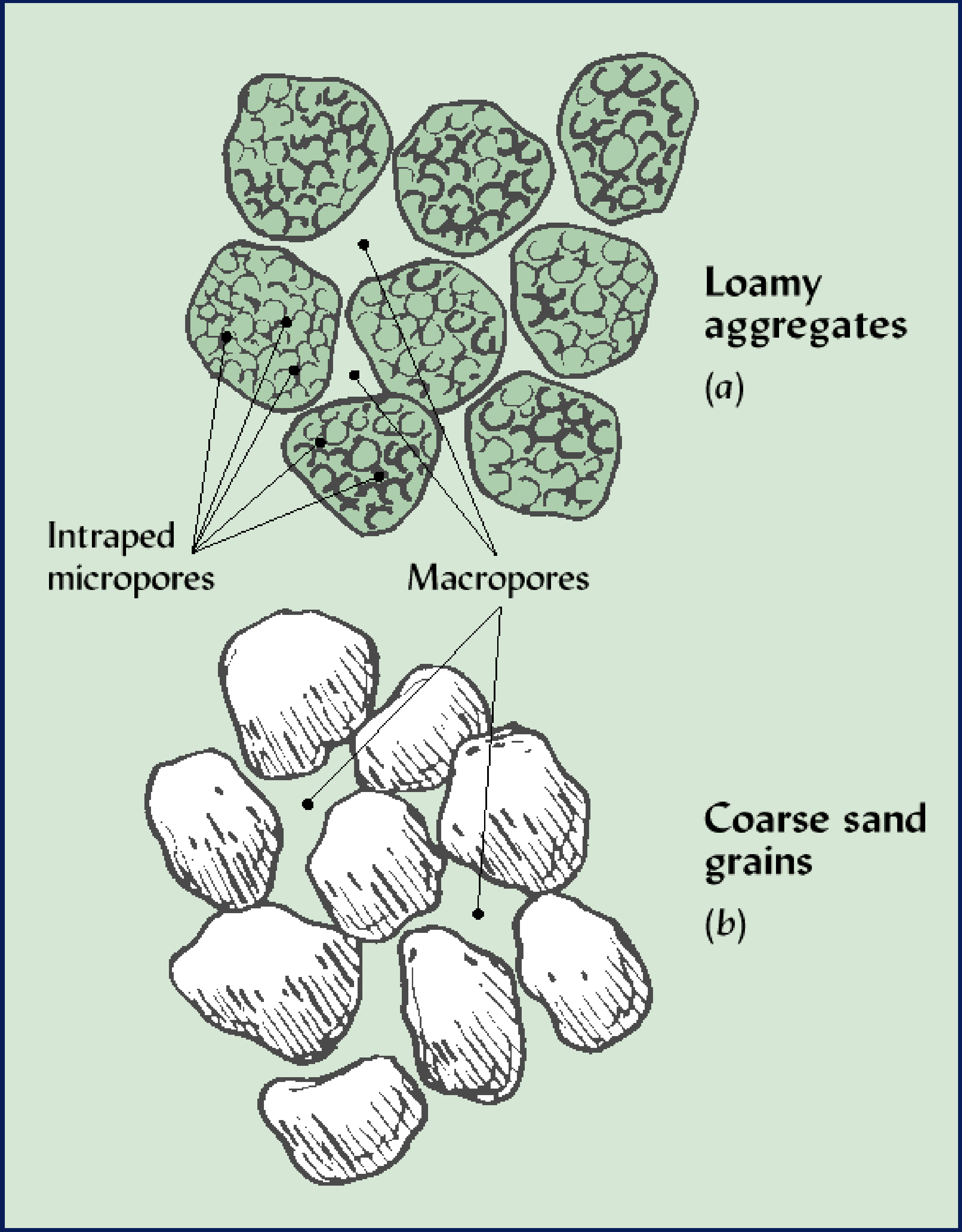
$$D_P = \frac{\text{wt. of solids (1.33 g)}}{\text{vol. of solids (0.5 cm}^3\text{)}}$$

$$D_P = 2.66 \text{ g cm}^{-3}$$

A schematic comparison of sandy and clayey soils showing the relative amounts of large (macro-) pores and small (micro-) pores in each.

There is less total pore space in the sandy soils than in the clayey one because the clayey soil contains a large number of fine pores within each aggregate (a), but the sand particles (b), while similar in size to the clayey aggregates, are solid and contain no pore spaces within them.

This is the reason why, among surface soils, those with coarse texture are usually more dense than those with finer textures. (Fig 4.35)



BULK DENSITY OF SOILS

- Loose & porous soils have low D_B
- More compact soils have high D_B

- Sandy soils - particles lie in close contact, will have high D_B; most sandy soils contain low OM which further causes high D_B

- Fine textured soils - particles generally do not rest close together; these surface soils are relatively well granulated, due to the relatively high OM content

BULK DENSITY OF SOILS

- D_B of well-granulated silt loam surface soil is < D_B of a sandy loam
- Sandy soils: D_B = 1.20 - 1.80 g cm^{-3}
- Fine textured soils: D_B = 1.00 - 1.60 g cm^{-3}
- Compact subsoils: D_B = up to 2.0 g cm^{-3}, regardless of texture
- D_B generally increases with depth: lower OM & root penetration, less aggregation in lower horizons

BULK DENSITY OF SOILS

Management Practices Affecting Bulk Density

Forest: - conventional logging activities increase D_b; could use cables, balloons or chopper for tree removal

- Camping, hiking activities cause soil compaction (see text, Fig 4.18)

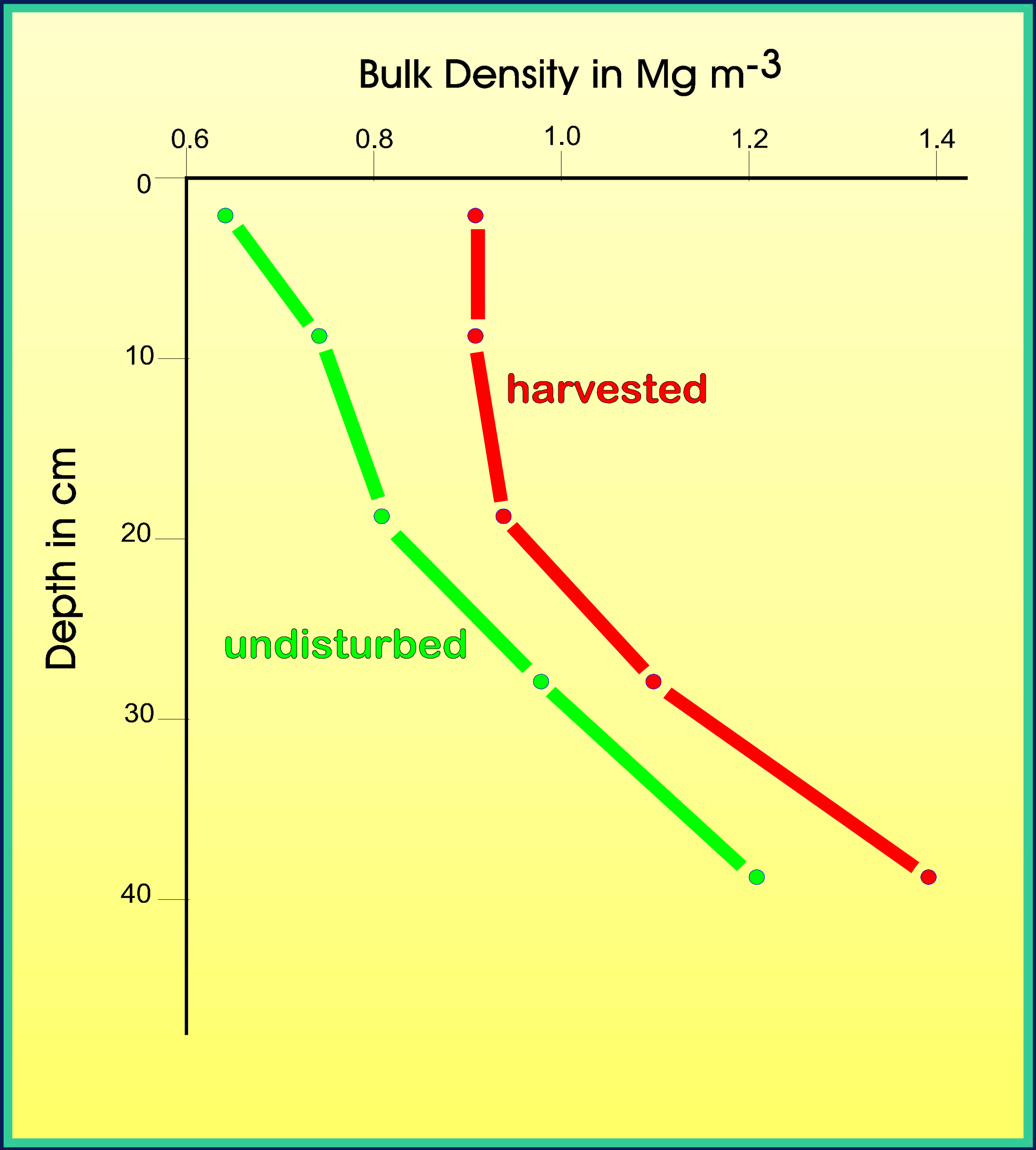
Agricultural - long term effect of tillage is destruction of structure & compaction

- may have formation of plow pans or traffic pans

LOGGING ACTIVITIES

Volcanic Ash Soil

Timber Harvest



BULK DENSITY OF SOILS

Urban

- most often have compacted soils
  - fill material ???
  - subsoil material (topsoil gone)
- use as large of a planting hole as possible
- construct porous channels for root growth
- use thick layer of mulch
- parking vehicles on lawn ???

BULK DENSITY OF SOILS

D_b and Soil Strength & Root Growth:

- High D_b and soil strength will restrict root growth (text, FIGURE 4.41)
- Compaction generally increases both D_b & soil strength
- Greater resistance to root penetration in dry soil
- Greater amount of clay will give greater resistance to root penetration at given Db

PORE SPACE OF MINERAL SOILS

- Pore space - occupied by air and water
  - determined by arrangement of solid particles
- porosity is low in sands and compact subsoils
- porosity is high in medium textured soils, with high OM

$$\% \text{ solid space} = \frac{D_B}{D_P} \times 100$$

$$\% \text{ pore space} = 100 - \left[\frac{D_B}{D_P} \times 100 \right]$$

PORE SPACE OF MINERAL SOILS

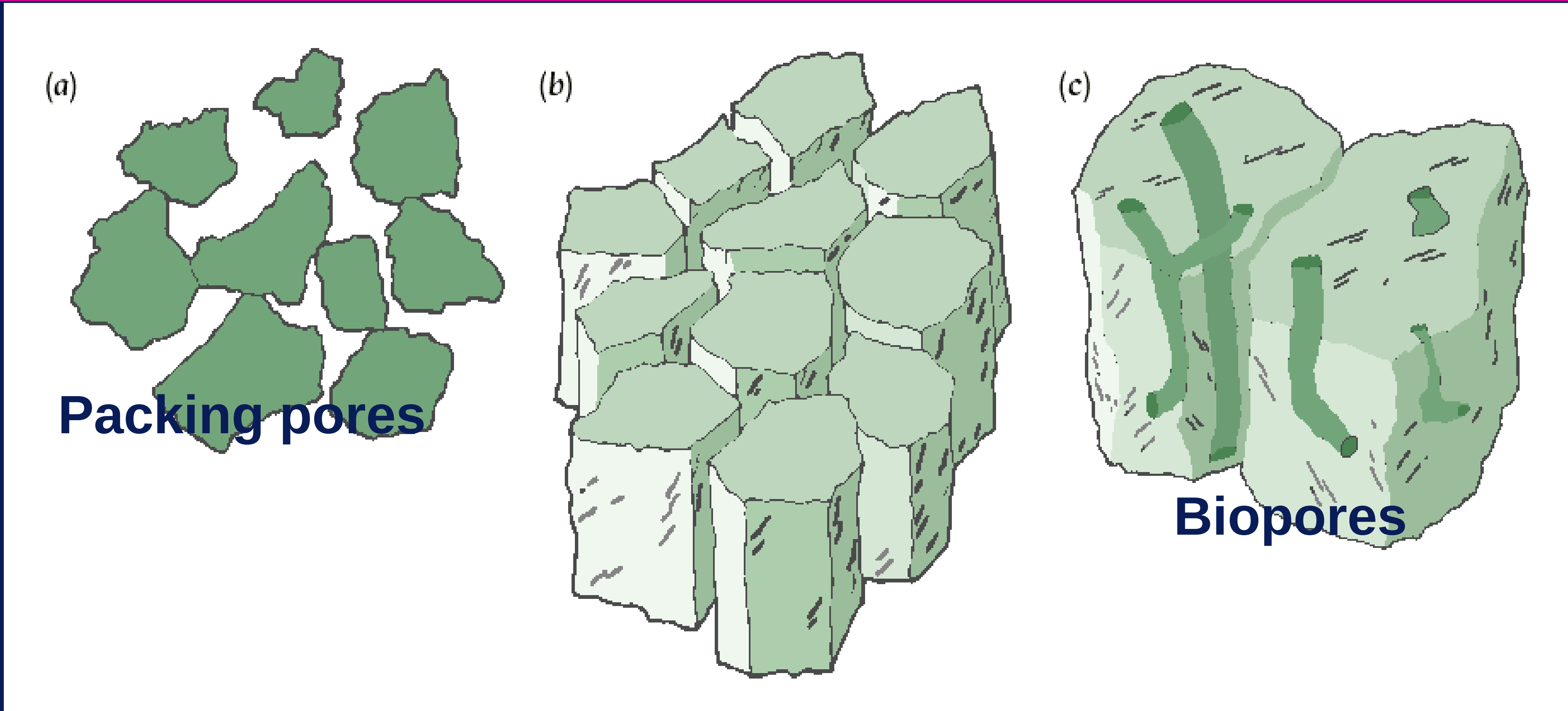
SIZE OF PORES:

Macropores - readily allow air & water movement (> 0.08 mm)

Micropores - air movement is restricted; water movement restricted primarily to slow capillary movement

- smallest micropores (ultramicropores or cryptopores) do not allow entry of smallest bacteria - can protect organic compounds for centuries

VARIOUS TYPES OF SOIL PORES

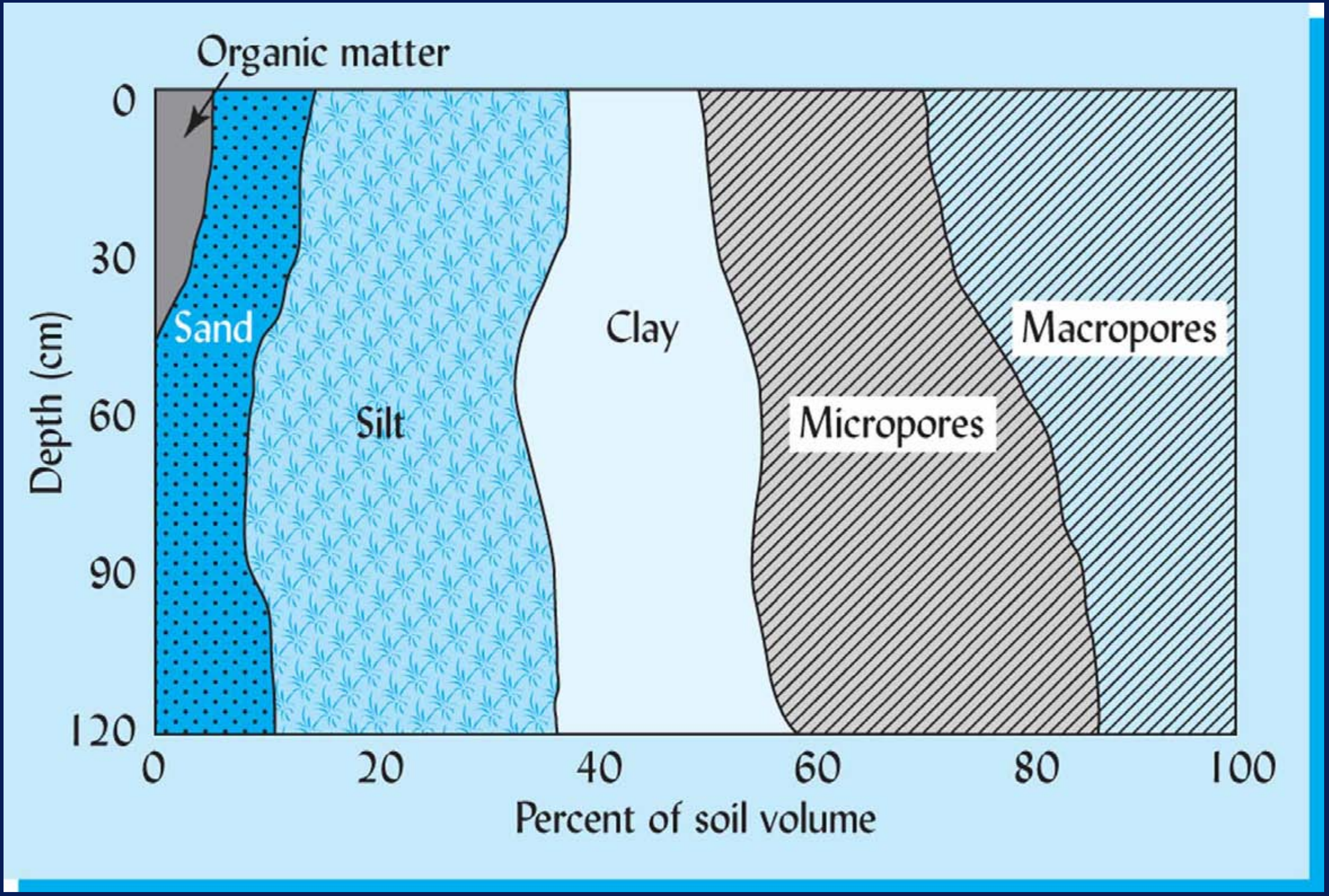


(a) Many soil pores occur as packing pores, spaces left between primary soil particles.

(b) In soils with structural peds, the spaces between the peds form interped pores.

(c) Biopores are formed by organisms such as earthworms, insects, and plant roots. (FIGURE 4.46)

Volume distribution of organic matter, sand, silt, clay and pores of macro- and microsizes in a representative medium– textured soil with good structure. (FIGURE 4.47)



SOIL PROPERTIES RELEVANT TO ENGINEERING USES

Consistence describes the resistance to mechanical stress: soft, hard, very hard

- described by resistance to rupture (by soil scientists)

- includes degrees of stickiness & plasticity

Consistency describes the resistance to deformation when a force is applied

- used by engineers

- measure by resistance to penetration

SOIL PROPERTIES RELEVANT TO ENGINEERING USES

Soil strength is most important property for engineering uses

Cohesive soils:

- electrostatic attraction between clay surfaces & H_2O in fine pores

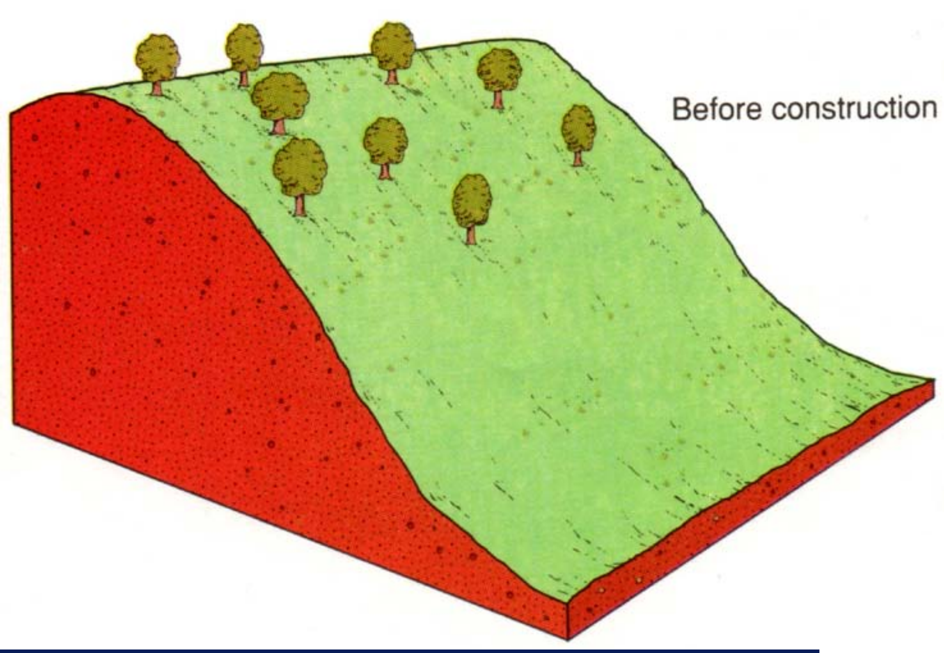
- frictional resistance between particles

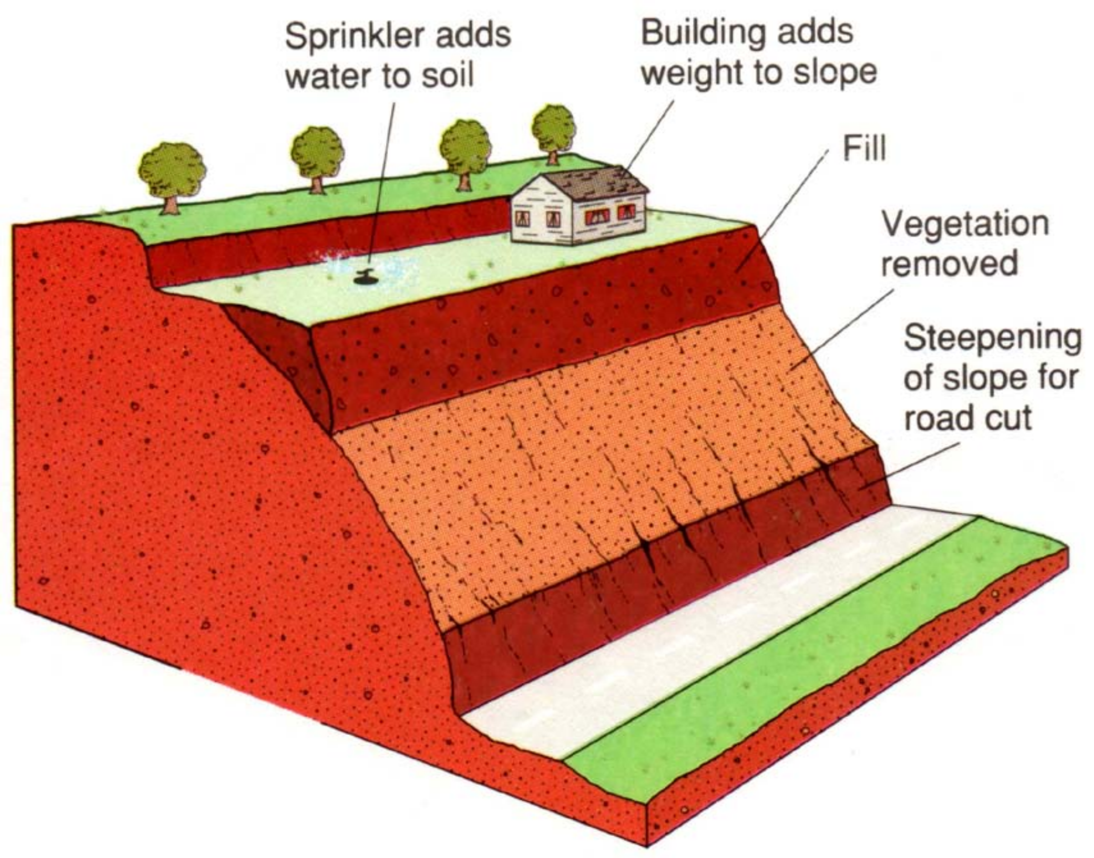
Noncohesive soils:

- frictional resistance between particles

- angle of repose important

Some causes of sudden slope failure due to construction activities





SOIL PROPERTIES RELEVANT TO ENGINEERING USES

Settlement - Gradual Compression:

- Uneven compression beneath roadway
- Rebound of certain clays after compaction
- Consolidation tests should be used to determine soil compressibility
- Compression occurs slowly in clay soils due to slow water loss

SOIL PROPERTIES RELEVANT TO ENGINEERING USES

Expansive Soils:

Expansive clays occur on ~20% 0f land in US

Damages due to expansive soils exceeds that of all types of natural disasters

Annual damages to pavements, foundations & utility lines about $4 billion

Smectitic clays are most expansive types