Basic Soil Science

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See http://pubs.ext.vt.edu/430/430-350/430-350_pdf.pdf
for more information on basic soils!

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CSES Crop & Soil Environmental Sciences

VirginiaTech
1872
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

http://www.cses.vt.edu/revegetation/

Well weathered (red, clayey) soil from the Piedmont of Virginia. This soil has formed from long term weathering of granite into soil like materials.

Native Forest Soil

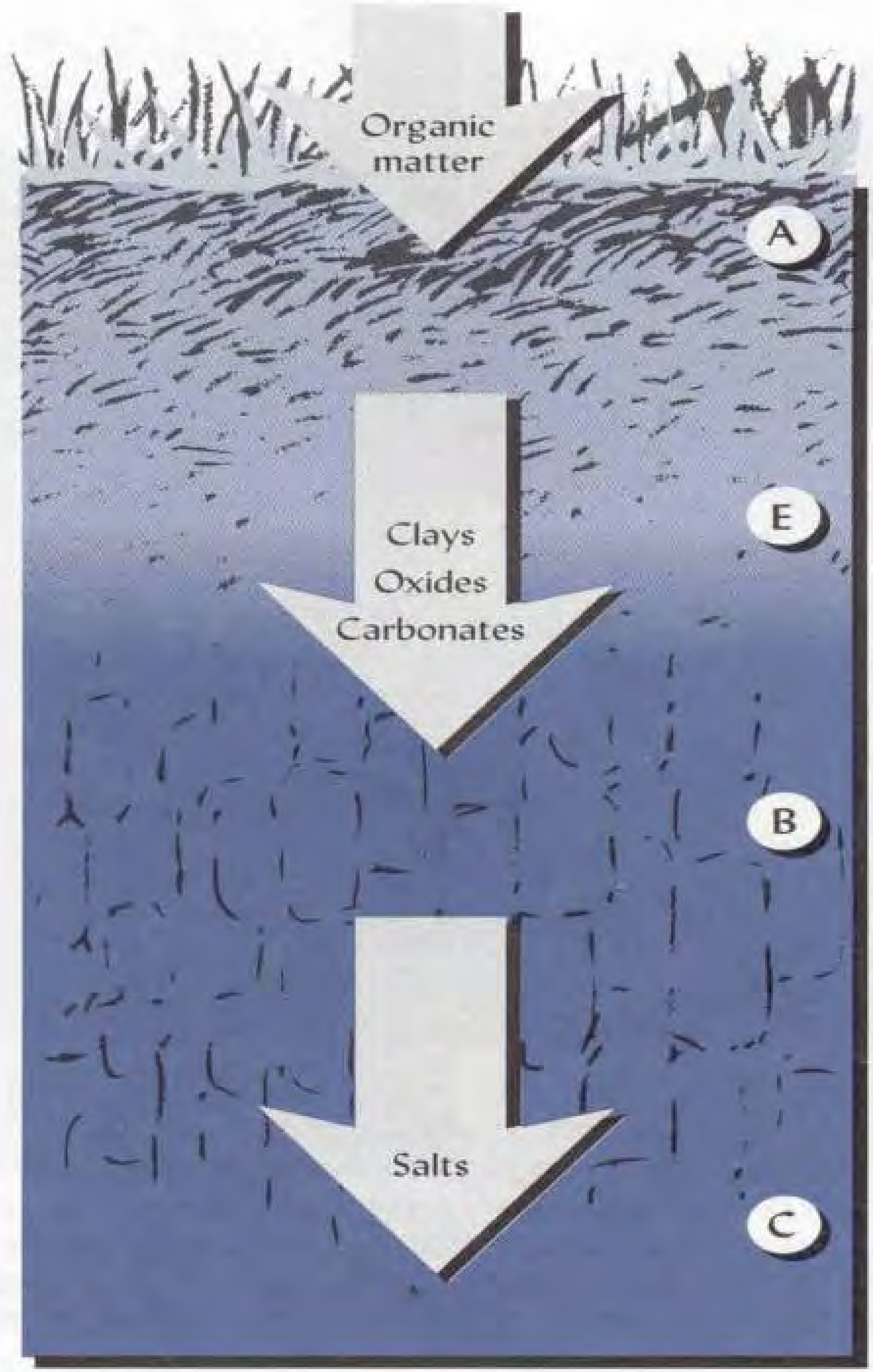
Leaf litter and roots (> 5 T/Ac/year are "bio-processed" to form humus, which is the dark black material seen in this topsoil layer. In the process, nutrients and energy are released to plant uptake and the higher food chain. These are the "natural soil cycles" that we attempt to manage today.

Soil Profiles

Soil profiles are two-dimensional slices or exposures of soils like we can view from a road cut or a soil pit.

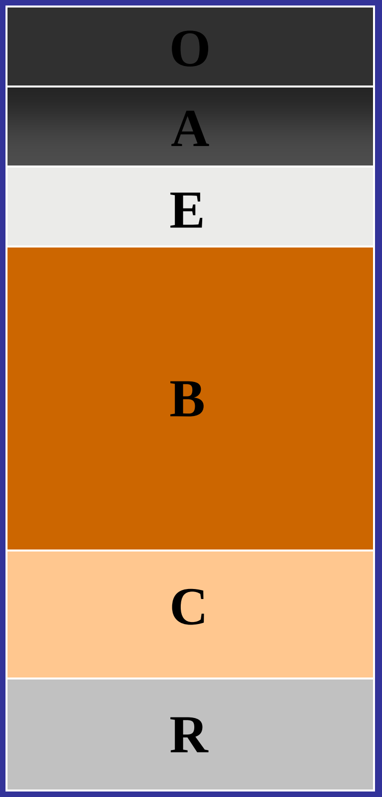
Soil profiles reveal ***soil horizons***, which are fundamental genetic layers, weathered into underlying ***parent materials***, in response to leaching and organic matter decomposition.

Fig. 1.12 -- Soils develop horizons due to the combined process of (1) organic matter deposition and decomposition and (2) illuviation of clays, oxides and other mobile compounds downward with the wetting front. In moist environments (e.g. Virginia) free salts (Cl and SO_4) are leached completely out of the profile, but they accumulate in desert soils.



Master Horizons

- O horizon
- A horizon
- E horizon
- B horizon
- C horizon
- R horizon



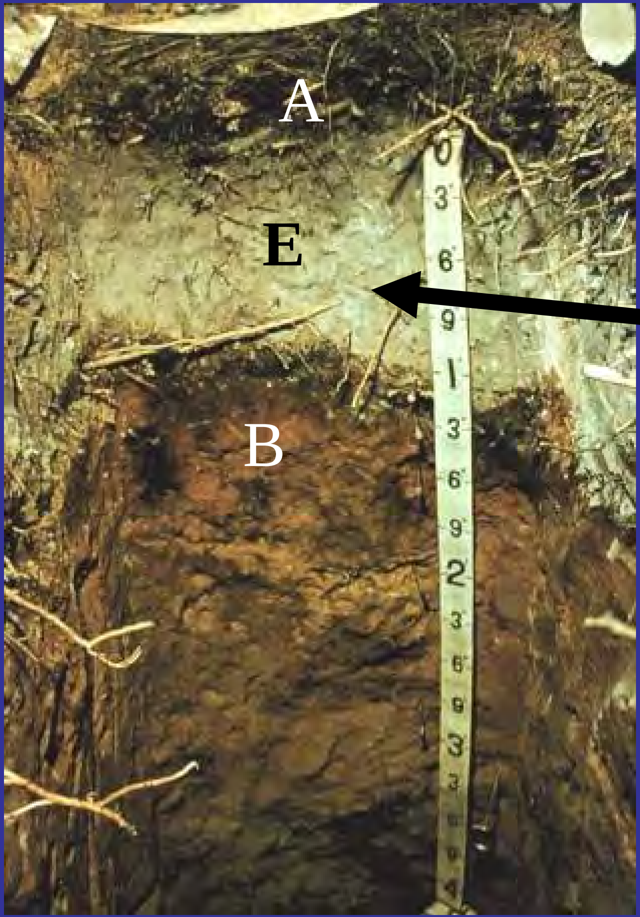
Master Horizons

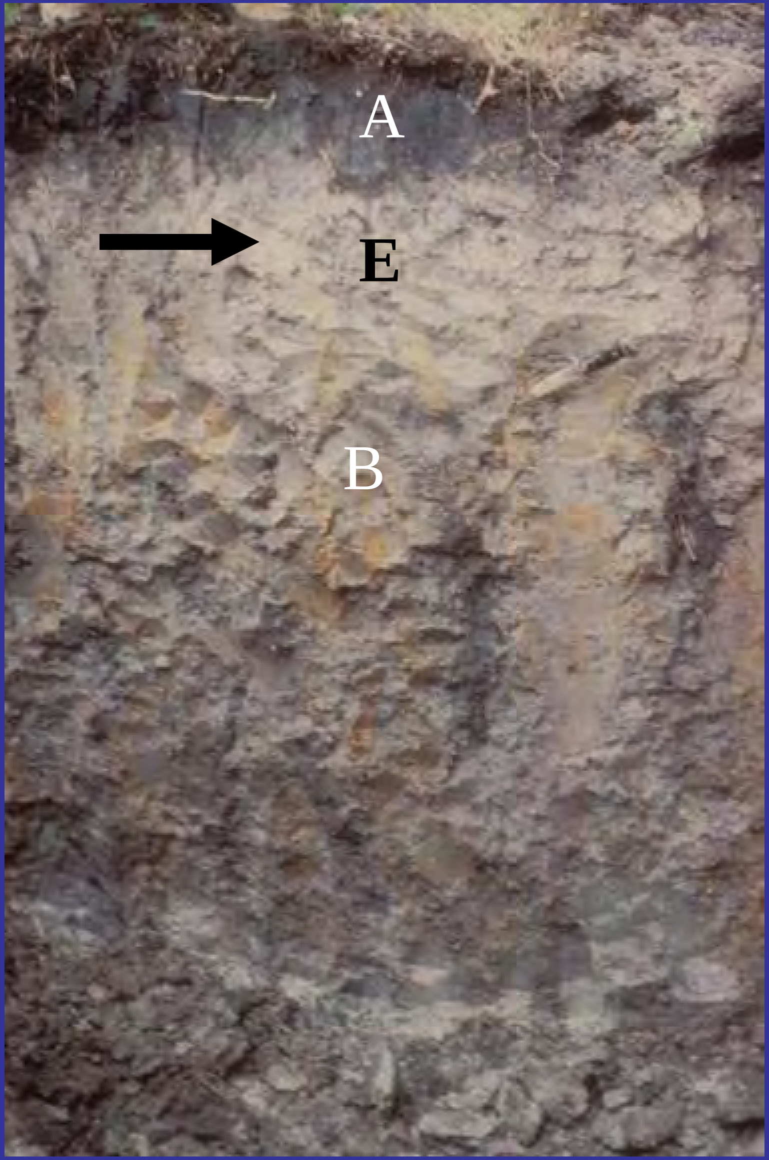
- **O horizon**
  - predominantly organic matter (litter and humus)
- **A horizon**
  - organic carbon accumulation, some removal of clay
- **E horizon**
  - zone of maximum removal (loss of OC, Fe, Mn, Al, clay…)
- **B horizon**
  - forms below O, A, and E horizons
  - zone of maximum accumulation (clay, Fe, Al, $CaC0_3$, salts…)
  - most developed part of subsoil (structure, texture, color)
  - < 50% rock structure or thin bedding from water deposition

Master Horizons

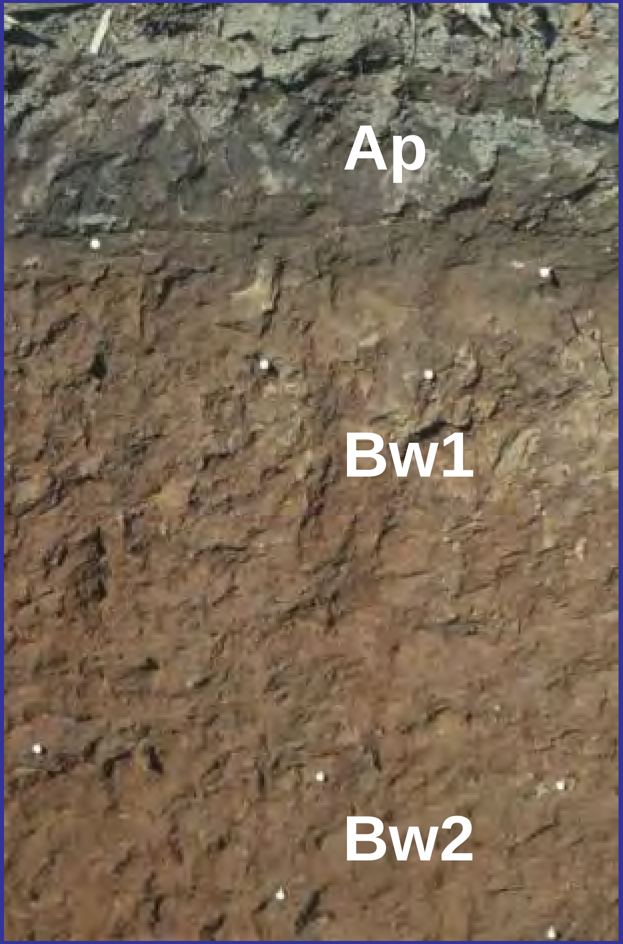
- **C horizon**
  - o little or no pedogenic alteration
  - o unconsolidated parent material or soft bedrock
  - o < 50% soil structure
- **R horizon**
  - o hard, continuous bedrock

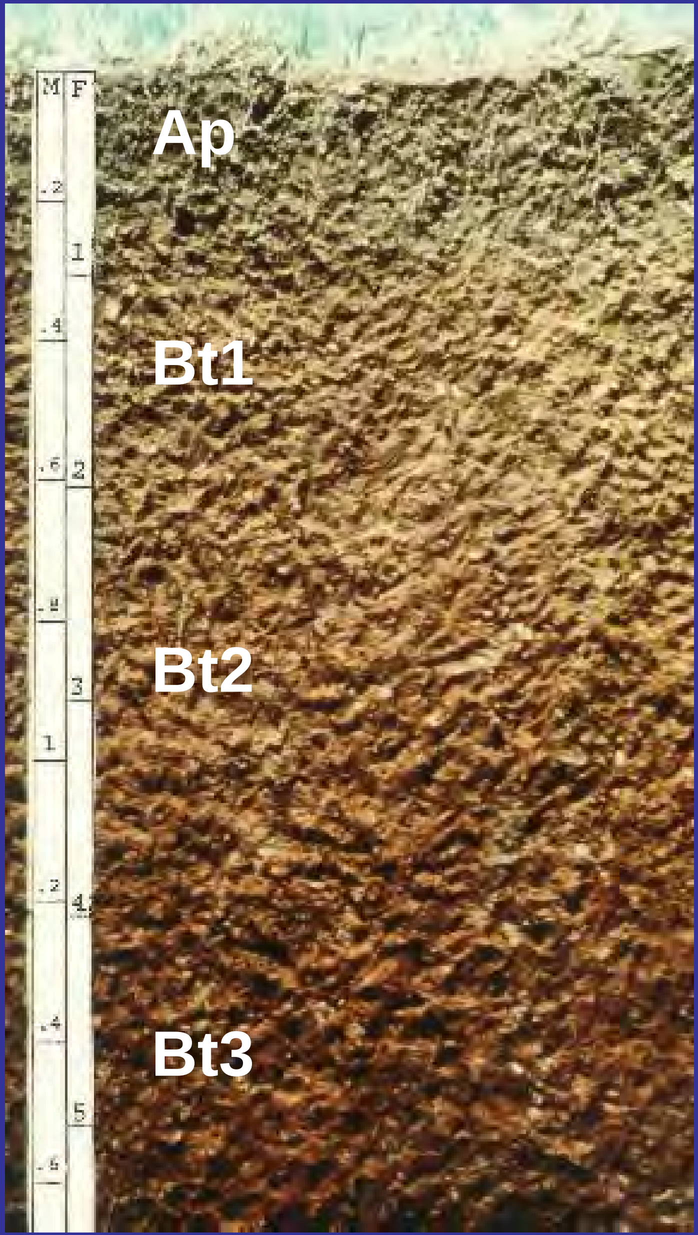
A vs. E horizon





A vs. B horizon Subscripts





What's In Soil?

Soil is a three-phase system containing solids, liquids, and gasses that strongly interact with each other.

Soil contains four components, mineral fragments, organic matter, soil air, and water.

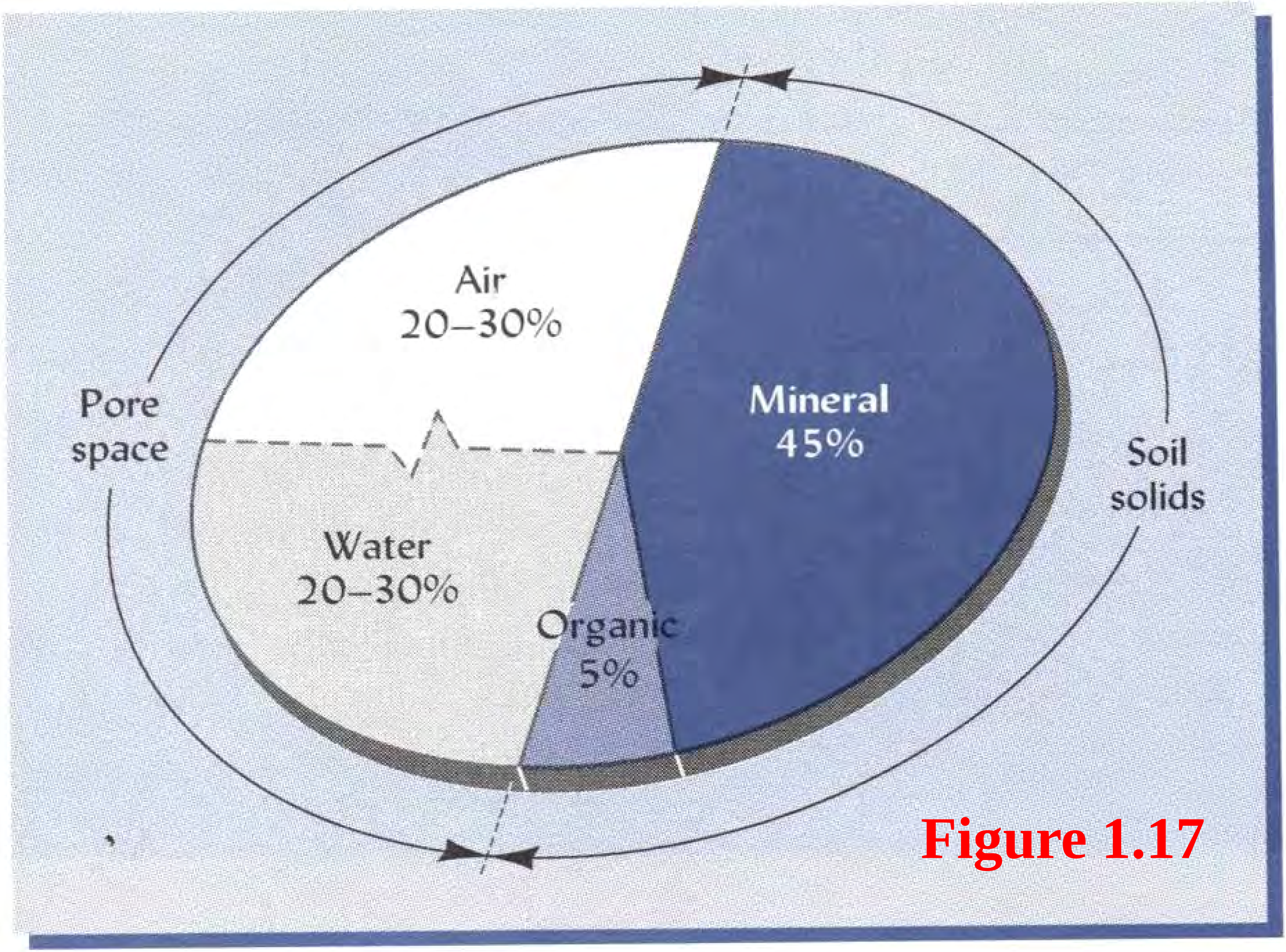

Air
20–30%
Mineral
45%
Pore
space
Soil
solids
Water
20–30%
Organic
5%

Figure 1.17

Mineral Constituents

- The majority of soil solids are ***primary mineral*** fragments like quartz and feldspars along with synthesized ***secondary minerals*** like clays and iron oxides.
- Particles > 2 mm are largely unreactive and are called ***coarse fragments***.

Some important soil Physical Properties

<u>Color</u> - as defined by the Munsell soil color book

<u>Texture</u> – the size distribution of the particles

<u>Structure</u> – how the particles are held together as aggregates

<u>Density</u> – pore space vs. solid space is in the soil

<u>Consistence</u> – resistance of aggregates to pressure

Soil Texture

Particle size distribution.

The relative proportions of sand, silt and clay.

Size separates (USDA)

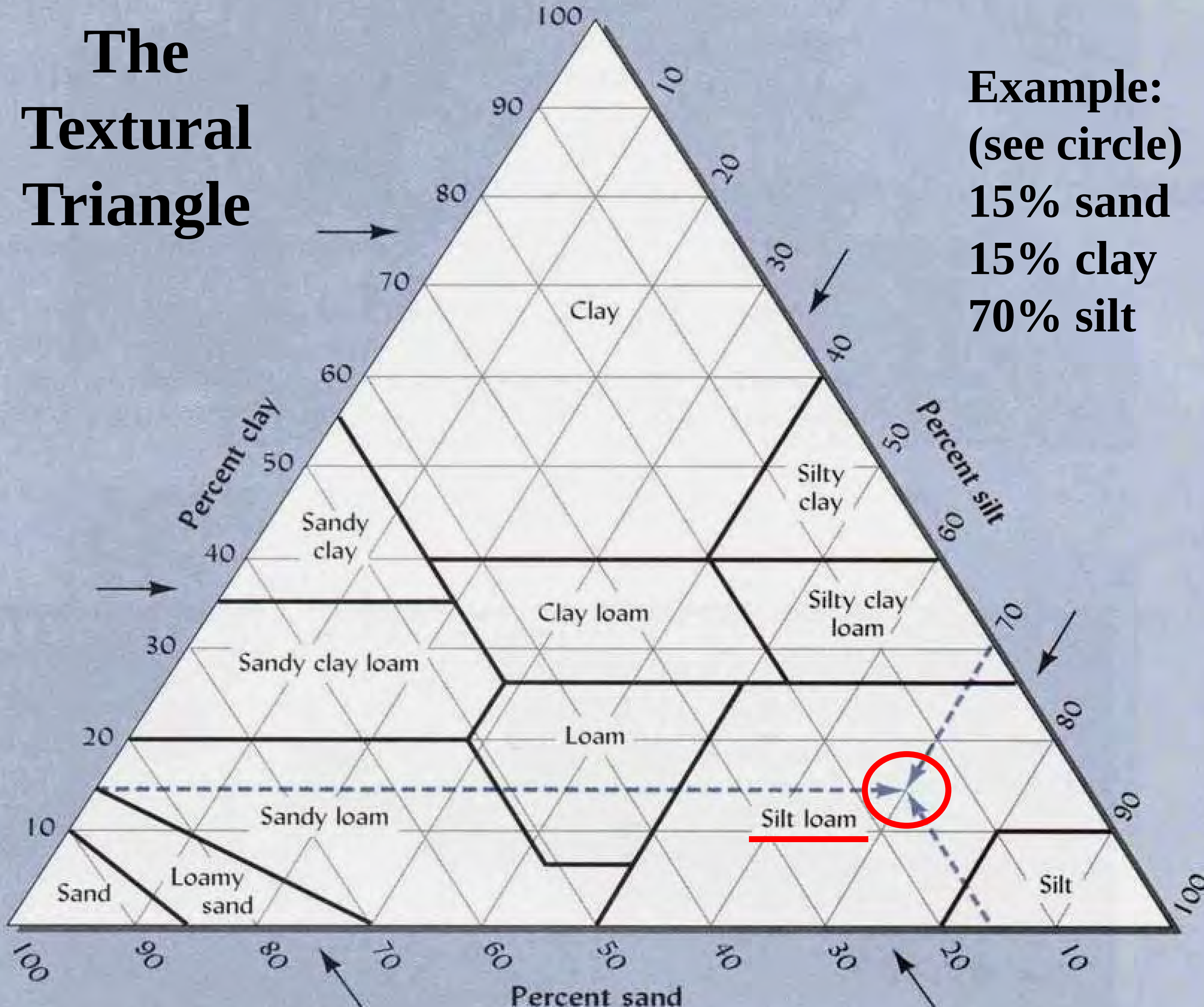
Sand	2 to 0.05 mm	gritty
Silt	0.05 to 0.002 mm	floury
Clay	< 0.002 mm	sticky

Fine earth fraction = sand, silt and clay

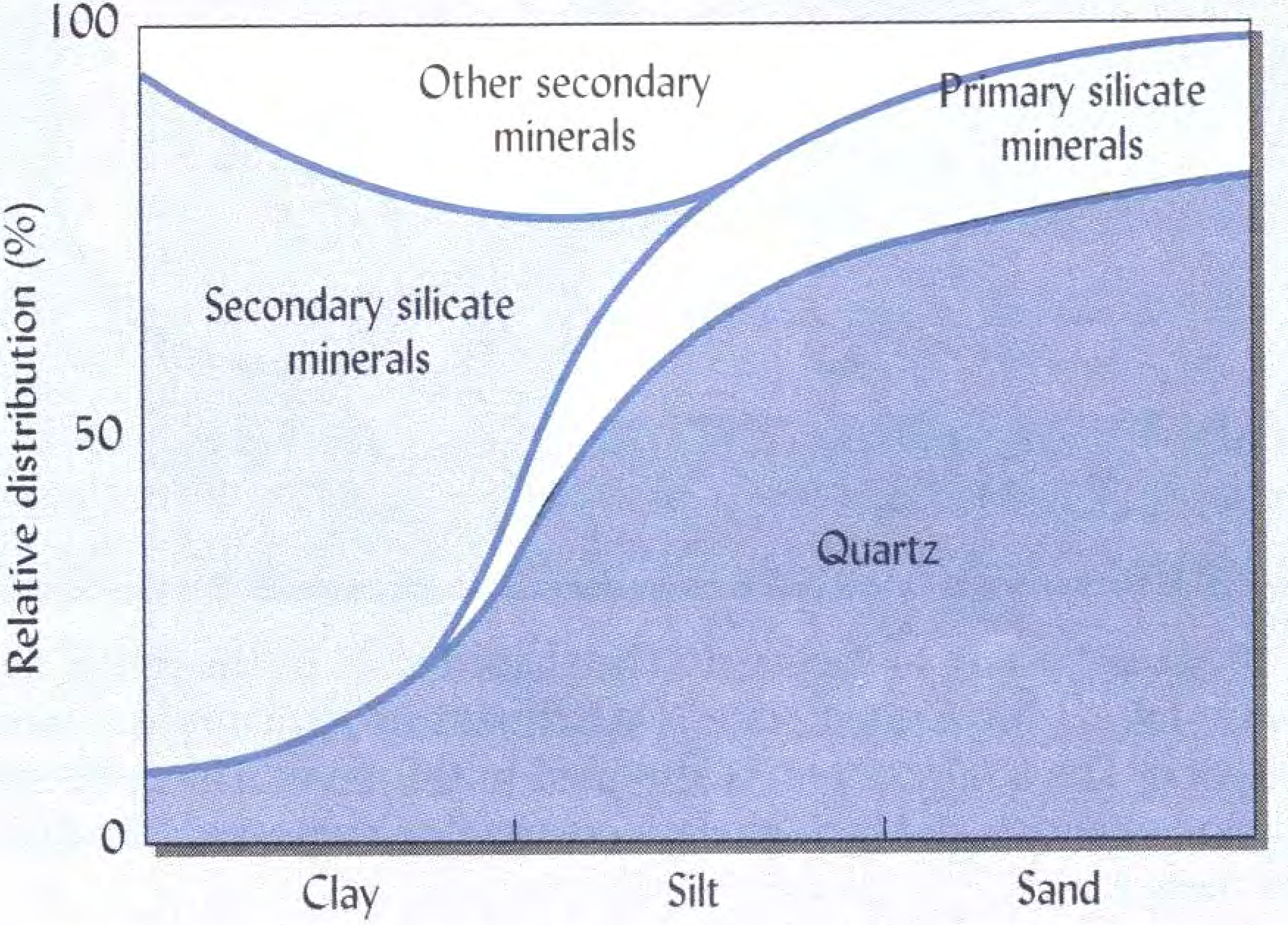
Coarse fragments are particles > 2 mm.

Soil texture describes the fine earth fraction!

The Textural Triangle



Example:
(see circle)
15% sand
15% clay
70% silt



100
50
0
Relative distribution (%)
Other secondary minerals
Primary silicate minerals
Secondary silicate minerals
Quartz
Clay
Silt
Sand

Montmorillonite clay

Quartz sand

Soil Structure

- Primary soil particles (sands, silts, clays) become cemented together by organic matter and/or electrostatic forces over time.

- These groupings are called **aggregates** or **peds**.

- The strength and shape of the peds greatly influence pore size distributions, water holding, gas exchange, and rooting.


Strong, coarse, crumb
structure (very rare)


Weak, fine, granular
(common in sandy soils)

Spheroidal

Characteristic of surface (A) horizons. Subject to wide and rapid changes.

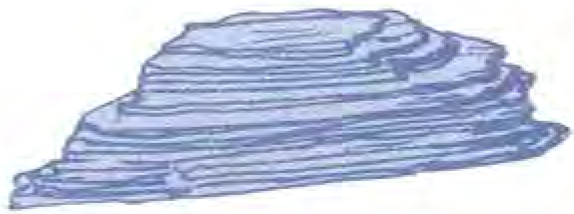
Granular (porous)

Crumb (very porous)

(a)

Plate-like

Common in E-horizons, may occur in any part of the profile. Often inherited from parent material of soil, or caused by compaction.



(b)

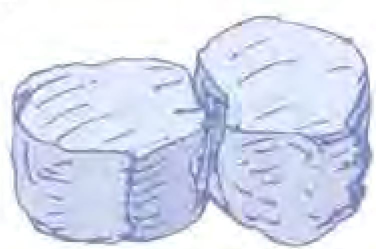
Block-like

Common in B-horizons, particularly in humid regions. May occur in A-horizons.

Angular blocky

(c)

Subangular blocky

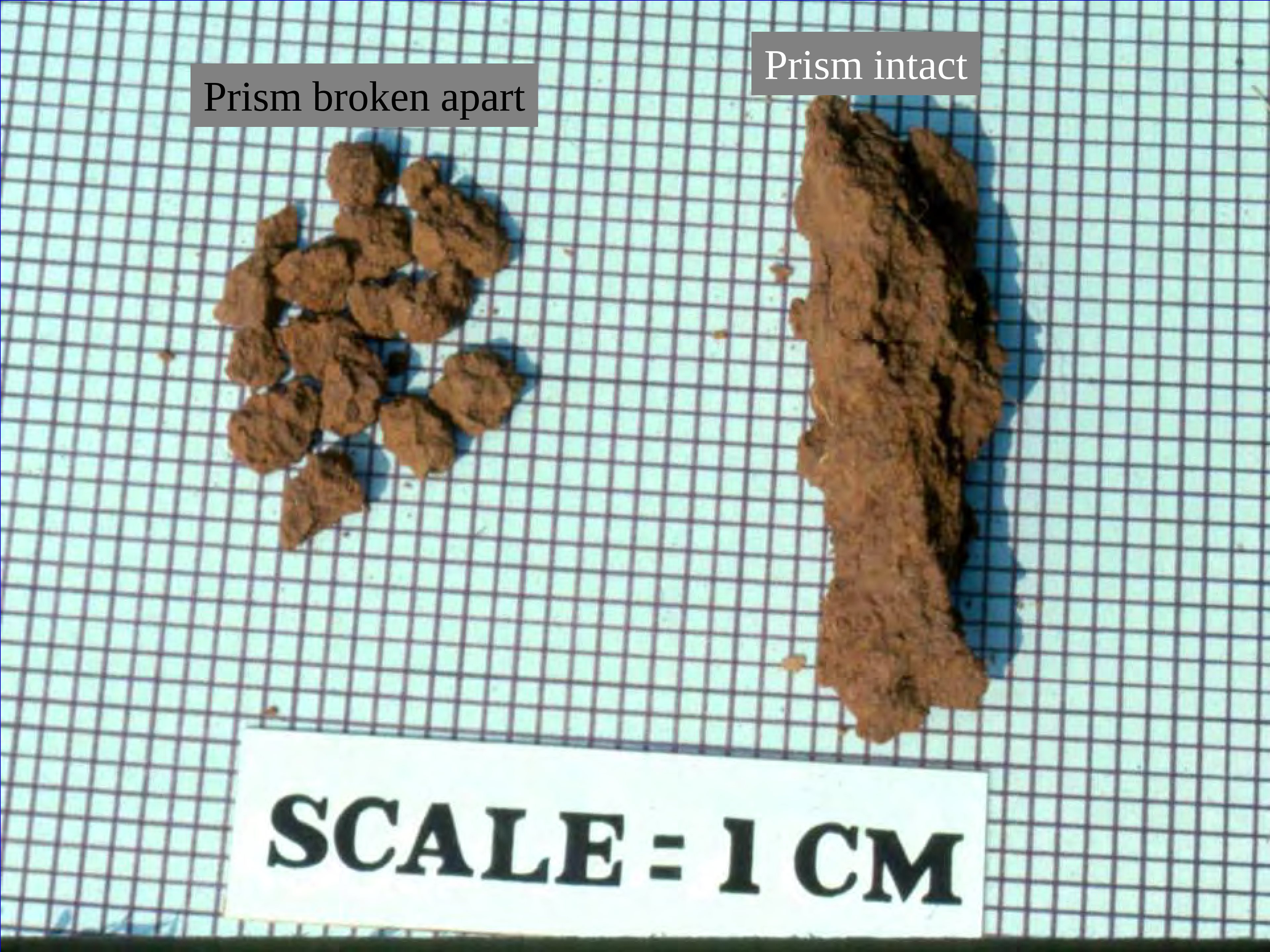


(d)

Moderate, medium, subangular blocky

Prismatic macrostructure that subdivides into moderate medium subangular blocky structure.

Note roots concentrated along macro-pores on ped faces.


Prism broken apart
Prism intact
SCALE = 1 CM

Compacted, platy replaced topsoil over highly compacted tails/slimes subsoil.


Pasture, silt loam
Db = 1.45 Mg/m3
Forest, silt loam
Db = 1.2 g/cm3

Factors promoting aggregation

- **Polyvalent cations (Al^{3+} or Ca^{2+}) rather than monovalent exchangeable cations like Na^{+}.**
- **Forces that act to physically push particles together, such as wet-dry (shrink-swell) and freeze-thaw cycles.**
- **Active microbial biomass generating humic substances that "glue" particles together.**
- **Physical binding effects of fine roots and fungal mycelia.**
- **Burrowing animals move soil particles, and mix organic matter with mineral particles in their guts producing stable**

Soil Bulk Density (Db)

$$\frac{\text{dry mass of soil}}{\text{total soil volume}} \qquad \frac{g}{cm^3} \quad \text{OR} \quad \frac{Mg}{m^3}$$

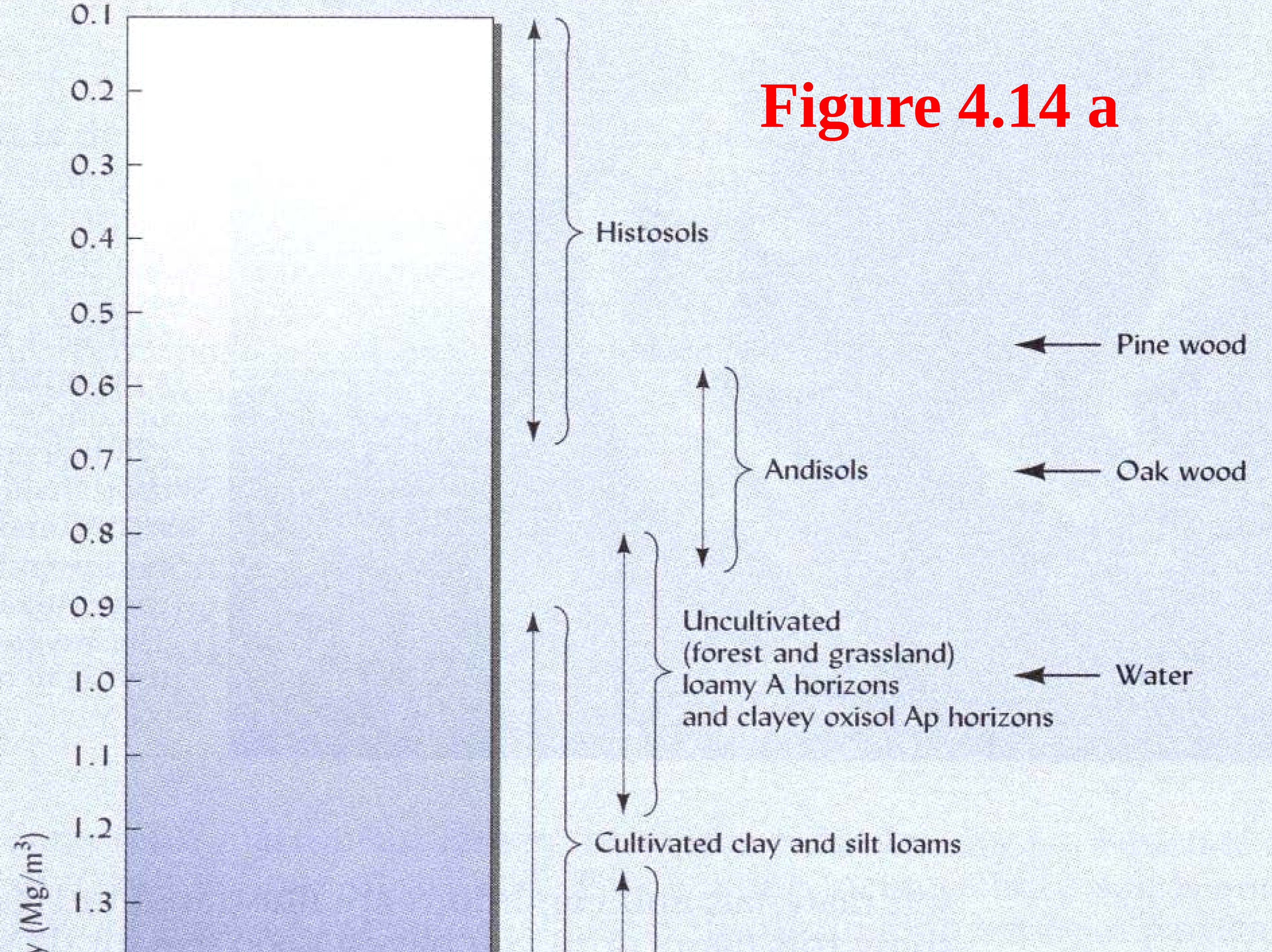
Total soil volume = volume of soil solids and pore space for a sample as it would occur naturally in the ground.

Soil Particle Density (Dp)

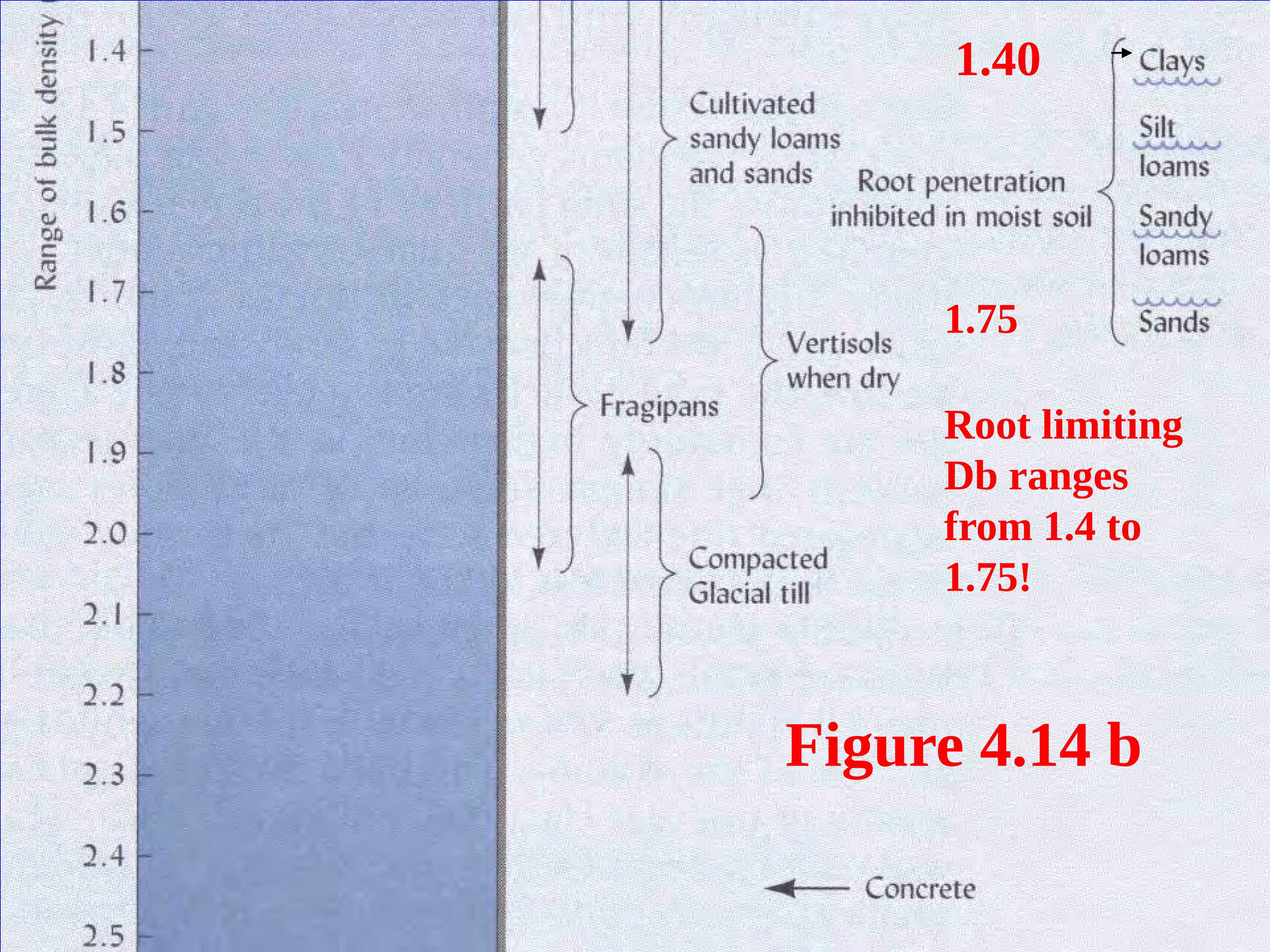
$$\frac{\text{dry mass of soil}}{\text{volume of soil solids}}$$

Average soil particle density is 2.65 Mg/m3.

Figure 4.14 a


0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
(Mg/m^3)
Histosols
Pine wood
Andisols
Oak wood
Uncultivated
(forest and grassland)
loamy A horizons
and clayey oxisol Ap horizons
Water
Cultivated clay and silt loams


Db = 1.75 Mg/m^3

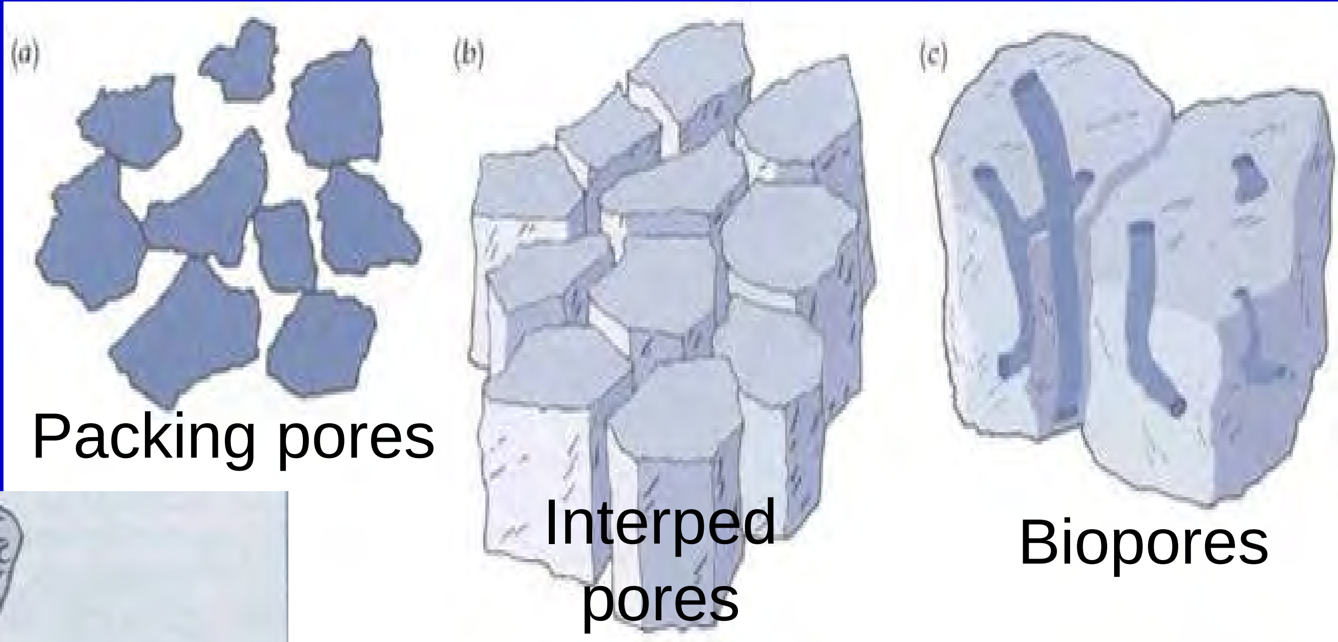


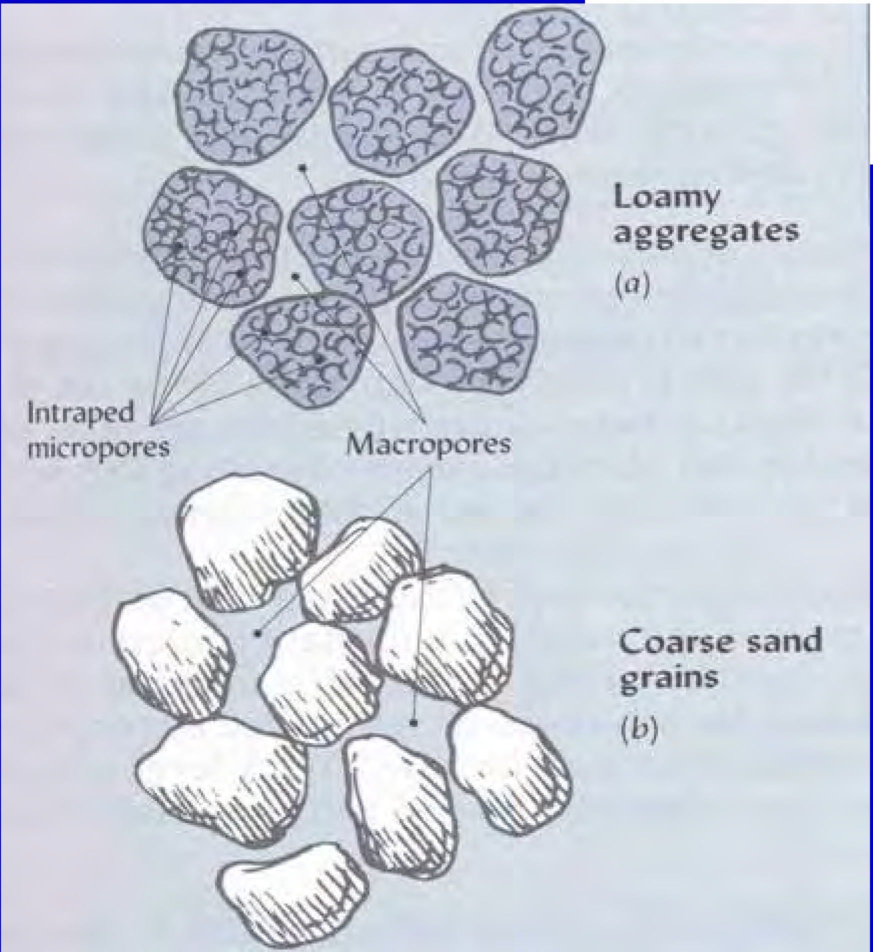
Root limiting Db ranges from 1.4 to 1.75!

Figure 4.14 b

Db = 1.75 Mg/m^3 at bottom of plow layer. See the roots turn sideways!

Total pore space does not indicate the size distribution of pores!

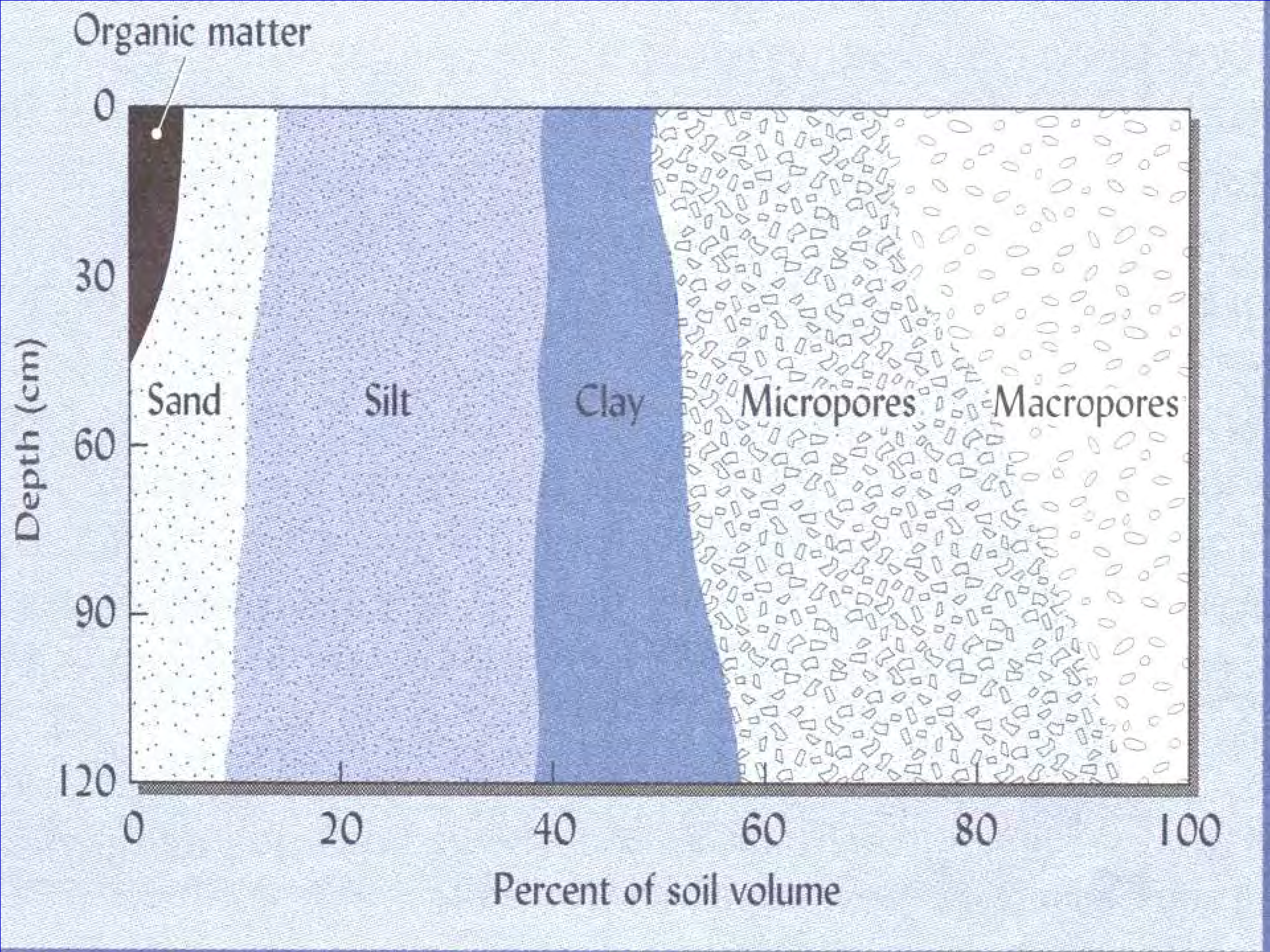




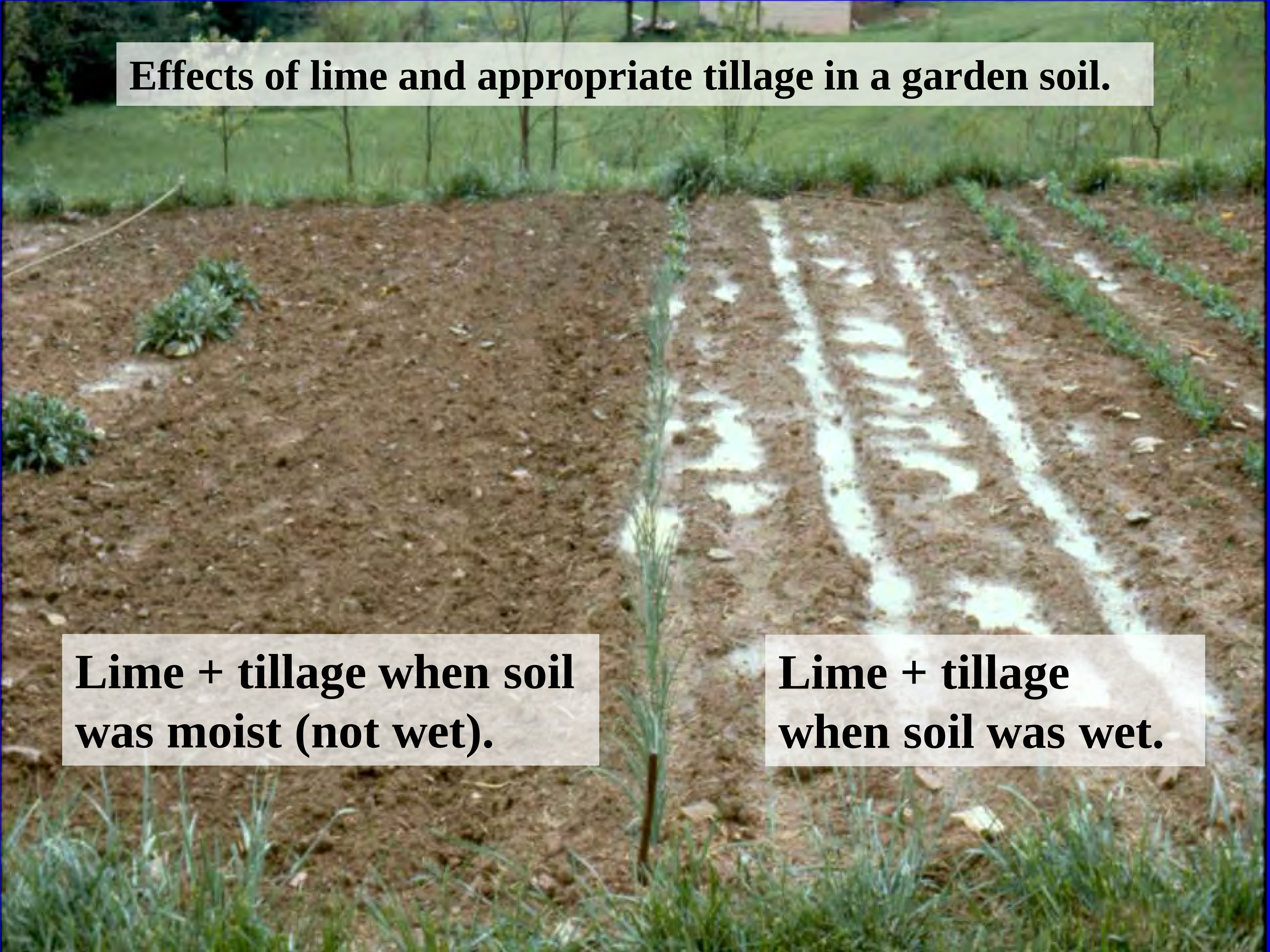
Packing and texture affects soil porosity.

Micropores are the packing voids between fine clay and fine silt grains.

Macropores are found between peds of fine-textured soils or between sand grains in coarse textured soils.



Organic matter
Depth (cm)
0
30
60
90
120
Sand
Silt
Clay
Micropores
Macropores
0
20
40
60
80
100
Percent of soil volume


Effects of lime and appropriate tillage in a garden soil.
Lime + tillage when soil was moist (not wet).
Lime + tillage when soil was wet.

Tillage has mixed effects on aggregation. In general, it decreases macropores. However, if we add lime plus organic matter as we till, the overall effects can be beneficial.

No-till corn crop with thick surface layer of dead rye straw (killed in spring at planting) which serves as a mulch. This drastically limits erosion and promotes water infiltration, but also has significant effects on soil temperature!

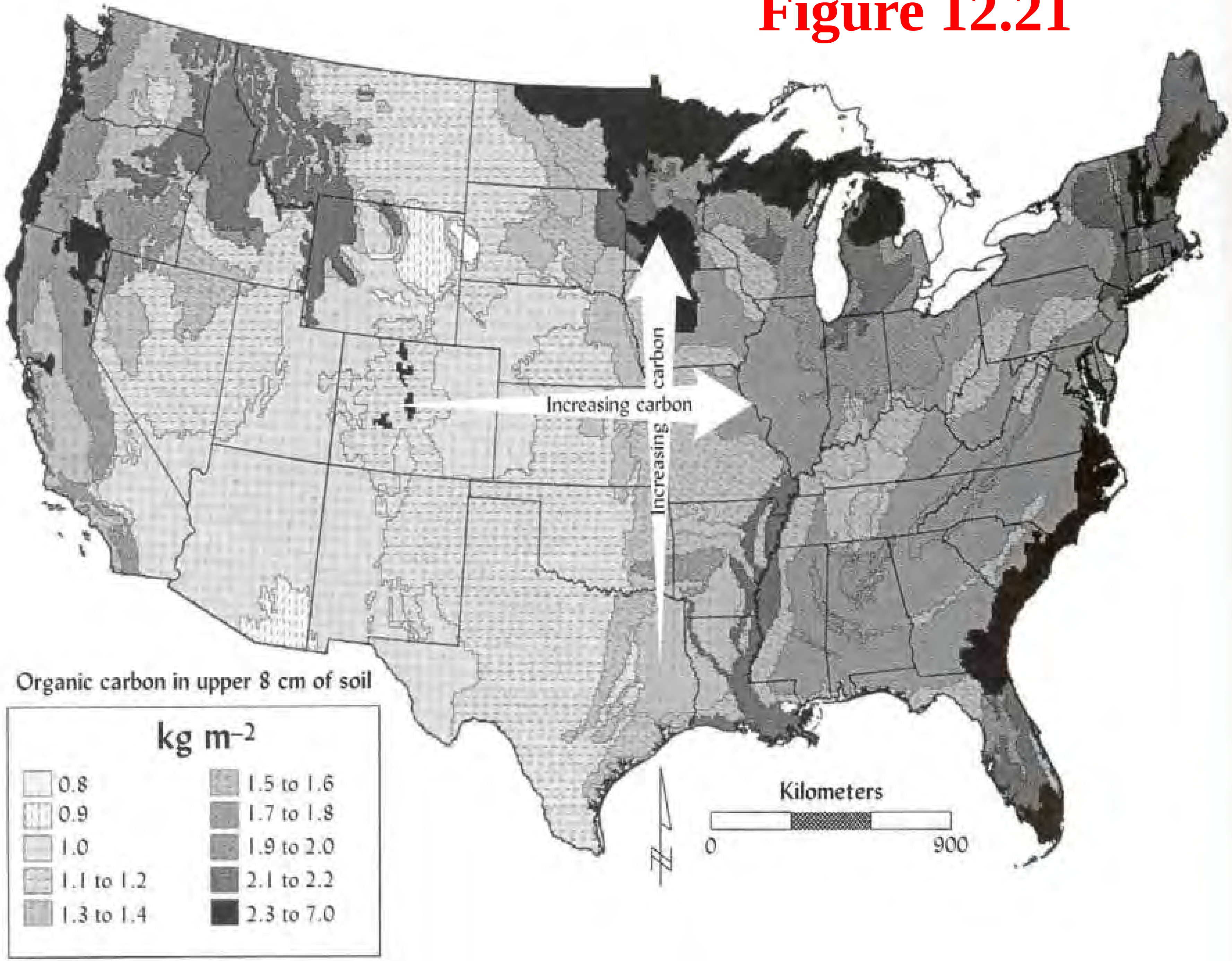
Soil Organic Matter

Humus is the dark brown to black complex decomposition product of organic matter turnover in soils. It is colloidal, much more highly charged than clay on a weight basis, and is typically what we report as ***organic matter content*** in soil testing programs.

What Controls SOM Levels?

- Climate/Vegetation: Moist cool climates generate more OM inputs. Cool and/or wet soils limit microbial decomposition, leading to OM accumulation
- Grasslands vs. trees add detritus in differing ways: deeper thicker A's in Mollisols vs. distinct litter layers (O's) in Alfisols

Figure 12.21



Increasing carbon
Increasing carbon
Organic carbon in upper 8 cm of soil
kg m−2
0.8
0.9
1.0
1.1 to 1.2
1.3 to 1.4
1.5 to 1.6
1.7 to 1.8
1.9 to 2.0
2.1 to 2.2
2.3 to 7.0
Kilometers
0
900

What Controls SOM Levels?

- **Texture**: Sandy soils allow ready losses of CO_2 while clayey soils retain OM via humus clay associations. So, SOM increases with clay content!
- **Drainage**: Poorly drained wet soils retain SOM due the slow nature of anaerobic decomposition

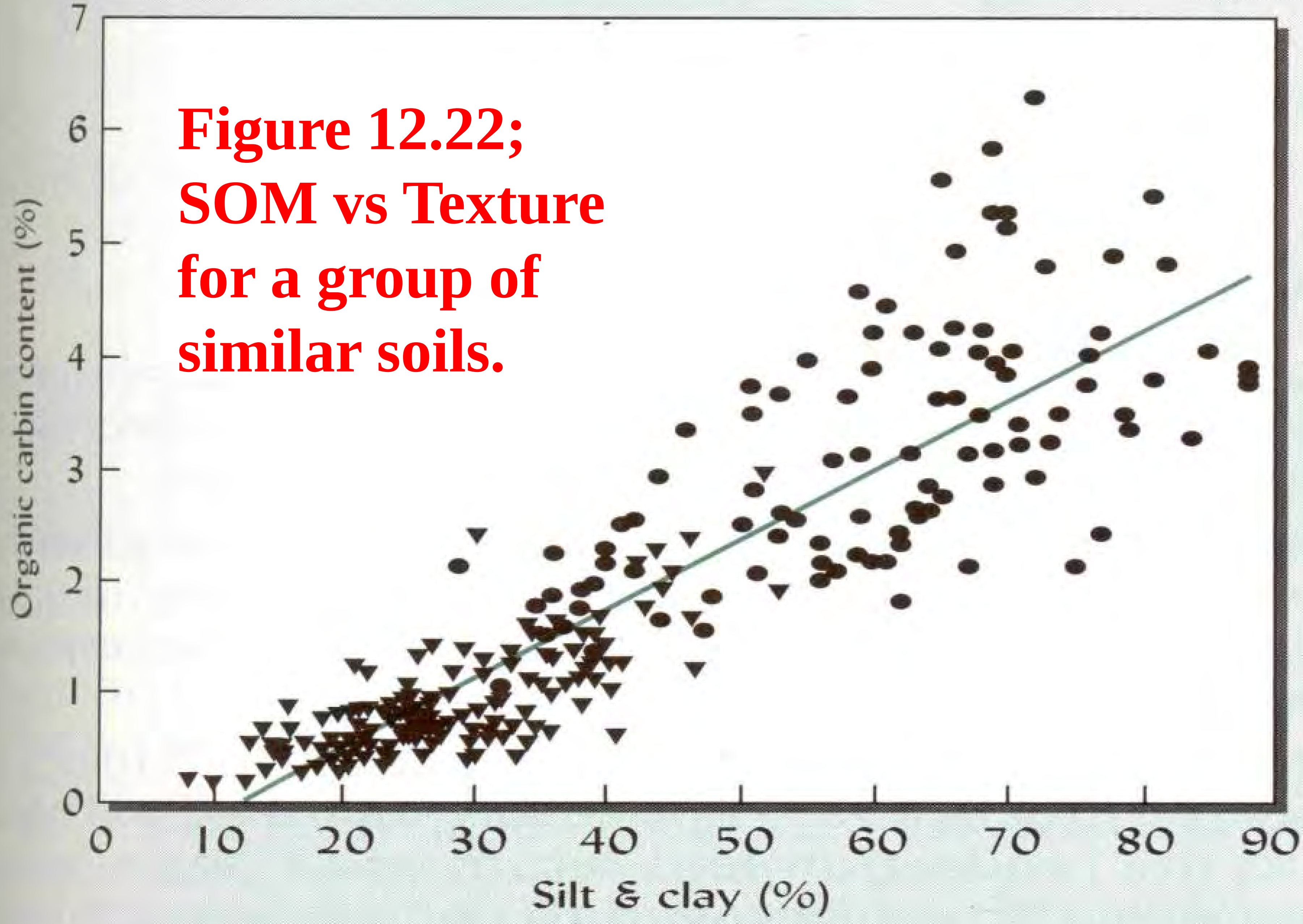


Figure 12.22;
SOM vs Texture
for a group of
similar soils.
Organic carbin content (%)
Silt & clay (%)
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80
90

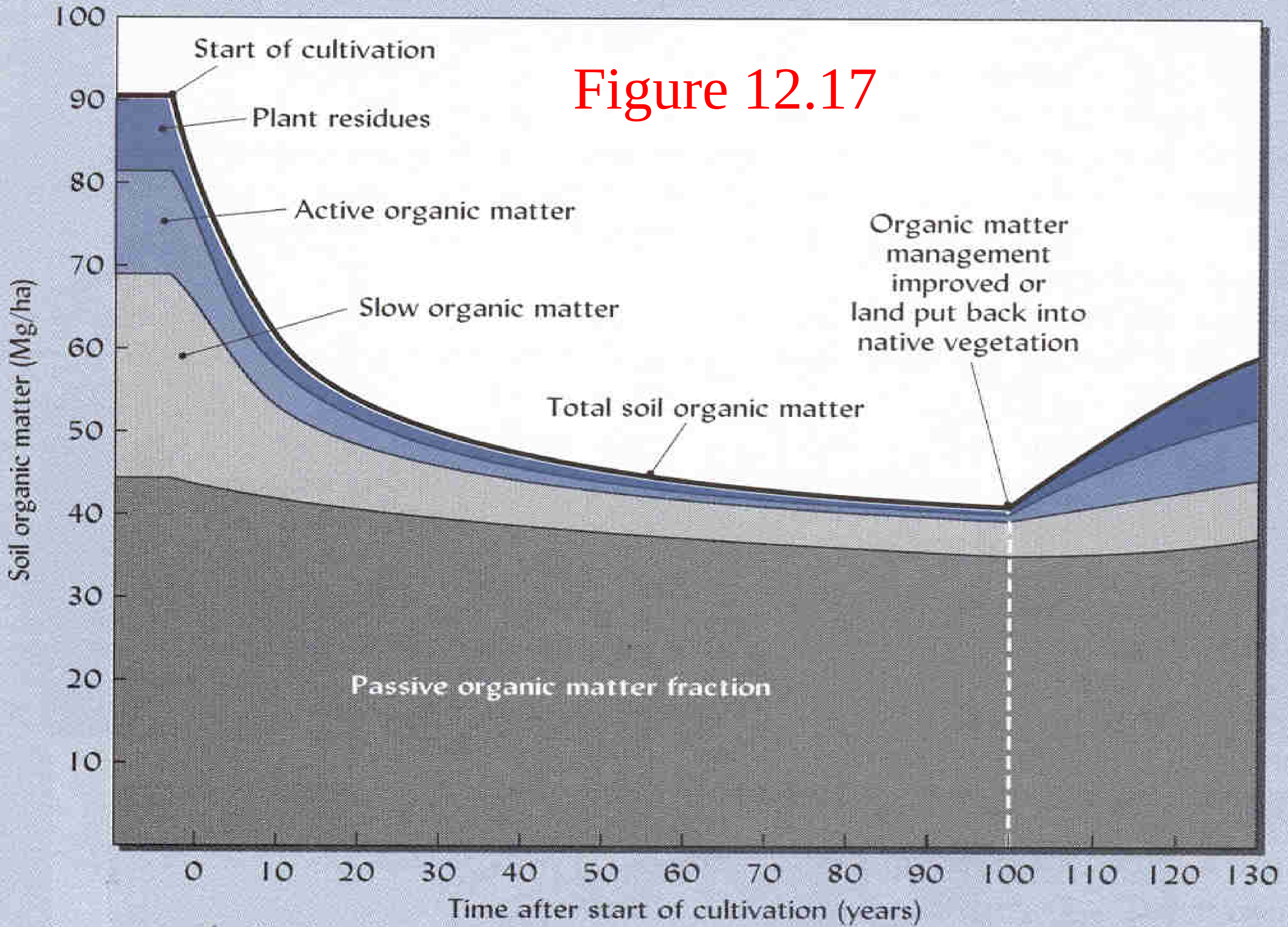
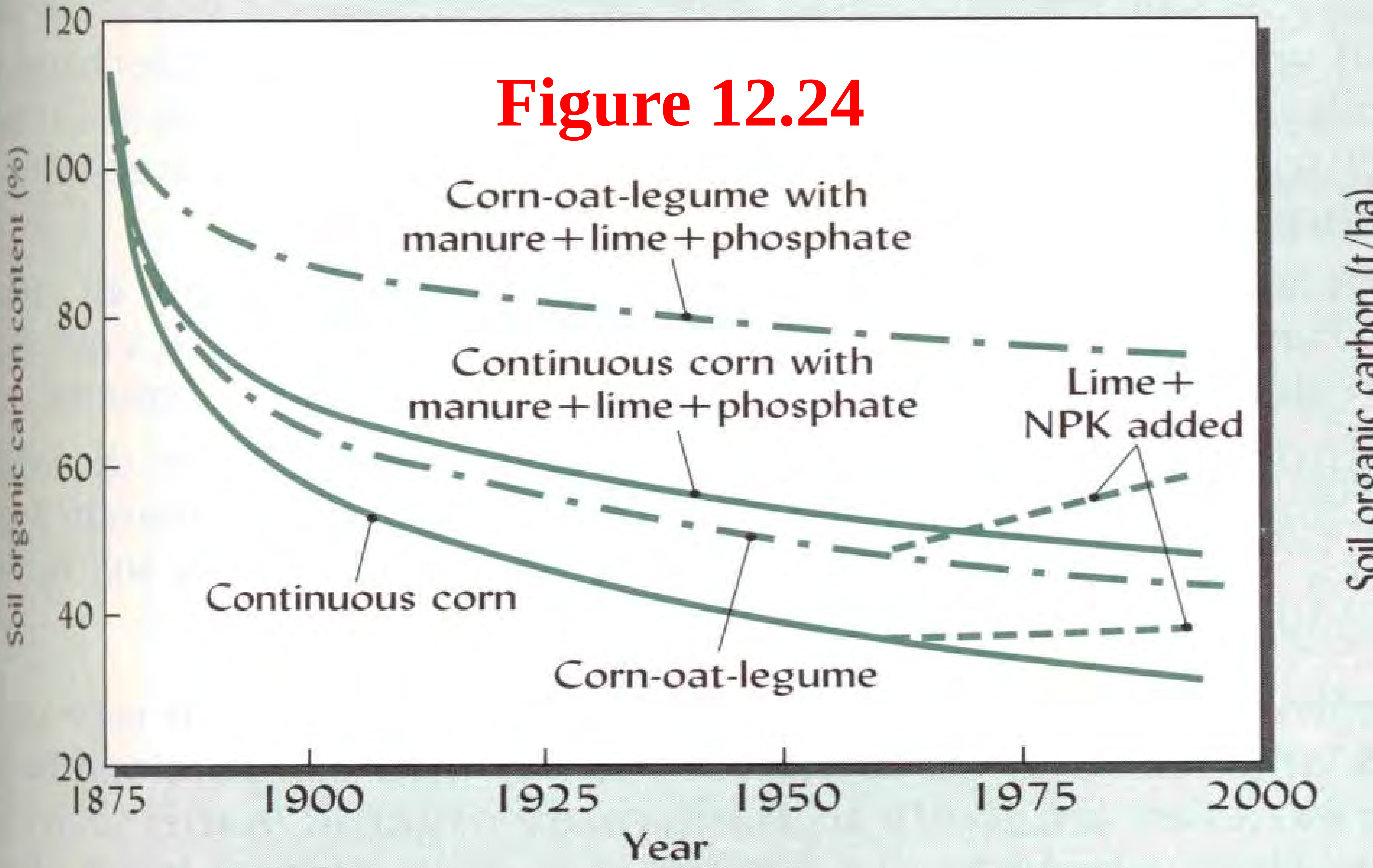


Figure 12.17
Start of cultivation
Plant residues
Active organic matter
Slow organic matter
Organic matter management improved or land put back into native vegetation
Total soil organic matter
Passive organic matter fraction
Soil organic matter (Mg/ha)
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Time after start of cultivation (years)

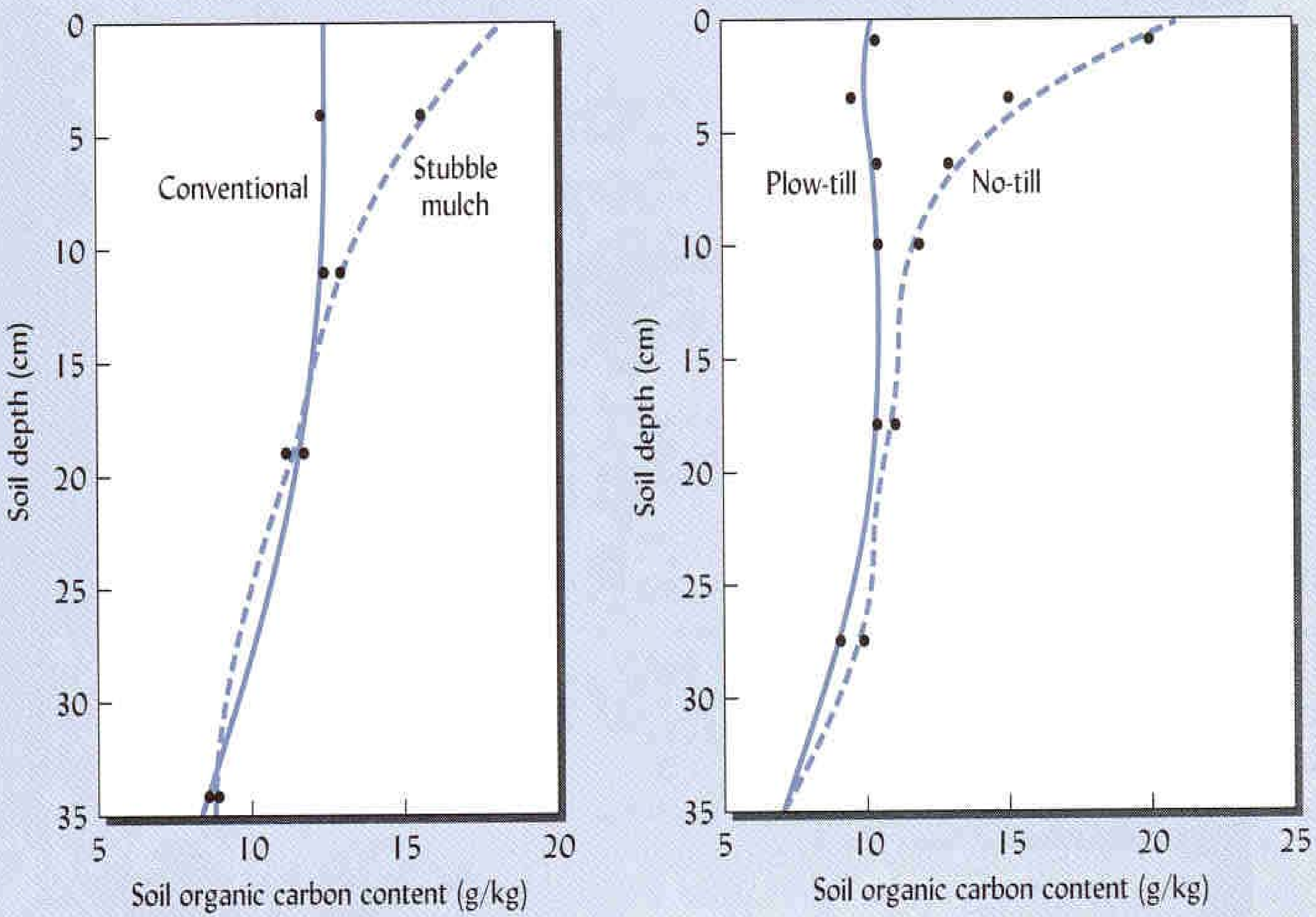
TABLE 11.5 Factors Affecting the Balance between Gains and Losses of Organic Matter in Soils

Factors promoting gains	*Factors promoting losses*
Green manures or cover crops	Erosion
Conservation tillage	Intensive tillage
Return of plant residues	Whole plant removal
Low temperatures and shading	High temperatures and exposure to sun
Controlled grazing	Overgrazing
High soil moisture	Low soil moisture
Surface mulches	Fire
Application of compost and manures	Application of only inorganic materials
Appropriate nitrogen levels	Excessive mineral nitrogen
High plant productivity	Low plant productivity
High plant root:shoot ratio	Low plant root:shoot ratio

Figure 12.24



(a) Morrow plots



(*a*) Stubble mulch tillage in Oregon

(*b*) No-till in Maryland

So, our ability to maintain SOM depends on dynamics of climate, drainage, texture, and perhaps most importantly, how we manage OM inputs vs. losses from the soil.

Managing Organic Matter

- Maintain a continuous supply of fresh inputs.
- You can only maintain a certain level of OM in any soil based on climate, drainage, texture, etc.. You can waste a lot of energy and money trying to “force” OM levels above their equilibrium point!

Managing Organic Matter

- Adequate N must be available in soils to sequester significant amounts of C. Without N, CO_2 losses dominate.
- Higher levels of plant growth generally increase SOM levels
- Tillage decreases SOM levels
- Perennial vegetation increases SOM levels

Soil Hydrology

- Soil and soil-landscape properties directly influence runoff/infiltration partitioning
- The soil is the major reservoir for water released back to the atmosphere via evapotranspiration
- The chemical quality of groundwater is directly controlled by soil chemistry

Runoff vs. Infiltration

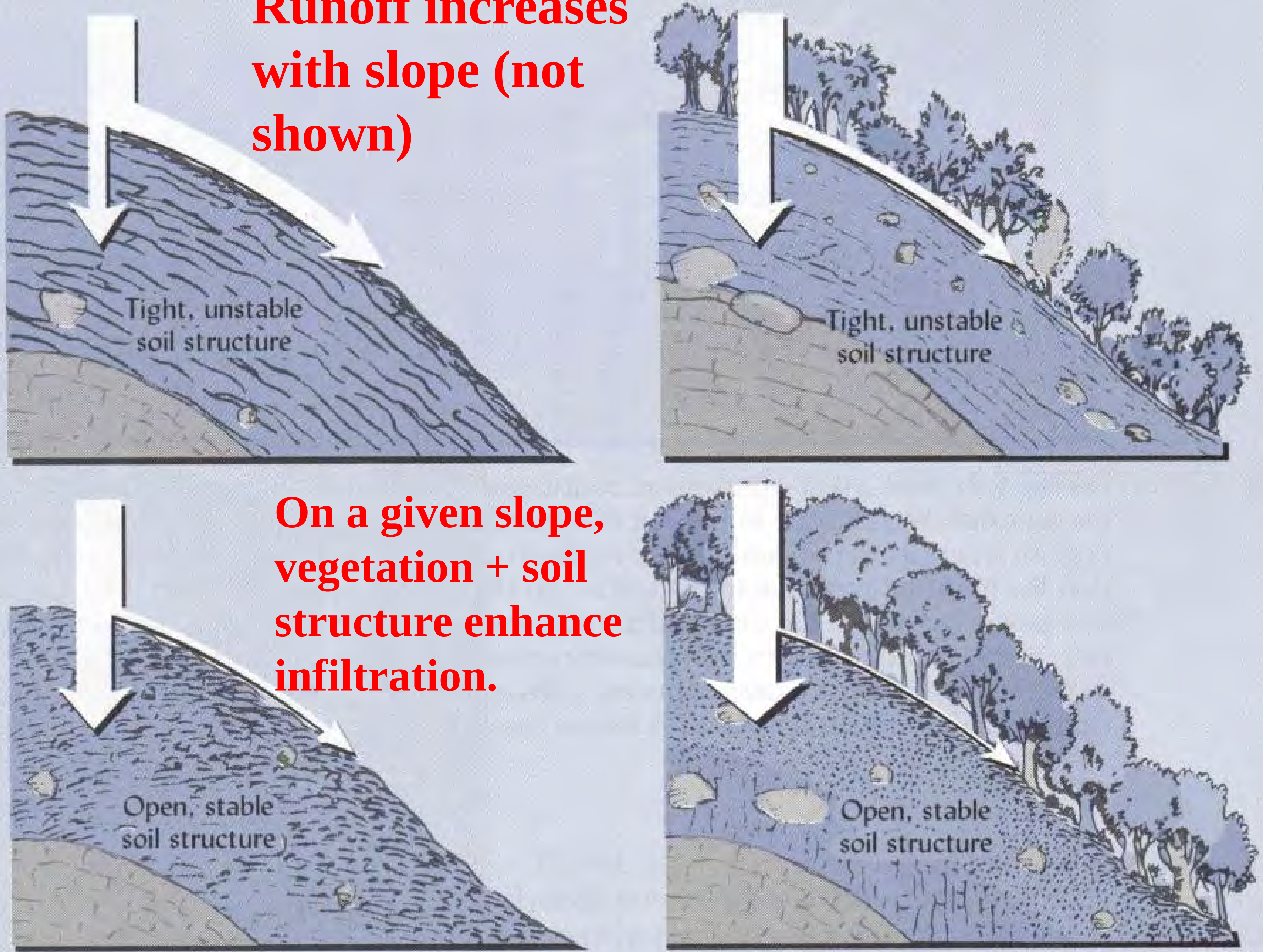
- Precipitation falling on a soil landscape will first be subject to ***interception*** losses on vegetation of anywhere from 5 to 30% (light rain on thick canopy).

- When the rate of rainfall exceeds the ***infiltration rate*** of the soil, net runoff results.

- The infiltration rate is direct function of the degree of **macroporosity** of the surface soil.

Runoff increases with slope (not shown)

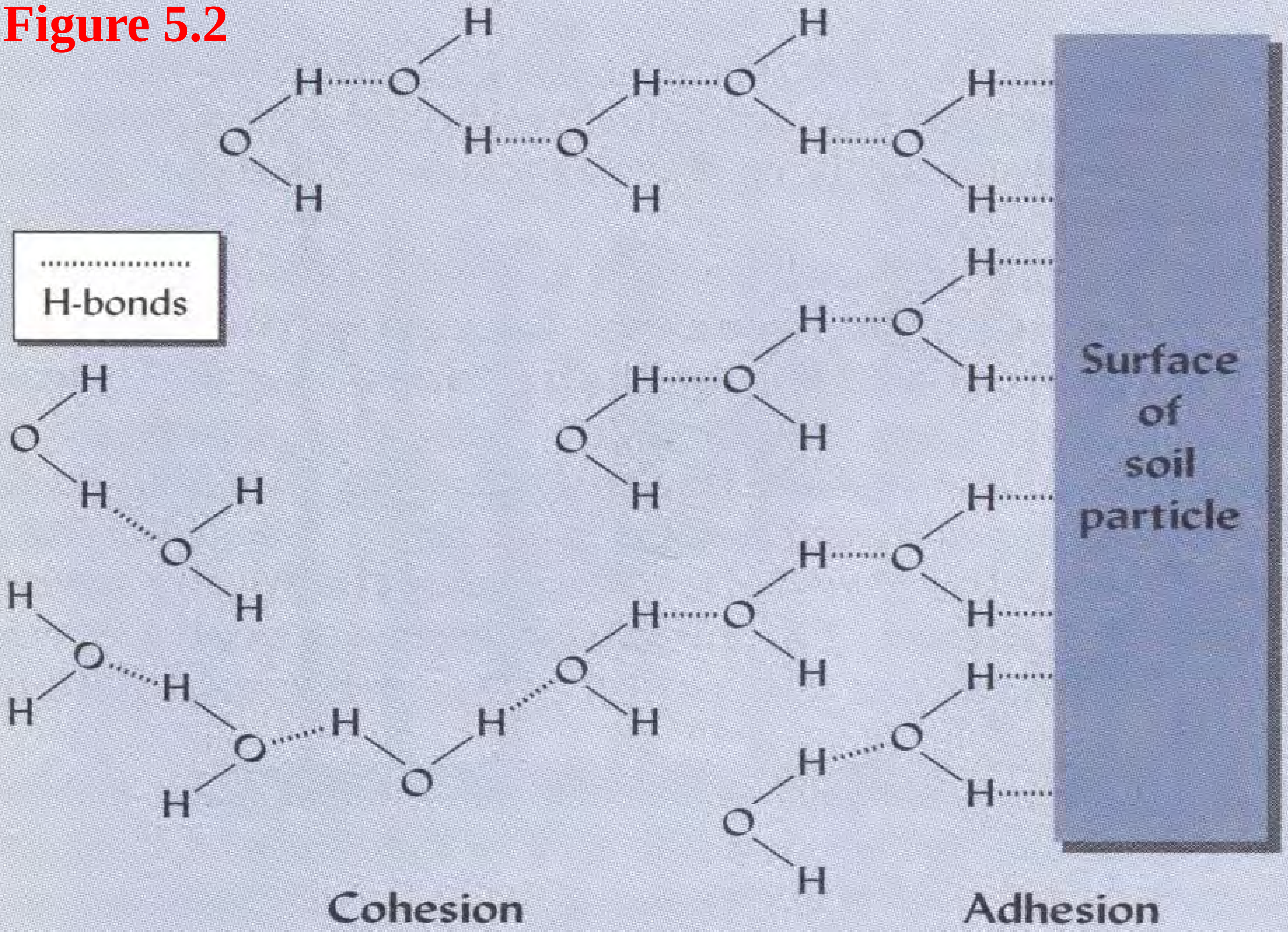
On a given slope, vegetation + soil structure enhance infiltration.



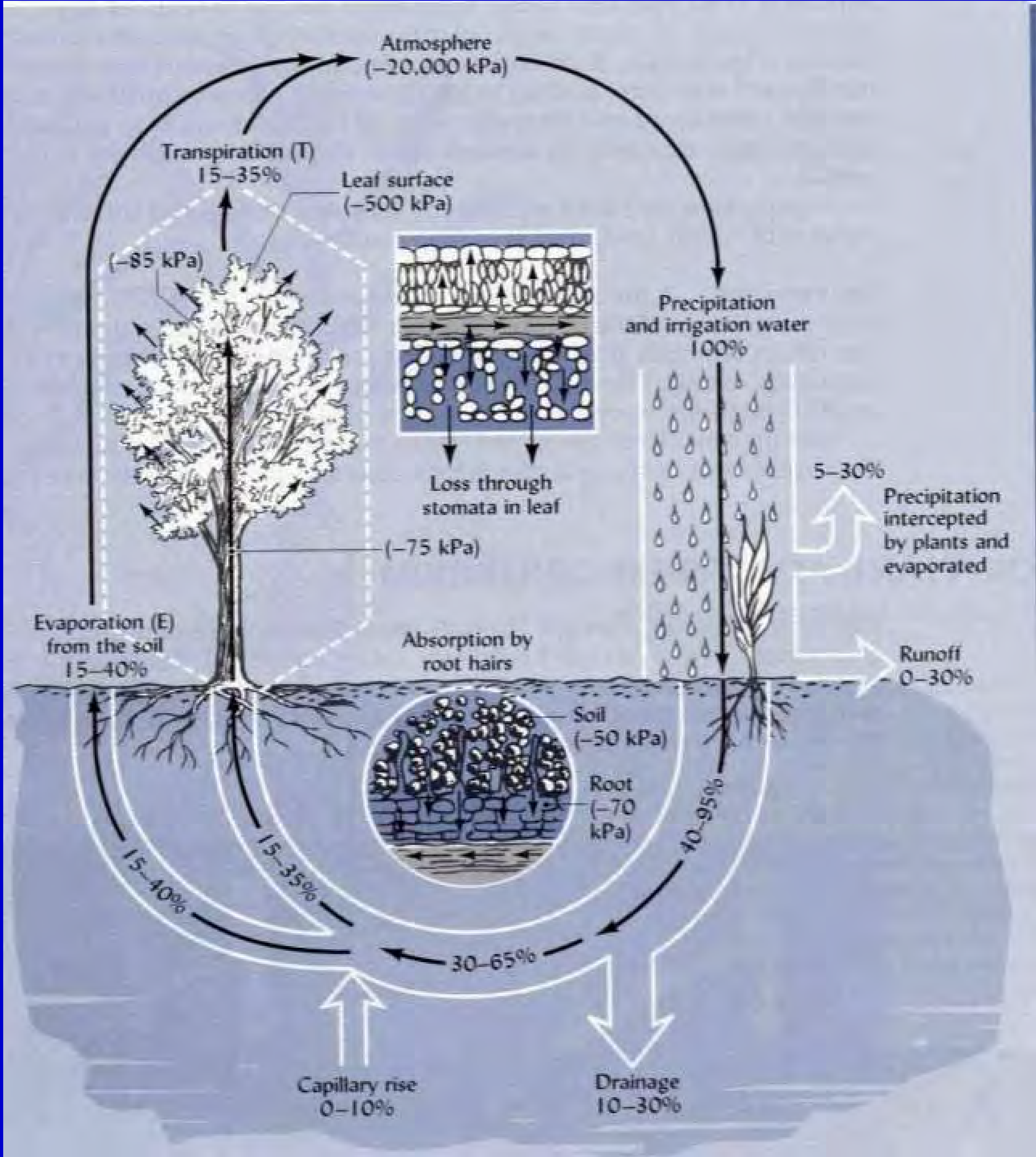
Drainage, Storage and ET

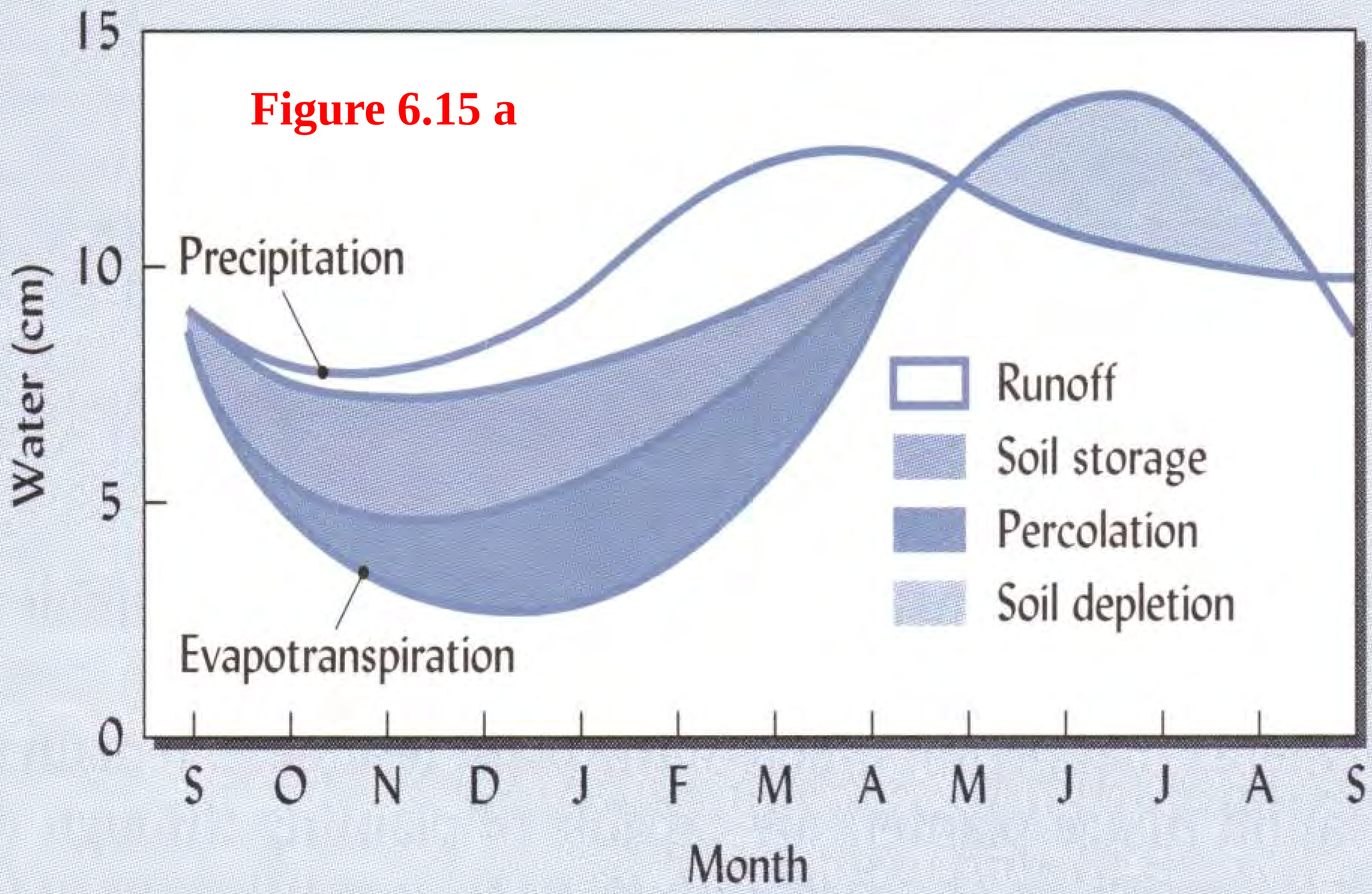
- Once water infiltrates the soil, water in large macropores will continue to move downward due to gravity via ***drainage***. This is the same concept as *gravitational water*.
- Water held up against leaching (see field capacity later) is referred to as ***"soil storage"*** available for evaporation (**E**) and transpiration (**T**) by plants.

Figure 5.2



Water cycles from the soil to the plant and then back to the atmosphere due to differences in what is known as "water potential" or "free energy". Basically, the demand for water in the atmosphere (very low water potential) sucks water up the plant from the soil.





(*a*) Humid region (Udic soil moisture regime)

Practical Applications

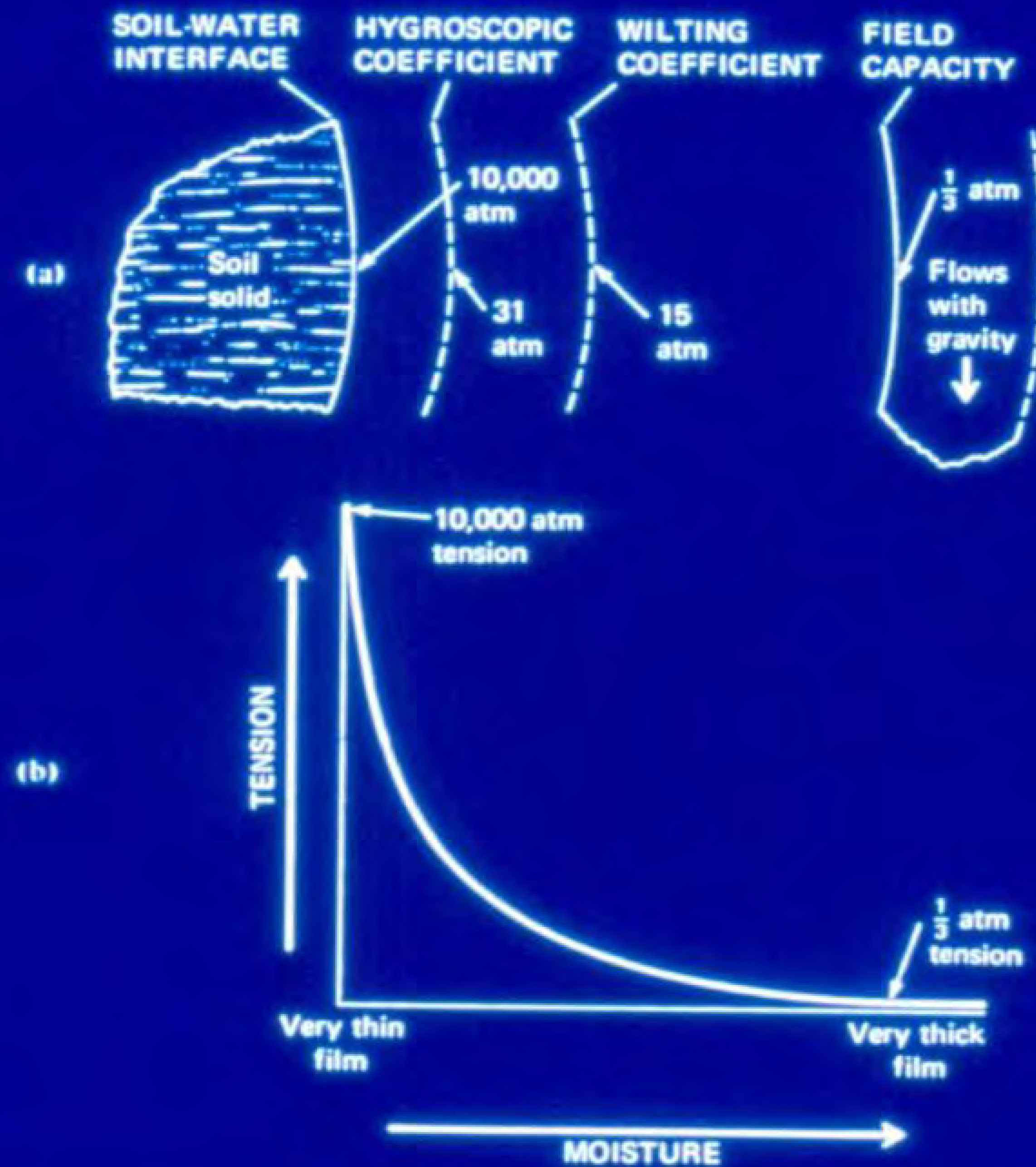
- Water moves throughout the soil-plant-atmospheric system due differences in free energy – always towards a more negative potential.
- Soils exert a much more negative potential on water than gravity, so the soil holds water until the plant root pulls it out due to atmospheric stress/suction.
- During the growing season in Virginia, particularly once we get plant canopy developed, it is very difficult to drive a wetting front all the way through the solum due to net ET demands of the vegetation.

Water and Plant Growth

- When the soil is saturated, all macropores are filled, but **<u>gravitational water</u>** rapidly percolates downward from macropores.
- This state of saturation is also called **<u>maximum retentive capacity</u>** and is the maximum amount of water the soil can hold.

Water and Plant Growth

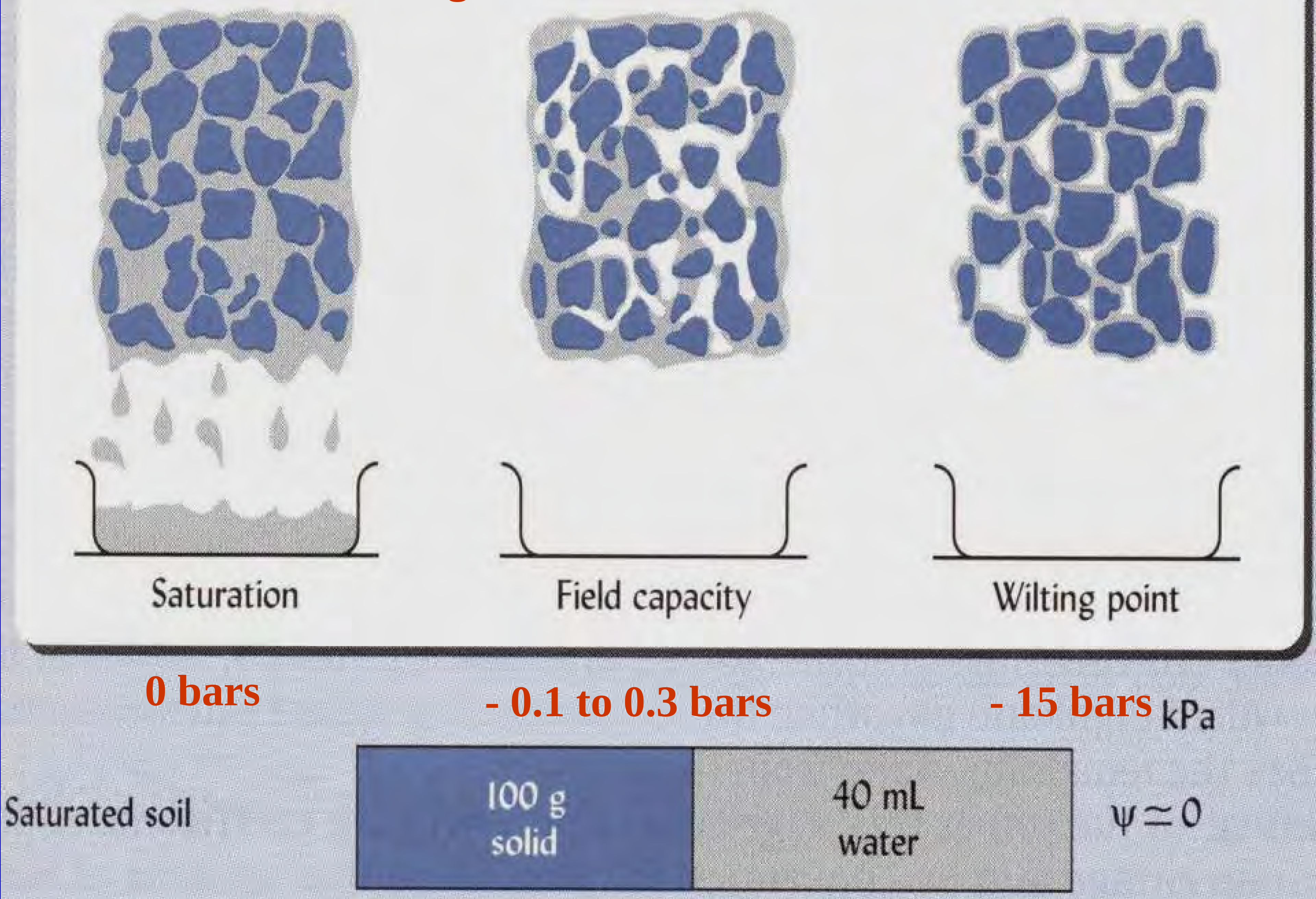
- Once the soil loses its' gravitational water downward (usually in minutes to hours), water that is held up the soil against leaching is bound there by matric forces which range from –0.1 to –0.3 bars in the thicker portions of water films extending into macropores. The soil is now at **field capacity.**


SOIL-WATER INTERFACE
HYGROSCOPIC COEFFICIENT
WILTING COEFFICIENT
FIELD CAPACITY
(a)
Soil solid
10,000 atm
31 atm
15 atm
$\frac{1}{3}$ atm
Flows with gravity
(b)
10,000 atm tension
TENSION
$\frac{1}{3}$ atm tension
Very thin film
Very thick film
MOISTURE

Water and Plant Growth

- As water continues to be evapotranspired away from the soil, the films of water around the soil surfaces become much thinner, so the matric forces holding water get much stronger (more negative). Finally, at about –15 bar potential (very thin water films), plants wilt because they can't pull water off the soil. This is the **wilting point.**

Figure 5.32 a


Saturation
Field capacity
Wilting point
0 bars
- 0.1 to 0.3 bars
- 15 bars
kPa
Saturated soil
100 g
solid
40 mL
water
$\psi \simeq 0$

Water and Plant Growth

So, overall, the most important concept here is that "plant available water" in a soil is taken as the *difference* between water held at Field Capacity and Wilting.

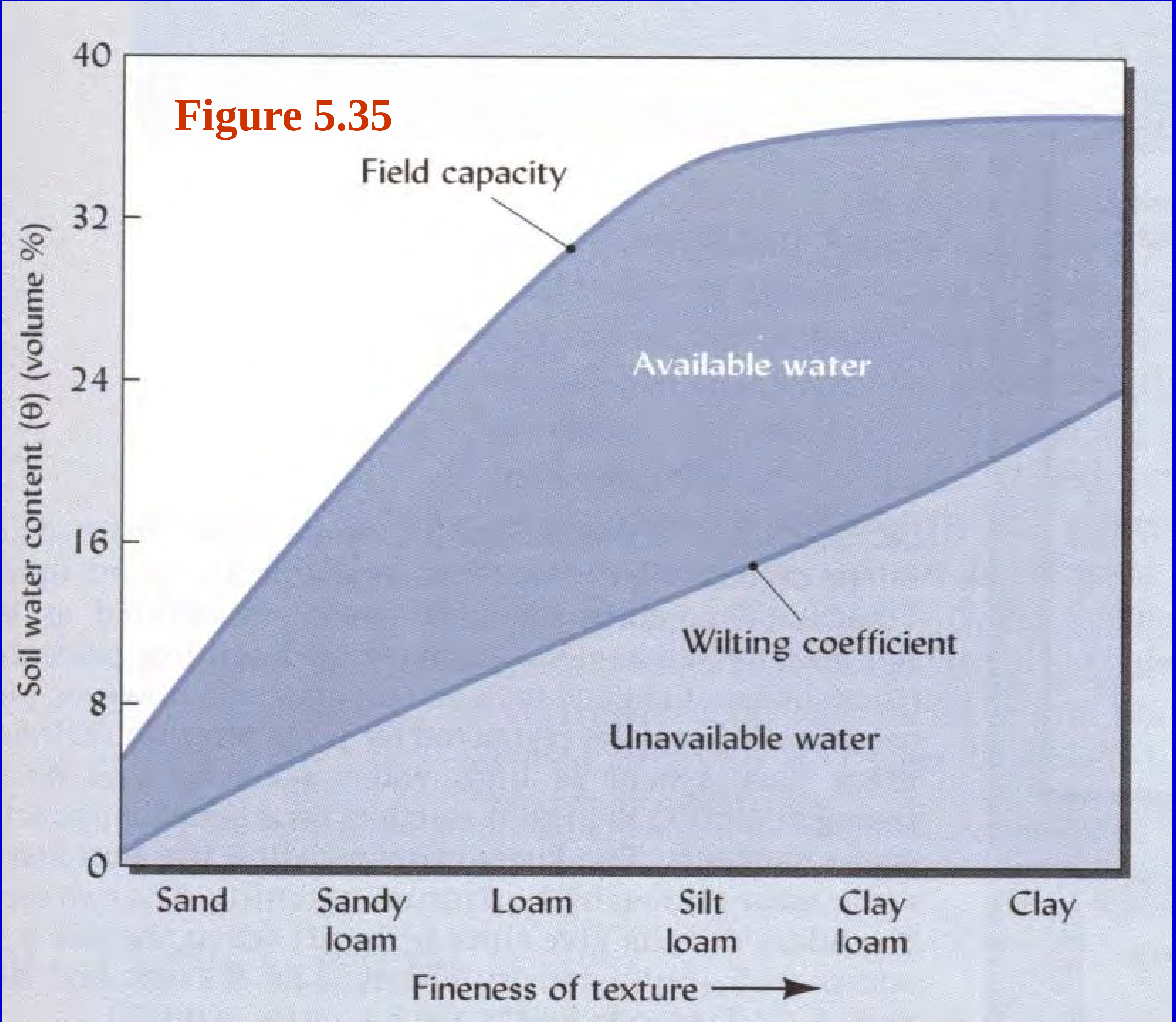
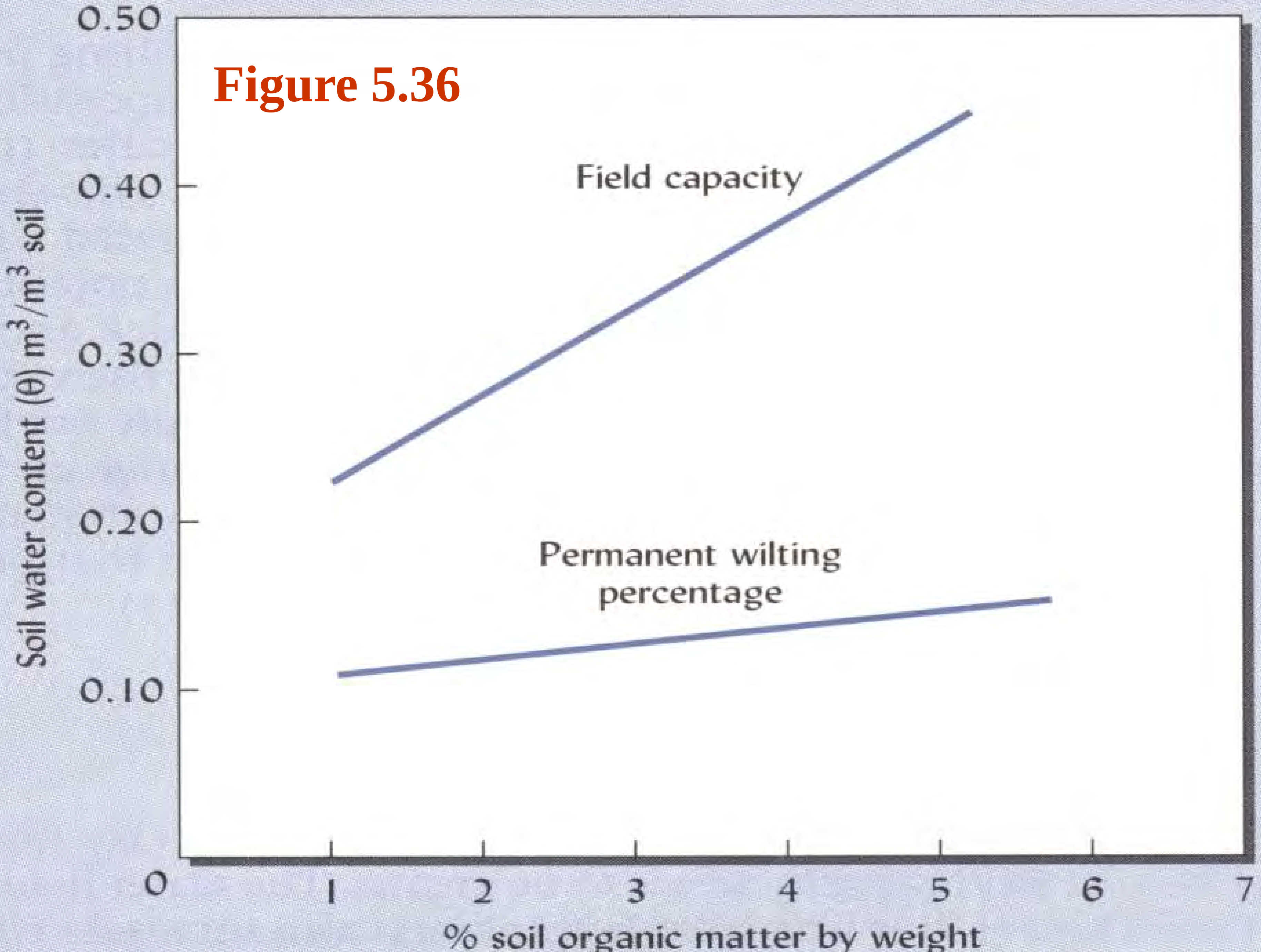


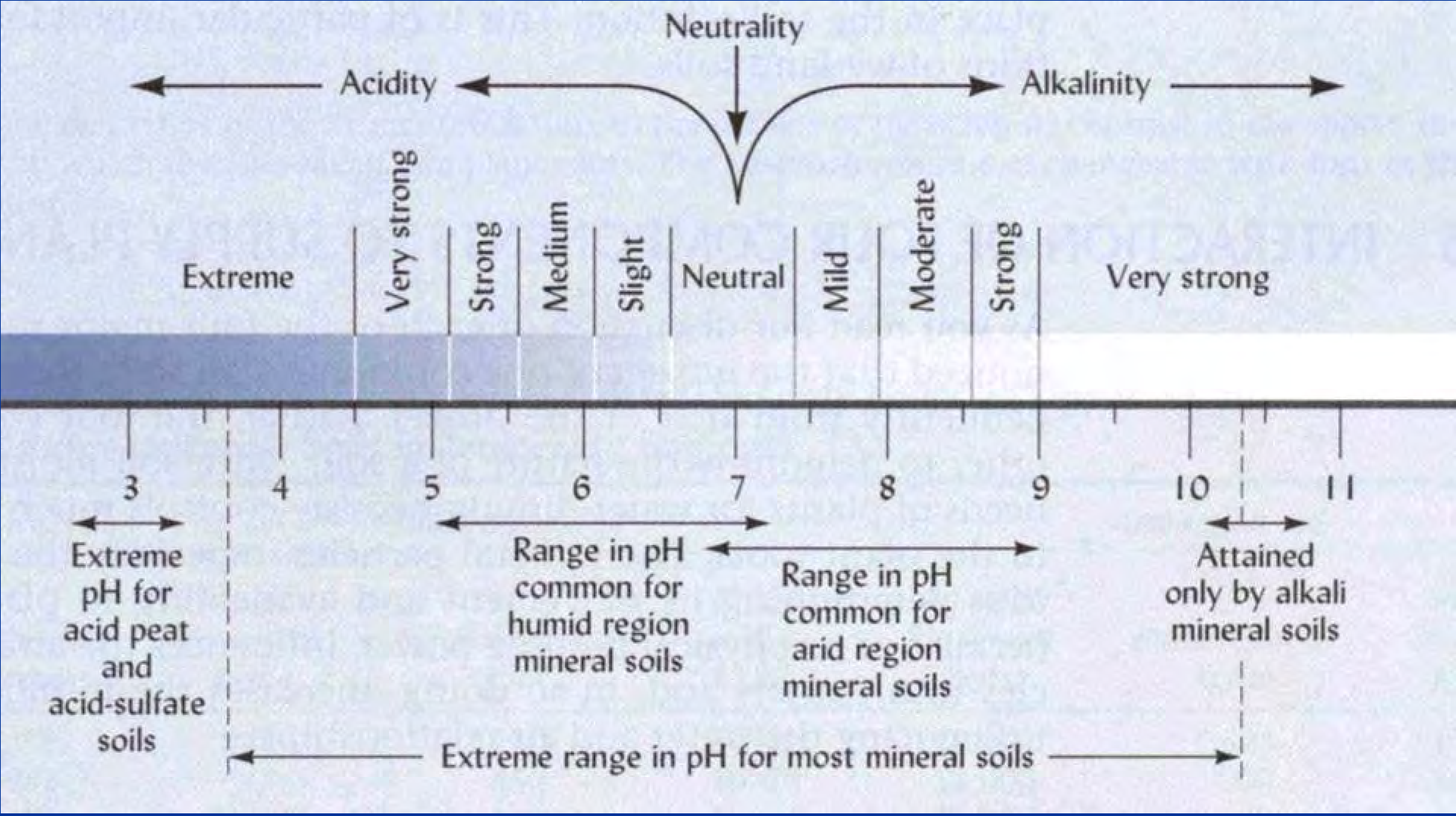
Figure 5.35
Field capacity
Available water
Wilting coefficient
Unavailable water
Soil water content (θ) (volume %)
40
32
24
16
8
0
Sand
Sandy loam
Loam
Silt loam
Clay loam
Clay
Fineness of texture

Figure 5.36

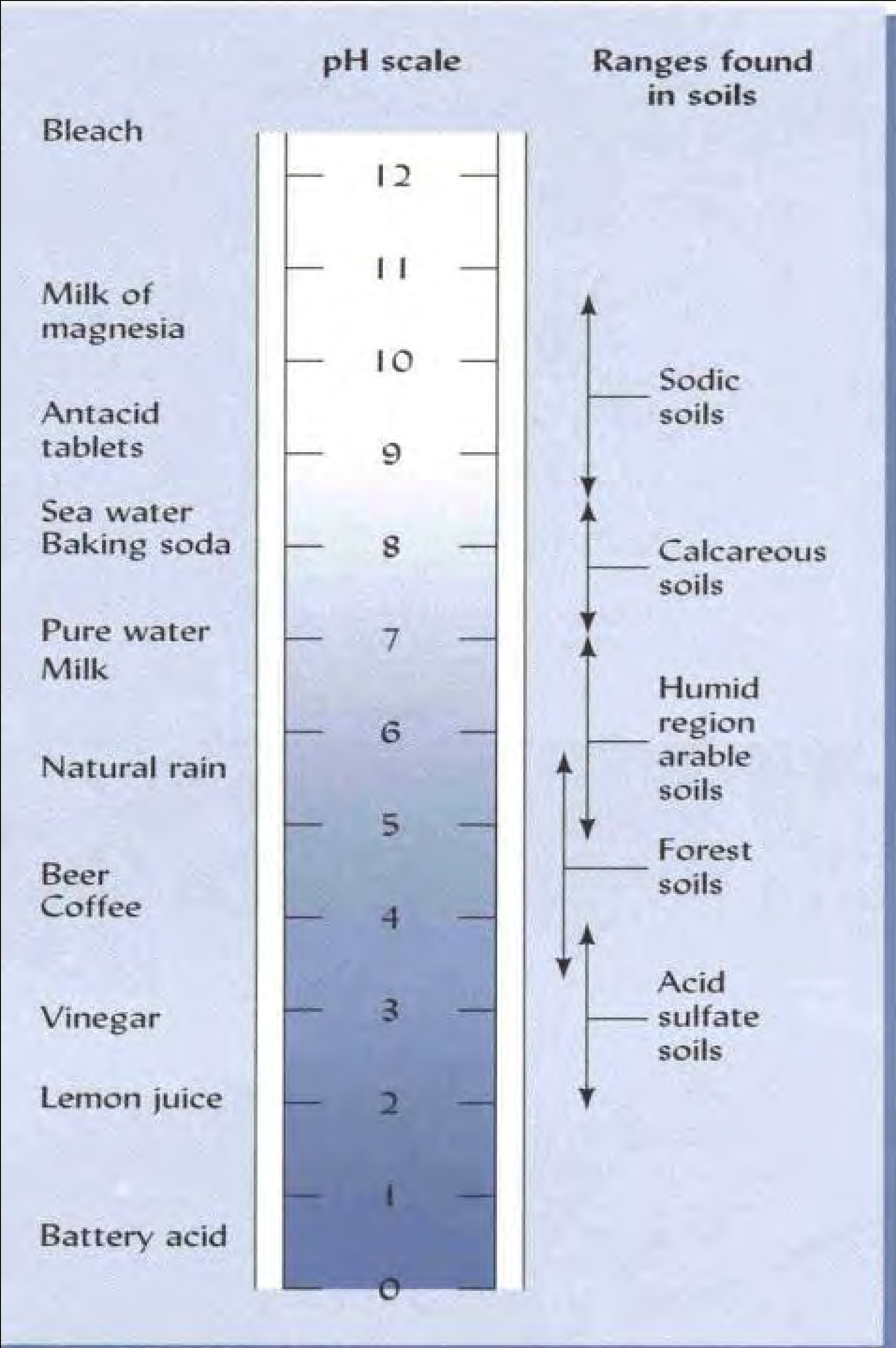

Field capacity
Permanent wilting percentage
Soil water content (θ) m³/m³ soil
0.50
0.40
0.30
0.20
0.10
0
1
2
3
4
5
6
7
% soil organic matter by weight

Important Points

- **Sandy soils hold relatively low amounts (< 10%) of total water at field capacity, but the vast majority of that water is plant available.**
- **Clayey soils hold relatively high amounts (>40%) of total water at field capacity, but the majority of that water is held at suctions below the wilting point, making it unavailable.**

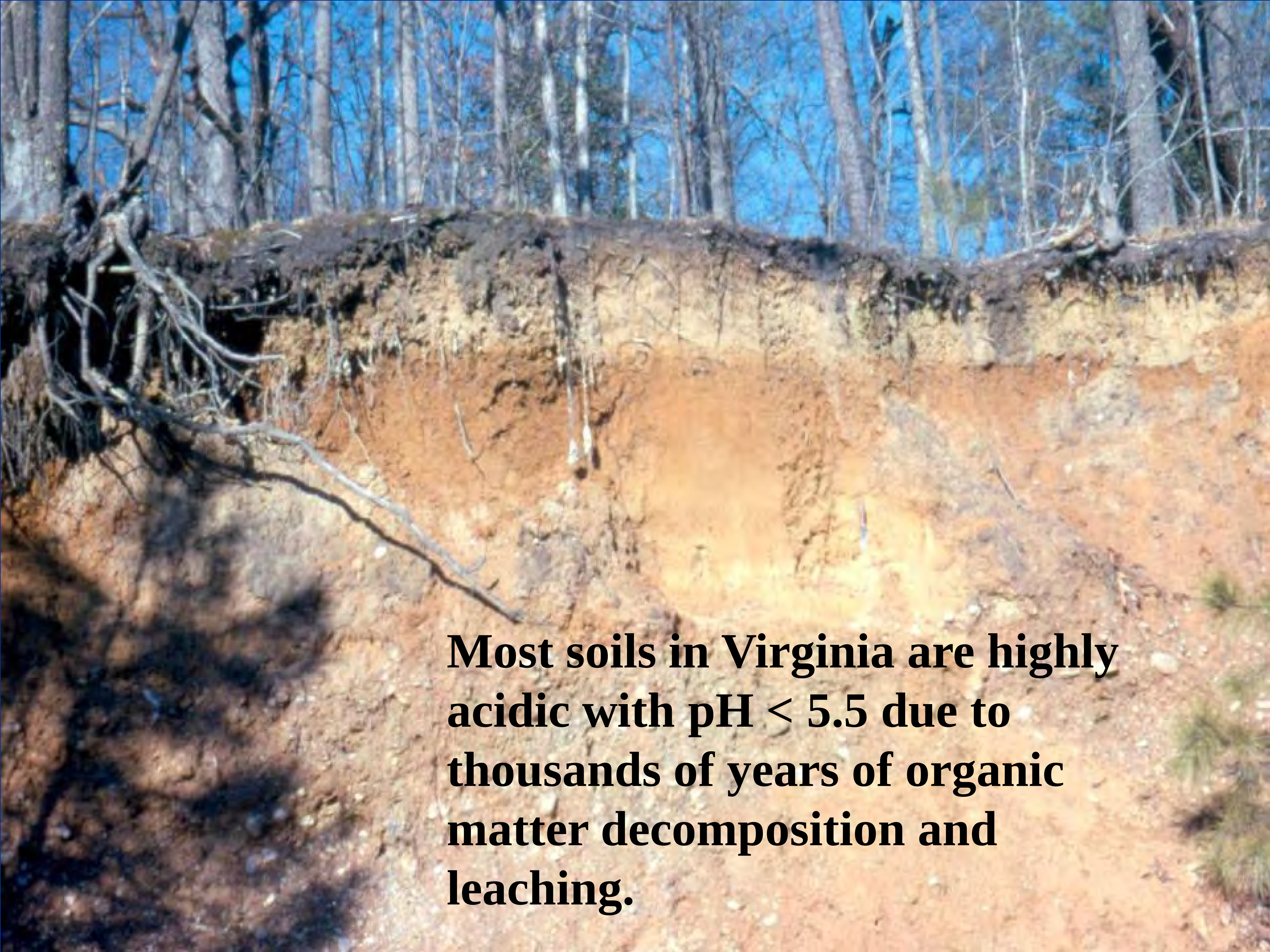


Soil pH Range. Note that the common range of soil pH under natural conditions is from 5.0 to 9.0. For each pH change of 1 unit, the concentration of H^+ changes 10X. So, how much more acidic is a pH 4.0 soil when compared with a pH 7.0 soil?



Note that the "normal extreme range" of pH is from 3.8 up to 8.5. Soils more acid than this are usually due to S oxidation; soils higher in pH are sodium dominated.

FIGURE 9.1 Chart showing a range of pH from 1 to 12 and the approximate pH of products commonly used in our society every day (left). Comparable pH ranges are shown (right) for soils we will be studying in this text.



Most soils in Virginia are highly acidic with pH < 5.5 due to thousands of years of organic matter decomposition and leaching.

$$\boxed{\text{Micelle}}\ Al^{3+} \rightleftharpoons Al^{3+}$$

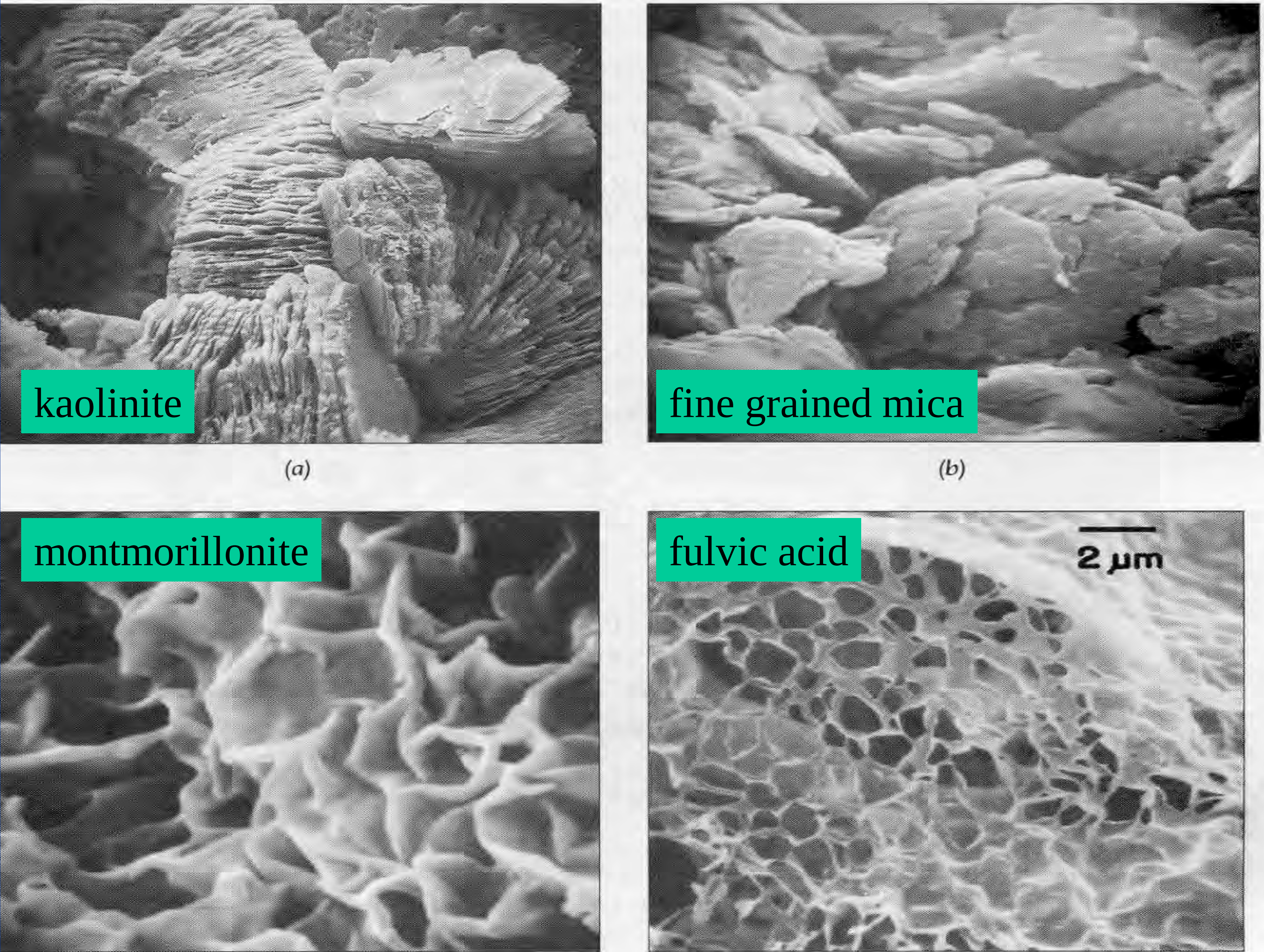
Adsorbed Soil solution

$$Al^{3+} + H_2O \rightleftharpoons AlOH^{2+} + H^+$$

Well weathered soil with a variety of charged clay mineral surfaces present. The Bt horizon here is dominated by kaolinite, which is extensively coated with Fe-oxides like goethite and hematite.

Types of Charged Surfaces (Colloids) in Soils

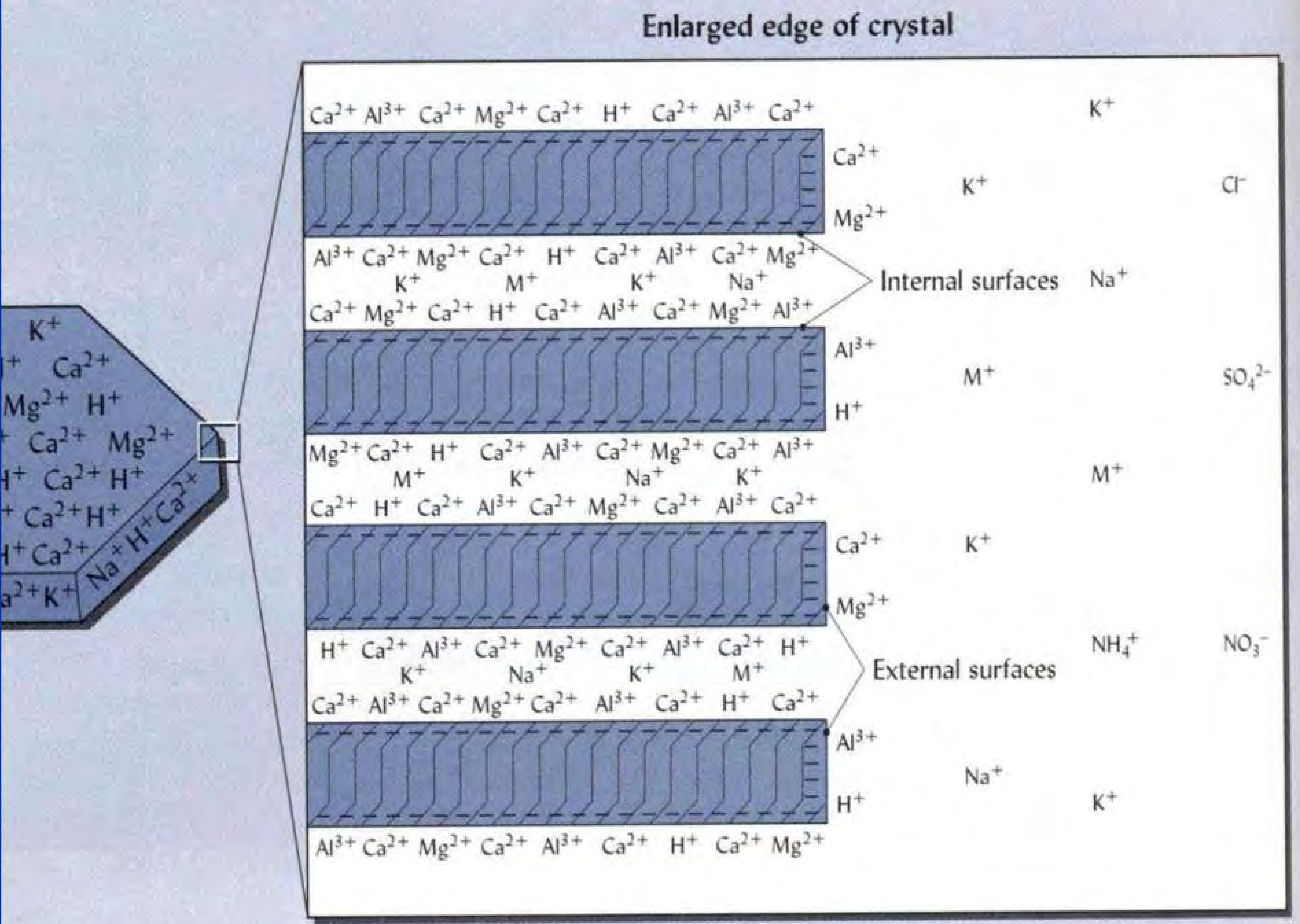
- **Layer Silicate Clays** like Kaolinite
- **Poorly crystalline minerals** like allophane and imogolite in Andisols
- **Iron** (Fe00H or Fe_20_3) or **Aluminum** [$Al(OH)_3$] **oxides** or hydroxides. These usually coat other mineral grains
- **Humus (organic compounds produced by microbial decomposition of OM)**


kaolinite
fine grained mica
(a)
(b)
montmorillonite
fulvic acid
2 µm

Adsorption Properties

- The colloidal surface attracts both charged **cations (Al^{3+}, Ca^{2+},** etc.) and **anions (NO_3^-, SO_4^{2-}** , etc.) into a diffuse cloud of ions that is retained against leaching very close, but not attached to, the colloid's surface.

- Water is also held against the surface by these same charges and by the attractive osmotic force of the ions here.

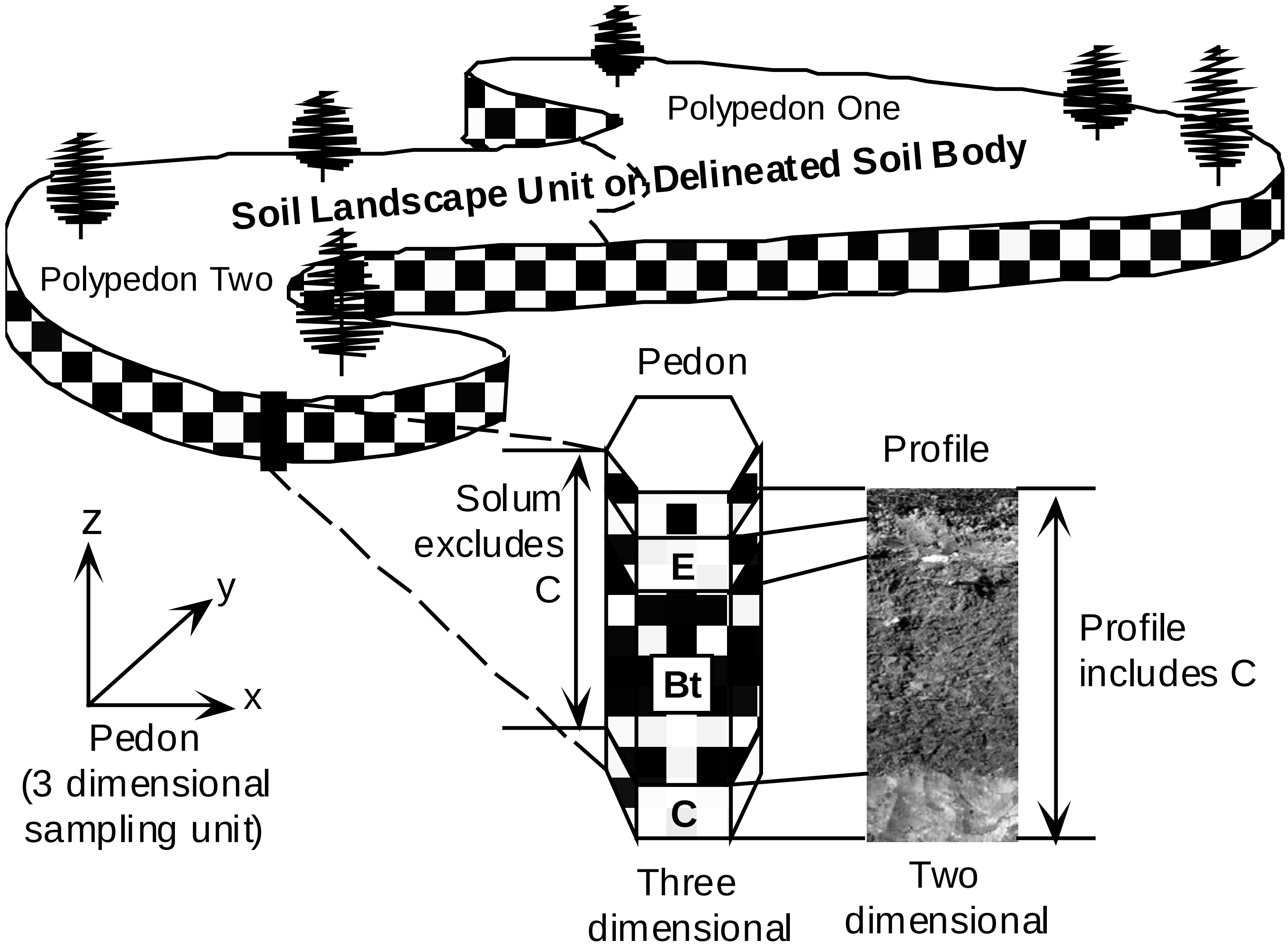


Enlarged edge of crystal
Internal surfaces
External surfaces
Ca2+ Al3+ Ca2+ Mg2+ Ca2+ H+ Ca2+ Al3+ Ca2+
Al3+ Ca2+ Mg2+ Ca2+ H+ Ca2+ Al3+ Ca2+ Mg2+
K+ M+ K+ Na+
Ca2+ Mg2+ Ca2+ H+ Ca2+ Al3+ Ca2+ Mg2+ Al3+
Mg2+ Ca2+ H+ Ca2+ Al3+ Ca2+ Mg2+ Ca2+ Al3+
M+ K+ Na+ K+
Ca2+ H+ Ca2+ Al3+ Ca2+ Mg2+ Ca2+ Al3+ Ca2+
H+ Ca2+ Al3+ Ca2+ Mg2+ Ca2+ Al3+ Ca2+ H+
K+ Na+ K+ M+
Ca2+ Al3+ Ca2+ Mg2+ Ca2+ Al3+ Ca2+ H+ Ca2+
Al3+ Ca2+ Mg2+ Ca2+ Al3+ Ca2+ H+ Ca2+ Mg2+
K+ Cl- Na+ SO42- M+ NH4+ NO3-

Cation Exchange Capacity

- Is measured in hundredths of moles (cmol) of charge ($cmol^+$) per kilogram (kg) dry soil.
- So, our units of expression are $cmol^+$/Kg!
- CEC's usually range from <5 to around 30 $cmol^+$ for natural soils.
- This is the same unit as meq/100 g, just gyrated around to fit the international system of units (SI). Many labs and books still report CEC as meq/100 g.

Soils are 3-dimensional



Soil maps delineate different types of soil. In the example below the label # represents the type of soil or soils found in that area, and the letter indicates the slope.

What’s in a delineation?

The soil within a given delineation on a soil map may be almost exclusively one series, or it may be a combination of series.

Soil series are subdivisions of the “family” level of classification by <u>Soil Taxonomy.</u>

A **soil series** consists of soils that are similar in all major profile characteristics. The soils look, classify, and behave alike.

Soil series descriptions can be found at:

http://ortho.ftw.nrcs.usda.gov/osd/osd.html

Includes: a typical profile description, range in characteristics, competing series, associated series, and more…..

Example - Pamunkey Series

<u>Classification</u> - Fine-loamy, mixed, semiactive, thermic Ultic Hapludalfs

Looks like this

Some whole soil properties

slope = 0 - 15%

drainage class = well

Depth to bedrock > 80”

Occur on nearly level to sloping stream terraces.

Phases of Soil Series

Phases are used to specify the properties unique to the survey area. Examples:

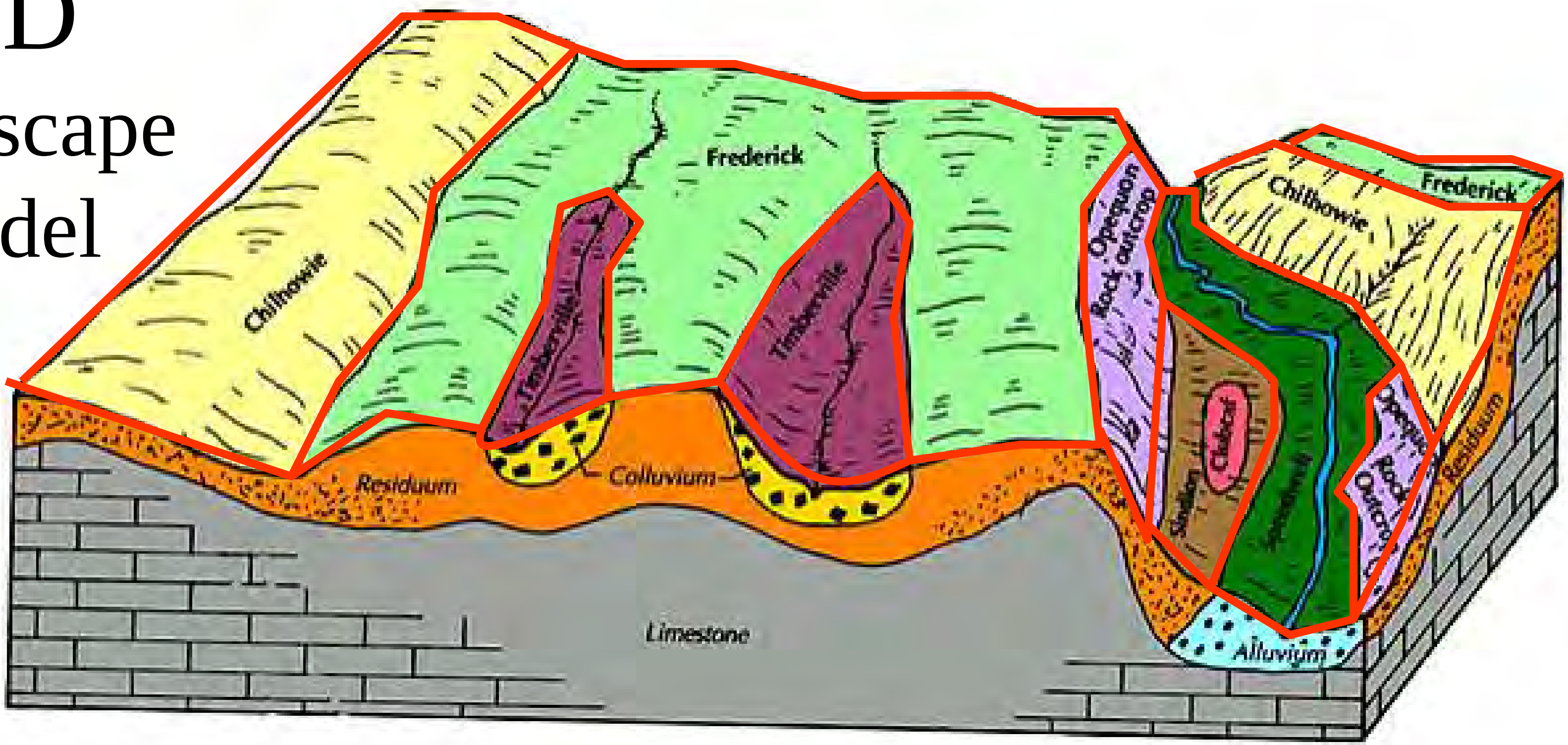
Slope Class (2 to 7% slopes)

Erosion (1- slight; 2 – moderate, etc.)

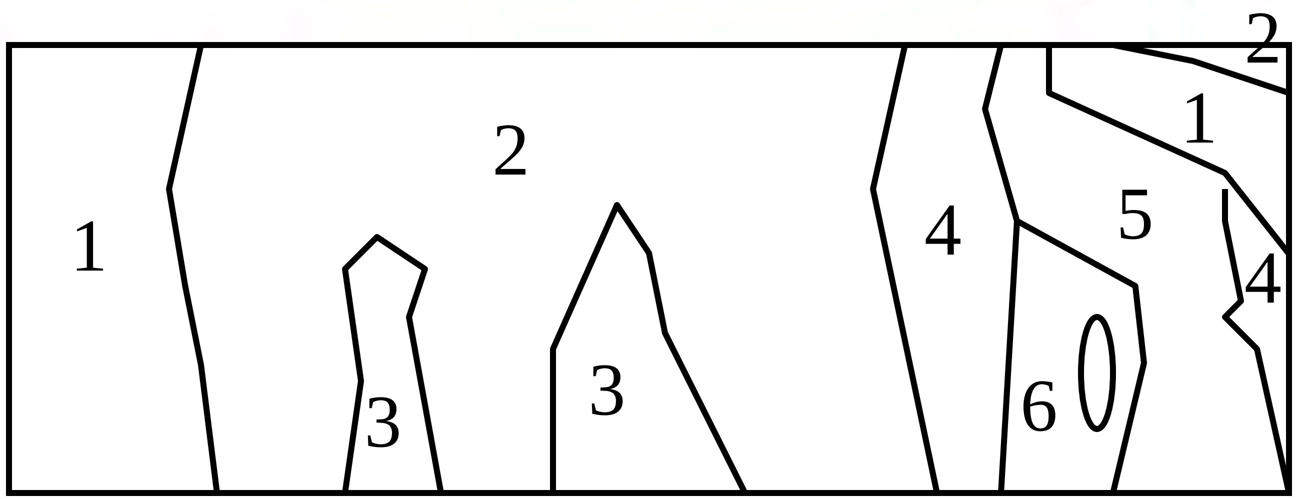
Stoniness, flooding, etc.

PaB2: Pamunkey loam, 2-7% slope, moderately eroded

3-D
Landscape model



2-D
Soil map



Major Map Unit Types

Soils that occur in relatively pure units (≥ 85%) on the original field map and are mapped as **consociations** The dominant soil series is named but may include other soils similar in use & management.

Complexes

2 or 3 dominant dissimilar components that consistently occur next to each other in a predictable pattern are named in map units called complexes.

The components cannot be separated at the scale of 1:24,000.

Complex of Alpha-Beta soils might occur on a heterogeneous parent material

Spot Symbols

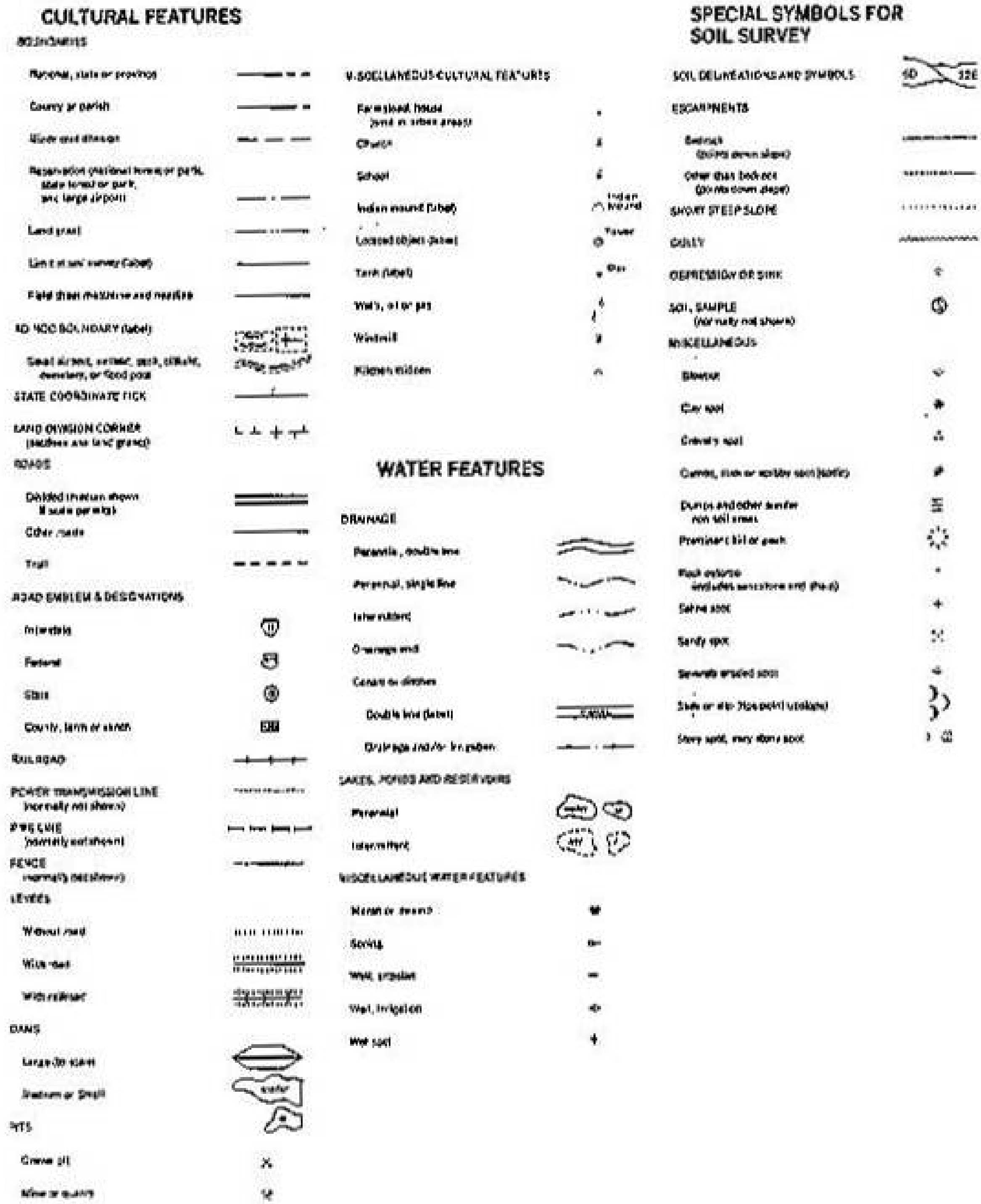
If a soil or **feature** is very unique but too small to be separated by a polygon, you can identify the feature on a map by using a special symbol.

Example: A rock outcrop or wet soil 20 ft across.

This **feature** is not a soil, it is called a miscellaneous land type. Other examples are: beaches, gravel bars, and urban land.

Spot Symbols

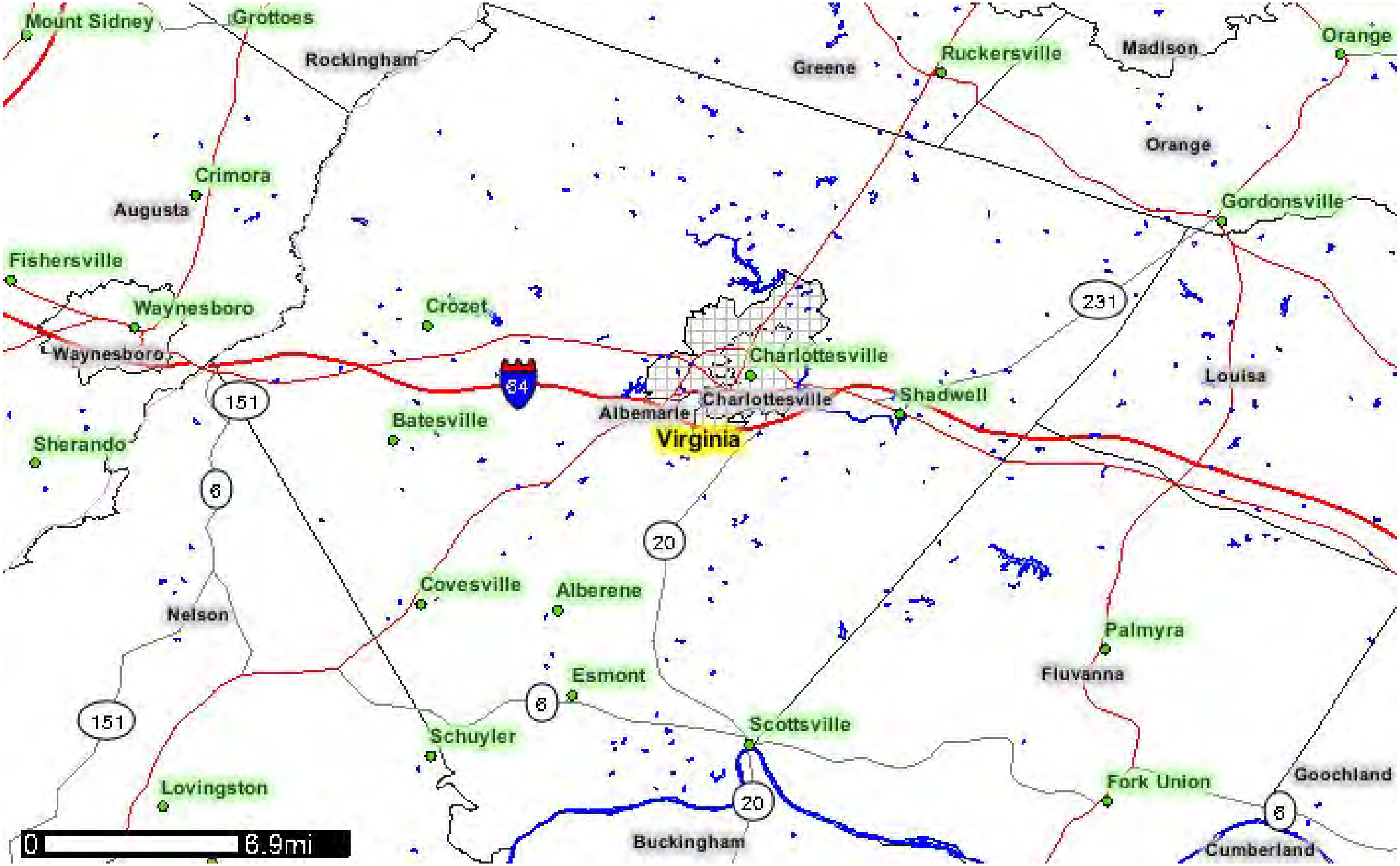
This legend is found on the 2nd folded map in the published survey



SYMBOL	NAME
1	Altavista fine sandy loam
2	Augusta fine sandy loam
3	Axis very fine sandy loam
4	Beaches
5	Bethera silt loam
6	Bohicket muck
7	Bojac sandy loam
8B	Caroline fine sandy loam, 2 to 6 percent slopes
9	Chickahominy silt loam
10B	Craven fine sandy loam, 2 to 6 percent slopes
10C	Craven fine sandy loam, 6 to 10 percent slopes
11B	Craven-Uchee complex, 2 to 6 percent slopes
11C	Craven-Uchee complex, 6 to 10 percent slopes
12	Dogue loam
13	Dragston fine sandy loam
14B	Emporia fine sandy loam, 2 to 6 percent slopes
14C	Emporia fine sandy loam, 6 to 10 percent slopes
15D	Emporia complex, 10 to 15 percent slopes
15E	Emporia complex, 15 to 25 percent slopes
15F	Emporia complex, 25 to 50 percent slopes
16	Izagora loam
17	Johnston complex
18B	Kempsville fine sandy loam, 2 to 6 percent slopes
19B	Kempsville-Emporia fine sandy loams, 2 to 6 percent slopes
20B	Kenansville loamy fine sand, 2 to 6 percent slopes
21	Levy silty clay
22	Munden loamy fine sand
23	Newflat silt loam
24	Nimmo fine sandy loam
25B	Norfolk fine sandy loam, 2 to 6 percent slopes
26B	Pamunkey soils, 2 to 6 percent slopes
27	Peawick silt loam
28	Seabrook loamy fine sand
29A	Slagle fine sandy loam, 0 to 2 percent slopes
29B	Slagle fine sandy loam, 2 to 6 percent slopes
30	State fine sandy loam
31B	Suffolk fine sandy loam, 2 to 6 percent slopes
32	Tetotum silt loam
33	Tomotley fine sandy loam
34B	Uchee loamy fine sand, 2 to 6 percent slopes
34C	Uchee loamy fine sand, 6 to 10 percent slopes
35	Udorthents, loamy
36	Udorthents-Dumps complex
37	Urban land
38	Yemassee fine sandy loam

The map unit legend will list all soil X phase combinations that appear in that county survey. In surveys since the early 1980's, the map unit codes are #s; in earlier soil surveys letter codes are more typical.

1. Pick a county (example –Albermarle)



http://websoilsurvey.nrcs.usda.gov/app/

2. Pick an area of interest – see aerial photo

3. Display soils map

4. Display soil ratings for application of interest.

This example shows septic field limitations:
red = very limited, yellow = somewhat limited