Lecture 6: Crash course in soil

- **Ecological definition of soil**
- **Why are soils so crucial to ecological studies?**
- **Typical soil profiles**
  - **Soil horizon designations in the U.S. Soil Taxonomy**
- **Major process of soil development**
- **Elements of describing a soil**
- **Soil properties (physical and chemical properties): focus on properties we will examine in class (pH, texture, color)**
- **Trends in soil properties along toposequences and chronosequences**
- **Soil taxonomy**

Ecological definition of soil

Soil is a mixture of mineral particles, organic matter, water, and air that is capable of supporting plant life.

- **Mineral component**
  - Anchorage for plant roots.
  - Pore space for water and air.
  - Source of many plant nutrients through weathering.
  - Exchange sites for plant nutrients.
- **Organic component**
  - Source and exchange site for nutrient cycling.
  - Influences soil structure, pore space, and water holding capacity.
  - Energy source for soil microbes and other heterotrophs.
- **Water component**
  - Solvent for many essential plant nutrients.
  - Maintains equilibrium between cation and and anions that are held on exchange sites.
- **Air component**
  - Contains O_2 for aerobic metabolism of plant roots and soil organisms.
  - Exchange of CO_2 from soil respiration and which facilitates weathering.
  - Provides N_2 for N-fixing soil organisms.

Why are soils so crucial to ecological studies?

- They provide all or part of all essential factors for plant growth except light.
- Rooting material for the plants: the platform on which trophic levels of the ecosystem are built.
- Contains most of the decomposers that recycle energy and nutrients of the ecosystem.
- Contain the history of the site, which can be interpreted through paleoecological reconstructions.
- The soil is an ecosystem in itself (producers, consumers, and decomposers)

Major process of soil development

Physical weathering: The breakdown of rock (the regolith) into finer particles through weathering.

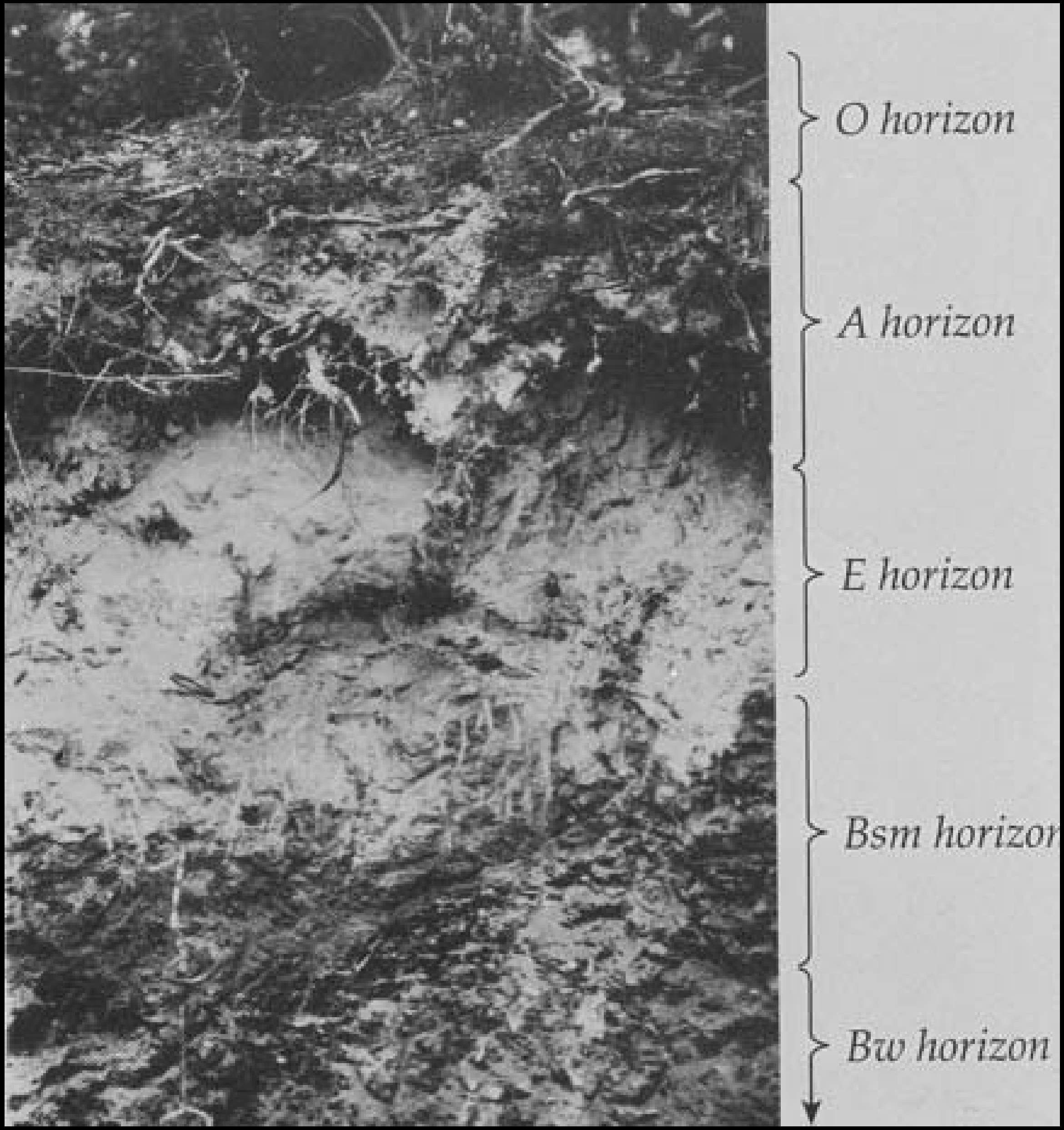
Chemical weathering: The breakdown and redeposition of organic and inorganic substances primarily through the processes of oxidation, dissolving, and leaching.

Decomposition: The breakdown of organic matter by bacteria and fungi into simpler organic substances (carbohydrates, lignins, proteins).

Mineralization: The ultimate breakdown of organic substances into nonorganic substances (minerals, carbon dioxide, water, salts).

Nitrification: The transformation by soil bacteria of ammonia compounds into nitrates and nitrites.

Soil horizons



Soil horizons

O - organic horizons.

A - predominatly mineral horizon that is mixed with humified organic material (an eluvial horizon, i.e. a source of organic material, clay, and cations to lower horizons).

E - light colored, bleached mineral horizon underlying the A horizon that occurs only in highly leached acidic soils.

B - mineral horizon that shows little or no evidence of the original rock structure and which has been altered by oxidation, and illuviation (addition of minerals, clays, and organic matter from the A horizon).

K - a subsurface horizon that is characterized by accumulation of calcium carbonate. Occurs mostly in desert and dry areas.

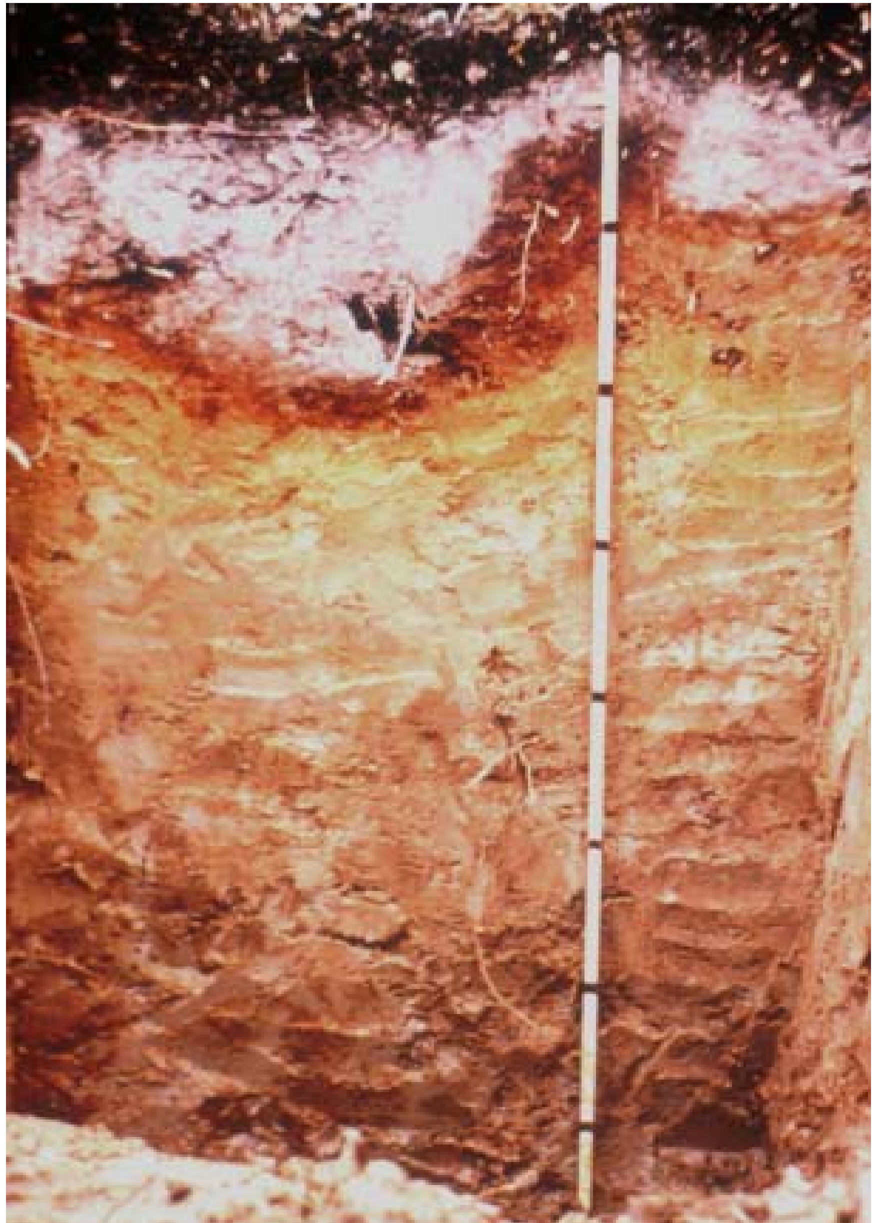
C - a subsurface horizon that is basically the material from which the soil formed (loess, alluvium, till, etc.). It lacks most of the properties of the A or B horizon, but can be somewhat oxidized (Cox horizon).

R - regolith (consolidated bedrock).

Horizon modifiers

a	Highly decomposed organic matter
b	Buried soil horizon
ç	Concretions or nodules
e	Intermediately decomposed organic matter
f	Frozen soil
g	Strong gleying
h	Illuvial accumulation of organic matter
i	Slightly decomposed organic matter
k	Accumulation of carbonates
m	Strong cementation
n	Accumulation of sodium
o	Residual accumulation of sesquioxides
p	Plowing or other disturbance
q	Accumulation of silica
r	Weathered or soft bedrock
s	Illuvial accumulation of sesquioxides
t	Accumulation of clay
v	Plinthite
w	Color or structural B
x	Fragipan character
y	Accumulation of gypsum
z	Accumulation of salts

Spodosol with a leached E horizon



A

E

Bsm

Bw

C

Organic soil: arctic Alaska

Oi1

Oi2

Oe

Elements of horizon description

- Horizon name
- Depth, top and bottom of horizon
- Color: Munsell color chart (name, hue, value, chroma)
- Structure
- Consistency and field texture
- Other notes
- Boundary

Sample soil description form

due to presence of a large number of rocks all soil samples are grab samples - not bulk density samples

Photo # 94S-7-20+21

ARCSS--Happy Valley, Alaska 1994 — ***Soil Description***

Soil Description: Location [illegible] ~100m west of [illegible] just east across Dalton Hwy from HV camp

Site no. HV-6 Date 7/21/94 Time 1431 Vegetation [illegible] dwarf shrub forb tundra

Elevation ____ Slope 0 Aspect — Geomorphic Surface featureless, <20 [illegible] scars

Parent Material(s) stabilized alluvium (sands + gravels) Described by [illegible]

Depth (cm)	Hori-zon	Color moist / dry	Structure	Gravel (%)	Consistence Wet	Consistence Mst Dry	Texture	pH	Clay films	Bound-aries	notes
0-½	Surface moss		m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo lo vfr so fr sh fi h vfi vh efi eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 d po 2 p br 3 co cobr	a s c w g i d b	
½-2	S-82 Oa	10YR2/2 v. dk. brown	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo lo vfr so fr sh fi h vfi vh efi eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 d po 2 p br 3 co cobr	a s c w g i d b	many fine and very fine roots in Oa, A, IIOa cobbles to 14cm in diameter
2-4	A S-83	10YR2.5/1 v. dk. gray black	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo lo vfr so fr sh fi h vfi vh efi eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 d po 2 p br 3 co cobr	a s c w g i d b	cobbles to 14 cm in diameter
4-6	IIOa S-84	10YR 2/1 black	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo lo vfr so fr sh fi h vfi vh efi eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 d po 2 p br 3 co cobr	a s c w g i d b	cobbles to 14 cm in diameter
6-30	S-85 IIB	10YR3/1 v. dk. gray	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk breaks to [illegible] sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo lo vfr so fr sh fi h vfi vh efi eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 d po 2 p br 3 co cobr	a s c w g i d b	common fine and very fine roots in IIB cobbles to 21 cm in diameter
30	very stony stopped digging here		m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	0 50 <10 75 10 >75 25	so po ss ps s p vs vp	lo lo vfr so fr sh fi h vfi vh efi eh	S SiCL LS SiL SL Si SCL SiC L C CL SC		v1 f pf 1 d po 2 p br 3 co cobr	a s c w g i d b	
	didn't reach permafrost		m vf gr sg f pl 1 m pr	0 50 <10 75 10 >75	so po ss ps s p	lo lo vfr so fr sh	S SiCL LS SiL SL Si		v1 f pf 1 d po 2 p br	a s c w g i	

Example soil description

Plot SWT-5 Soil Description

Classification: Pergelic Cryochrept, sandy-skeletal, mixed.
Location: South side of Toolik Lake, 68°37' N, 149°36' W.
Physiographic position: Top of glacial outwash terrace.
Topography: High centered polygons 6-8 m diameter, 20-40 cm height. Microrelief height: 2-5 cm.
Drainage: Well drained terrace bluff.
Vegetation: Dry *Arctous alpina*, *Hierochloë alpina* dwarf-shrub, fruticose-lichen tundra.
Parent material: Itkillik II outwash.
Sampled by: D.A. Walker and C. Westberg, August 2, 1989.
Remarks: Deep active layer, but very rocky soil. Weather: cold, raining.

Colors are for moist soil.

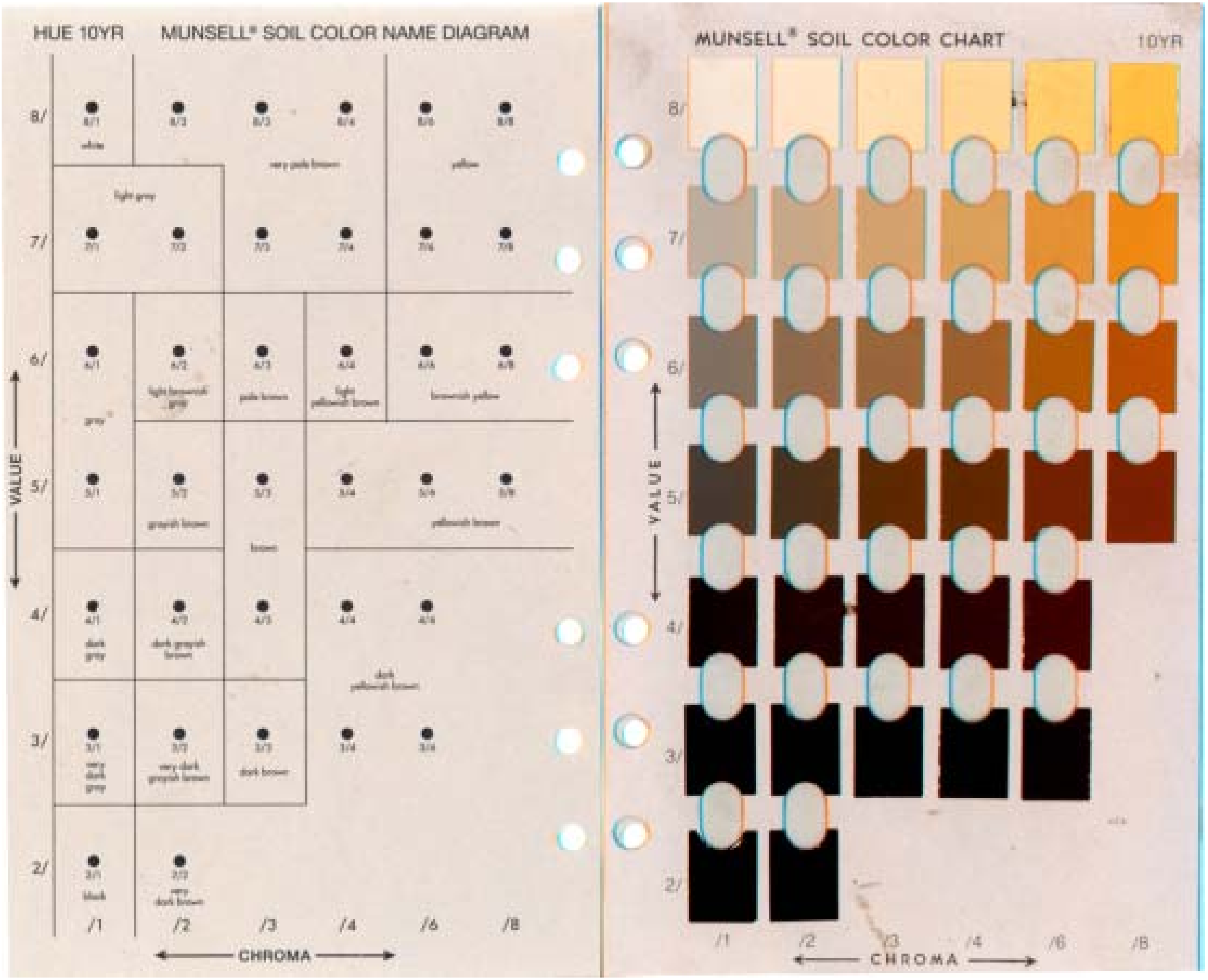
Oa 0-8 cm. Very dark brown (7.5YR 2.2) sapric organic material with est. < 5 percent silt loam; moderate fine granular structure; damp; smooth, slightly sticky, slightly plastic (wet); pH = 4.0; many fine and very fine roots; abrupt, irregular boundary. (Sample T-008).

B1 8-12 cm. Brown (7.5YR 4.5/4) cobbly sandy loam; weak medium subangular blocky structure; damp; friable (moist), gritty, slightly sticky, slightly plastic; pH = 4.1; common fine and many very fine roots; est. 75 percent gravel and cobbles to 10 cm diameter; clear, irregular boundary. (Sample T-009).

Bw 12-39 cm. Strong brown (7.5YR 4.5/6) very gravelly sandy loam; moderate medium subangular blocky structure; damp; slightly gritty, smooth, plastic; pH = 4.6; common fine roots; est. 80 percent gravel and cobbles to 20 cm diameter; wavy, clear boundary. (Sample T-010).

C 39-45+ cm. Dark yellowish brown (10YR 3/4) very gravelly loamy sand; single grained; damp; gritty, nonsticky, nonplastic; pH = 4.9; no roots; est. 90 percent gravel to 15 cm diameter. (Sample T-011).

Soil colors


HUE 10YR
MUNSELL® SOIL COLOR NAME DIAGRAM
VALUE
CHROMA
8/
7/
6/
5/
4/
3/
2/
/1
/2
/3
/4
/6
/8
MUNSELL® SOIL COLOR CHART
10YR

Quantification of color using the Munsell notation: Hue, value, chroma

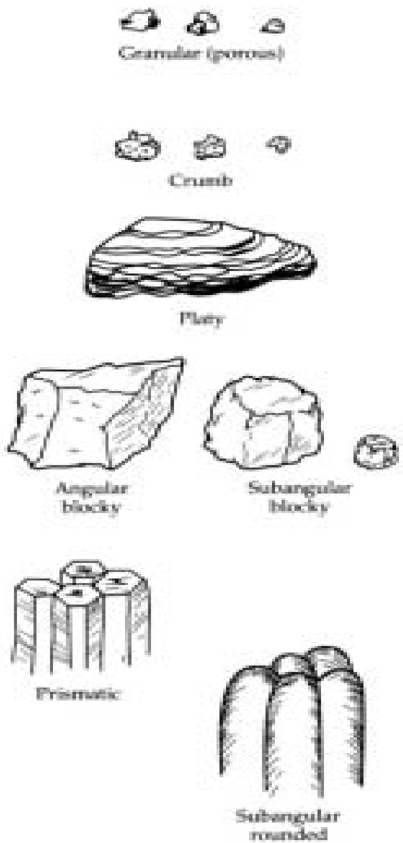
- **Hue (page in Munsell color book):** The dominant color, (e.g. 10 R is red; 2.5YR has some yellow, 7.5YR are tans and browns, 2.5 Y is yellow, G is green). As soils age they oxidize and change from yellow to brown to red (e.g., 2.5Y to 10YR to 7.5YR to 5 YR to 10R).
- **Value (rows on each page):** The relative darkness or lightness of the hue from 1 (dark) to 8 (light). The value is often a function of the amount of humic organic material in the soil. Darker soils have more organic material. Very black horizons may be buried charcoal or accumulations of MnO_2. Whiter horizons may be the result of leaching as in an E horizon, or the accumulation of carbonate or gypsum.
- **Chroma (columns on each page):** The strength or intensity of the color from 0 (least with none of the hue) to 8 (most vivid). This is indicative of the amount pigmenting material present, but it is strongly influenced by the texture of the soil.

Example: a soil with color 10YR5/6 is 10YR hue, 5 value, and 6 chroma, a yellowish brown in the U.S. system of color names.

Soil structure

Table 17-4 Classification, description, and illustration of various types of soil structure. Modified from *Nature and Properties of Soils*, 11th ed., by N. C. Brady and R. R. Weil. Copyright © 1996. Adapted by permission of Prentice-Hall, Inc.

Classification	Description	Illustration
Structureless		
Single grain	Each soil particle independent of all others.	
Massive	Entire soil mass clings together, no lines of weakness.	
Structured		
Spheroidal	Granular: Primary soil particles grouped into roughly circular peds, such that there is space between them as they do not fit tightly together. Enhances permeability.	Granular (porous)
	Crumb: Crumb structure is a more porous version of granular.	Crumb
Platelike May be platy-leafy or flaky	Peds with horizontal dimensions greater than vertical. Common at soil surface and often associated with lateral movement of water.	Platy
Blocky	Peds approximately equal in vertical and horizontal dimensions, but fit well together, unlike granular peds. May be angular or subangular.	Angular blocky; Subangular blocky
Prismatic	Peds taller than wide, common in B horizons of well-developed soils.	Prismatic
Columnar	Columnar peds may develop from prismatic peds due to old age or high sodium content.	Subangular rounded
Structure destroyed		
Puddled	Soils disturbed when wet, puddled, or run together; structure is destroyed, pores collapse.	



- **The bonding together into aggregates of individual soil particles into *peds*.**
- **These aggregates persist through cycles of wettting and drying.**
- **The amount of organic material is important in sphericalor *granular* shaped peds. Clay is more important in *angular, blocky, prismatic*, and *columnar* structures. *Platy* structures can result from ice-lens formation, sedimentation, or accumulation of organic layers.**

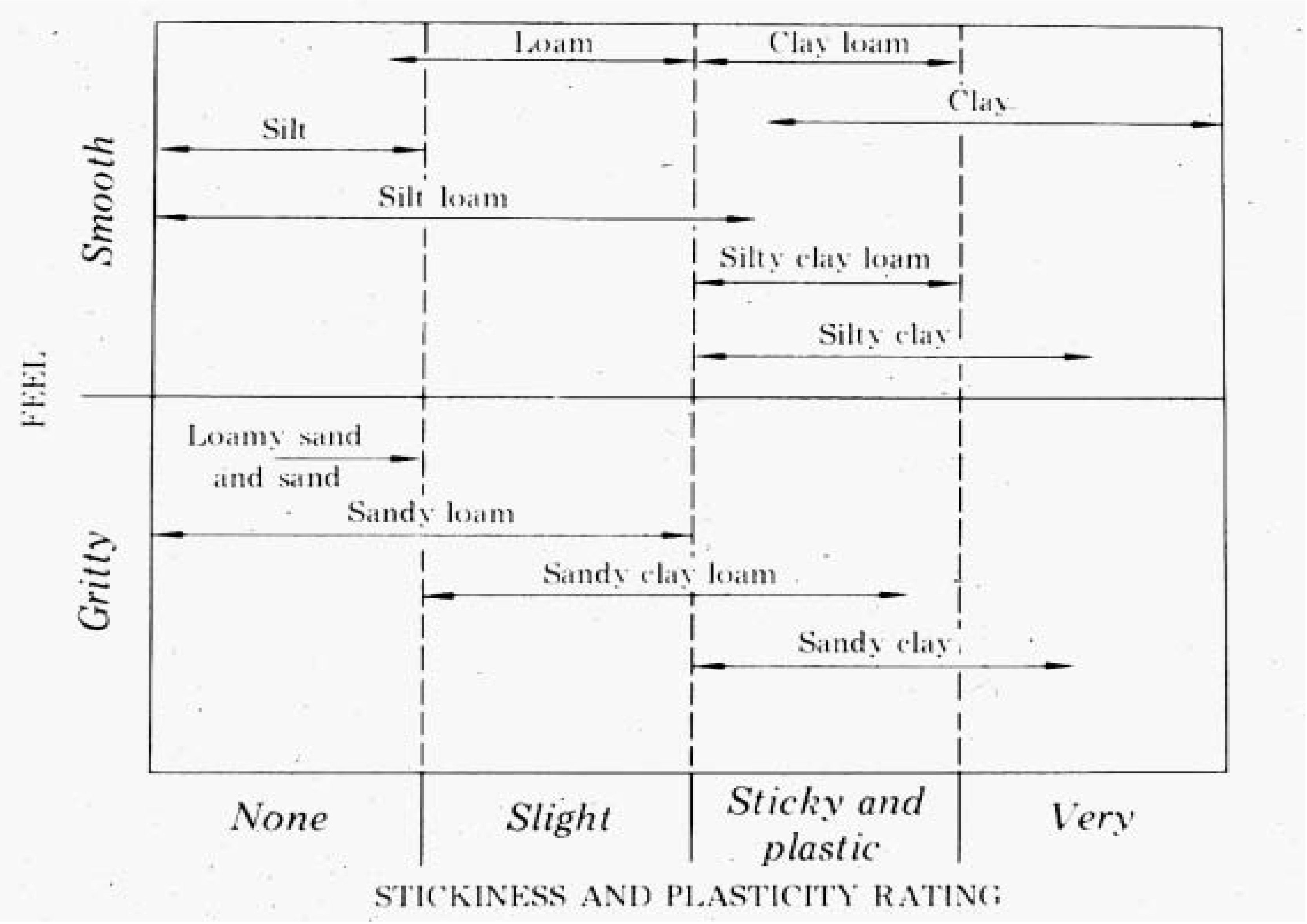
Soil structure

Figure 3:8. *A puddled soil (left) and a well-granulated soil (right). Plant roots and especially humus play the major role in soil granulation. For that reason a sod tends to restore the structural condition of cultivated land. (Photo courtesy U.S. Soil Conservation Service.)*

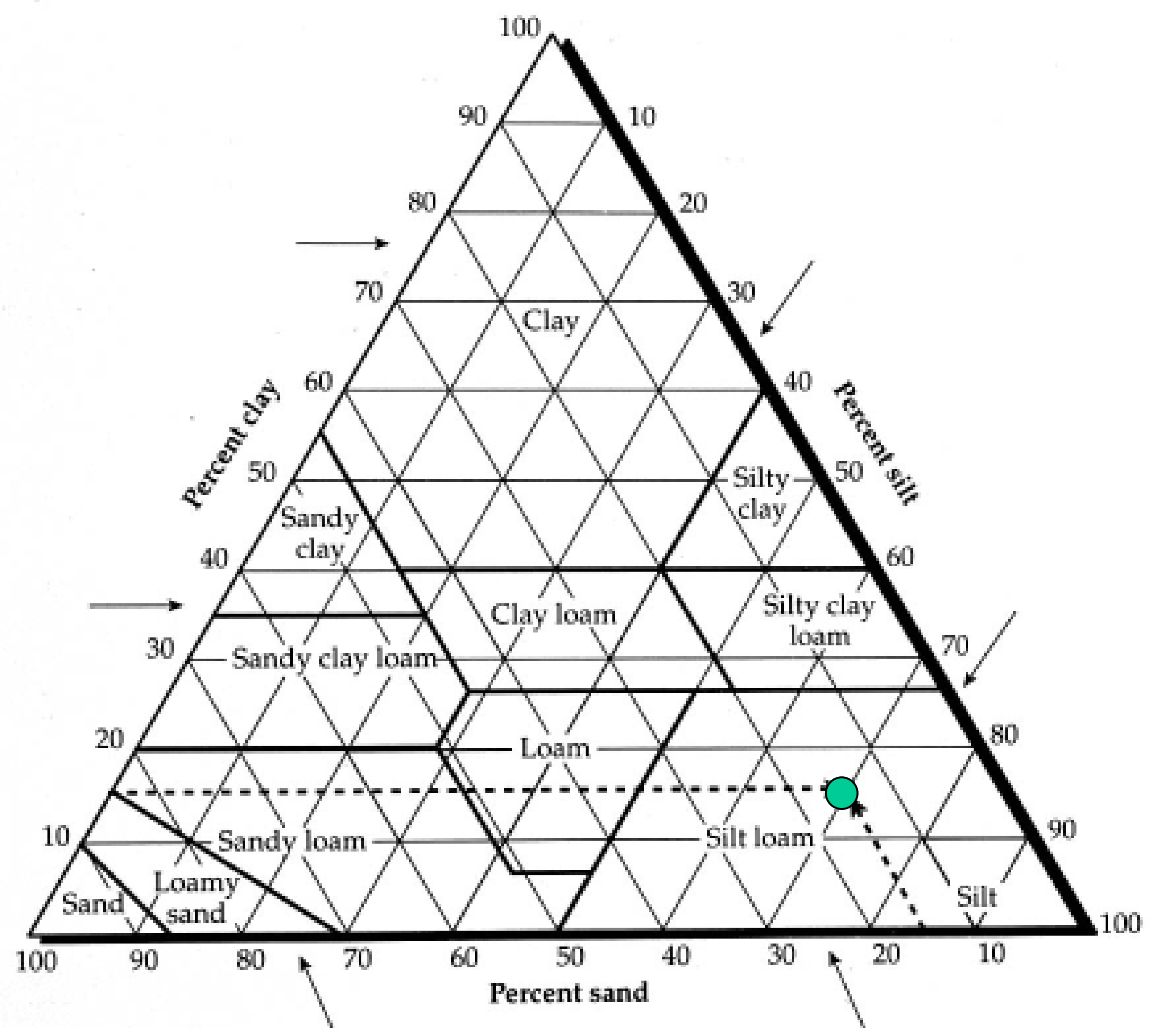
Soil particle sizes

- Gravel, >2 mm
- Sand, 2 - 0.05 mm
- Silt, 0.05 - 0.002 mm
- Clay, <0.002 mm

Consistence



Soil texture triangle



Percent of sand, silt and clay in various textured soils

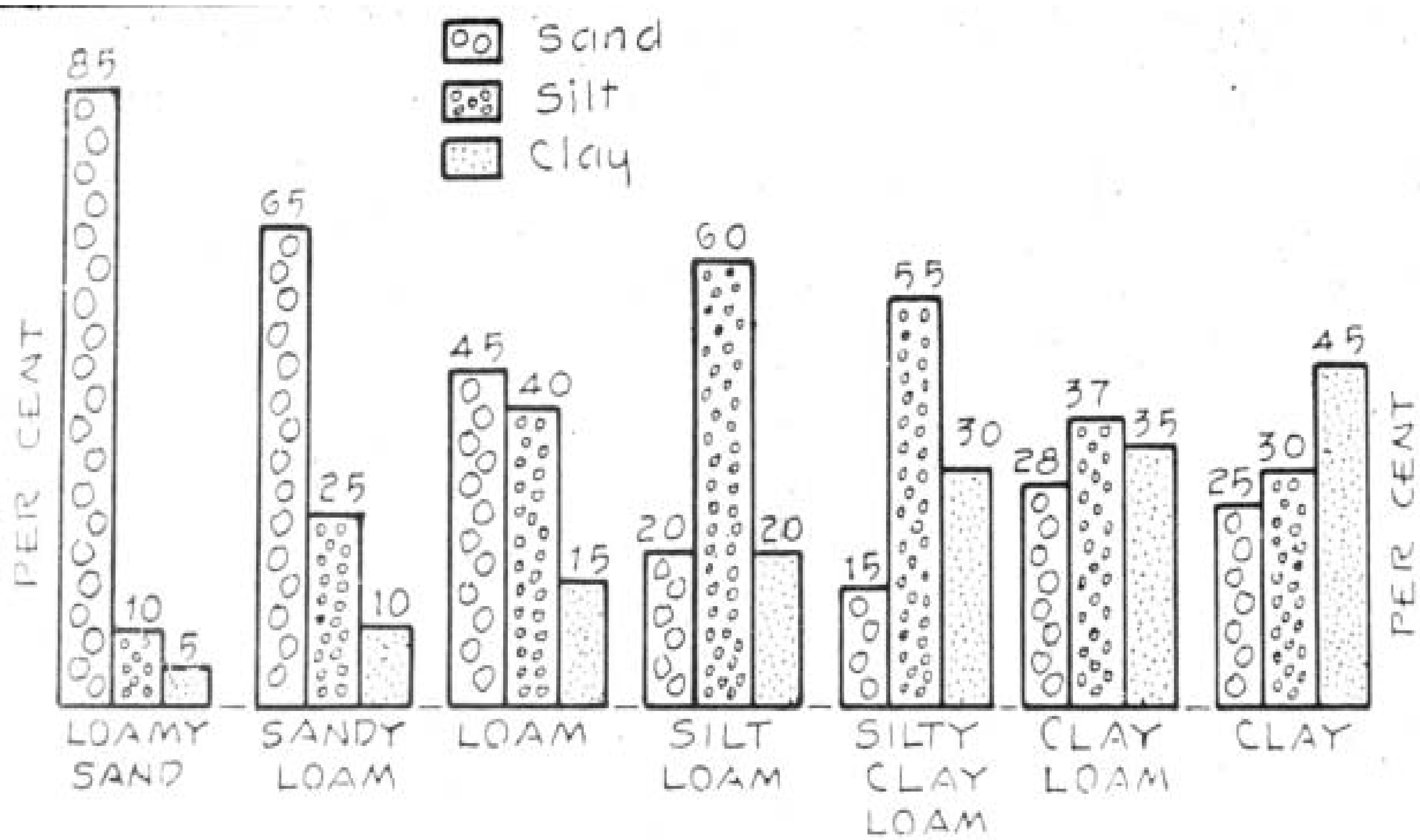
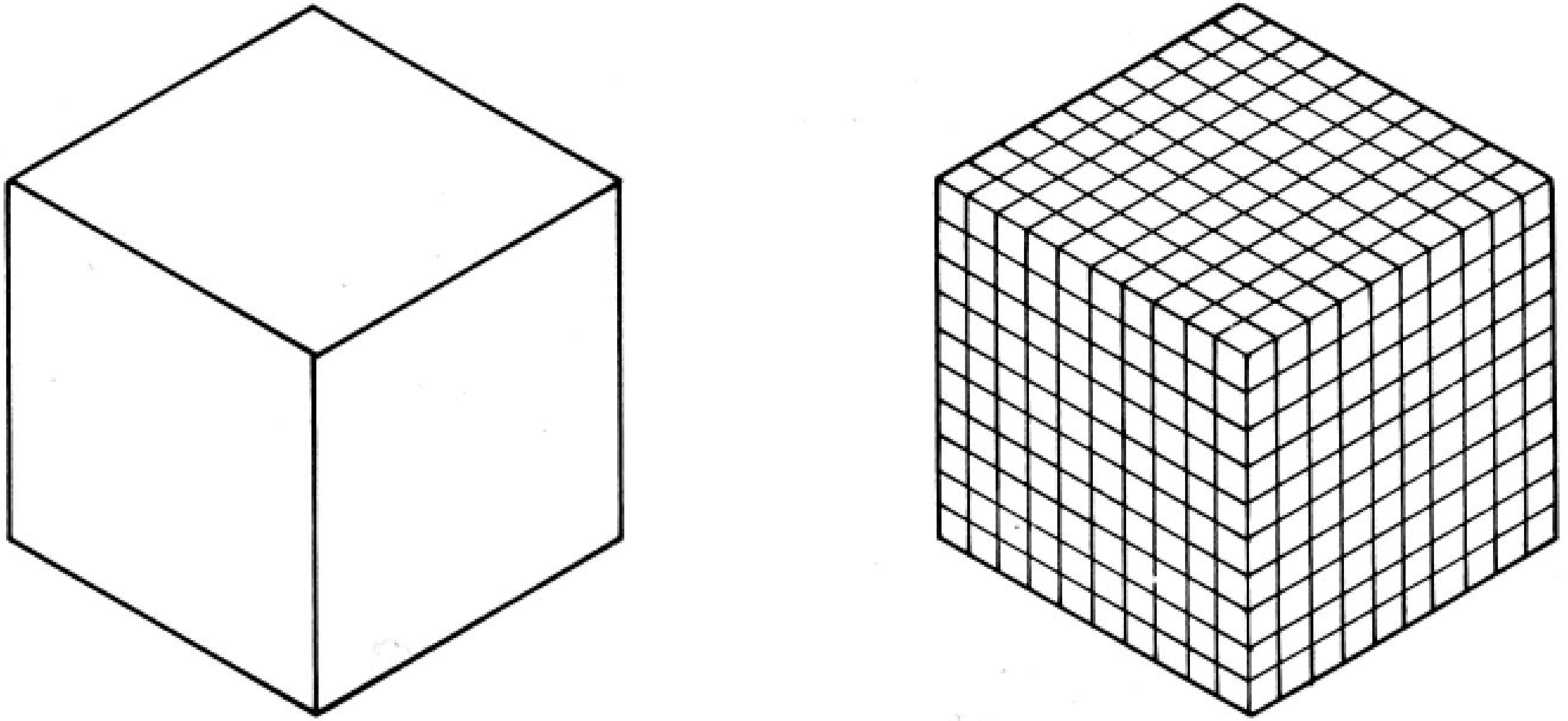


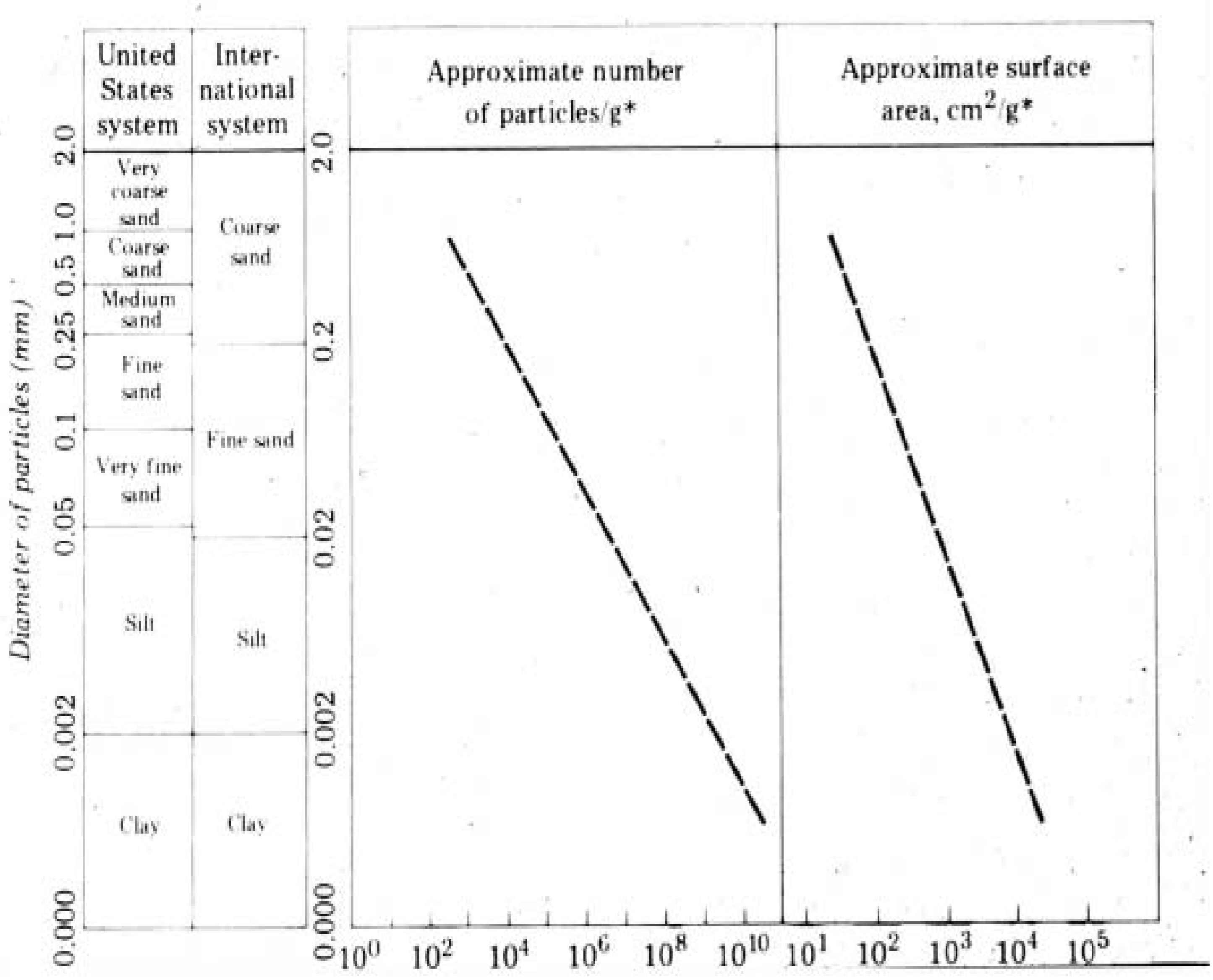
Figure 3:4. Graphic representation of the mechanical analyses of representative mineral soils.

Surface area vs. particle size

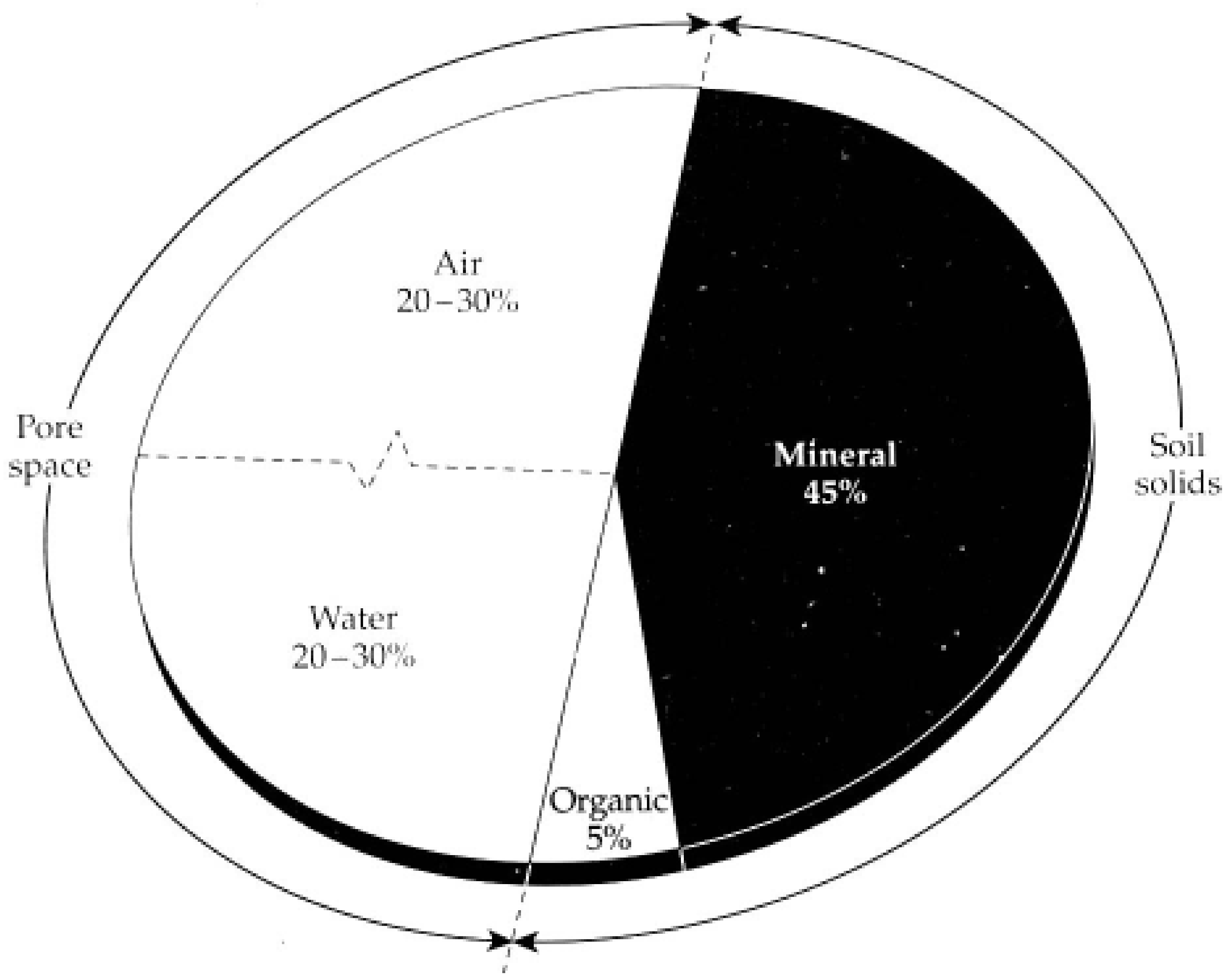


(a) (b)

Particle sizes and surface area of sand, silt and clay



Combination of mineral, organic, water and air in a loam soil



Soil particles and void space

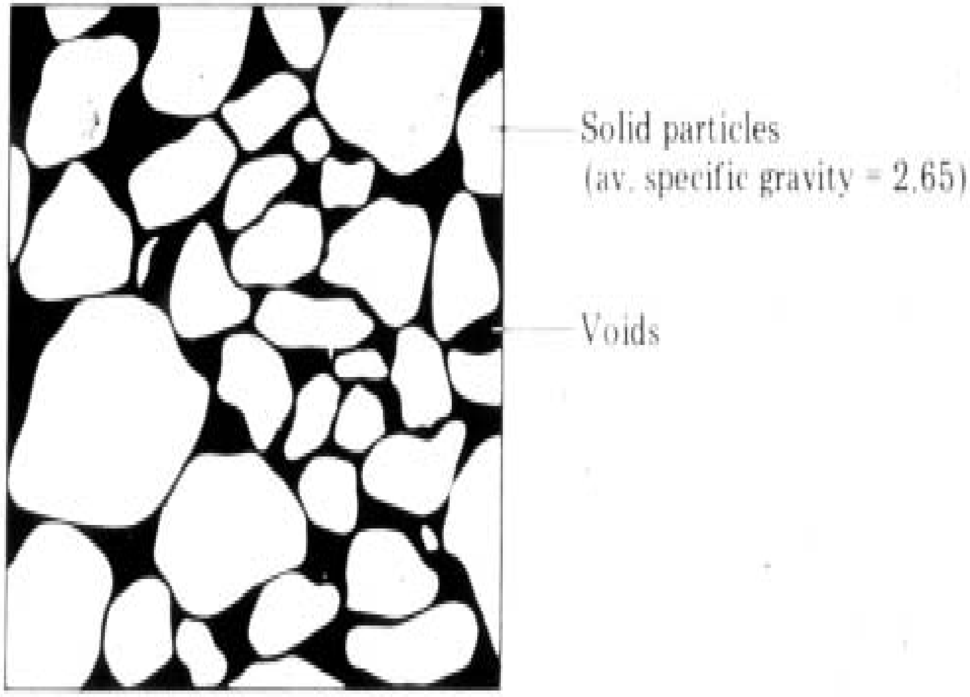
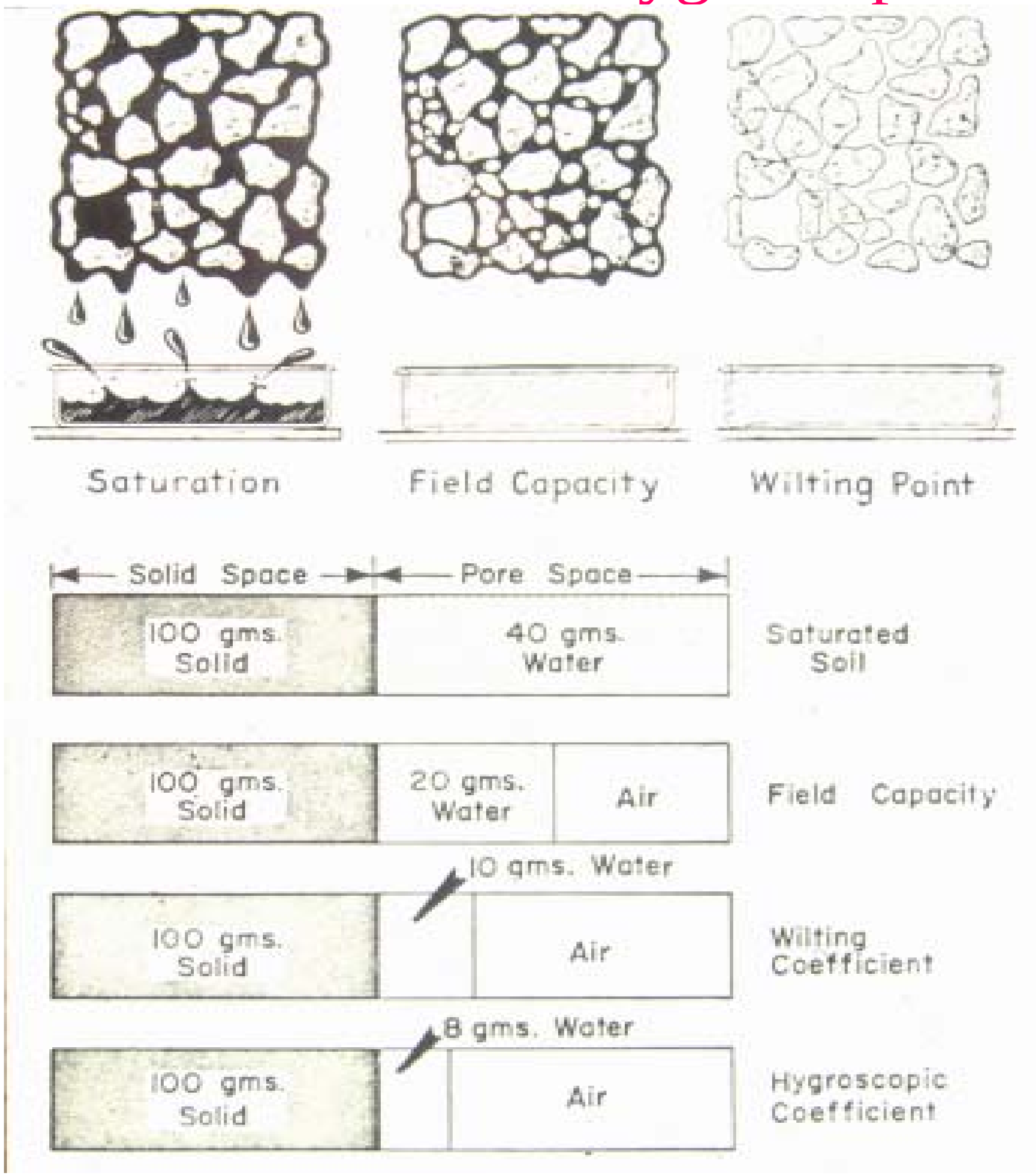


Fig. 1-5 Sketch of soil sample to show solid particle and void space distribution. The mineral grains in many soils are mainly quartz and feldspar, so 2.65 is an adequate average mineral specific gravity for the sand fraction. Bulk density and porosity are calculated as follows:

Saturation, field capacity, wilting point, and hygroscopic water



Field capacity: The percentage of water compared to the dry weight of soil that is held in the soil after drainage of the excess water, at 1 atmosphere of pressure.

Wilting point: The amount of water held in the soil at 15 atmospheres of pressure. (This is a standard that depicts a point at which many borad-leaved plants wilt.)

Available water: The difference between the Field Capacity and the Wilting Point.

Hygroscopic water: The water held at 30 atmospheres of pressure. This is representative of the amount of water that is tightly held to the soil particles, and which is not available to the plants.

Influence of soil organic matter on water holding capacity

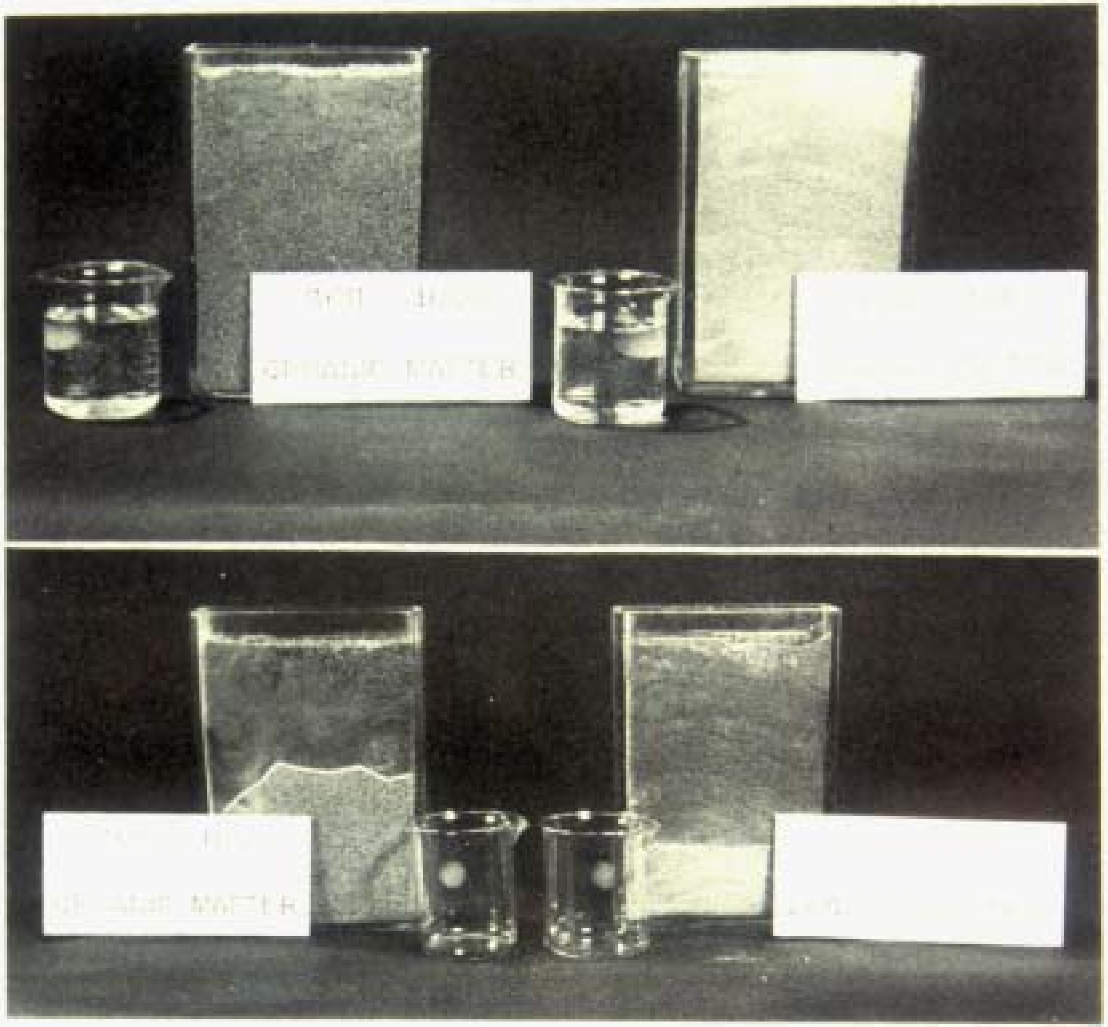


Figure 1:5. Soils high in organic matter are darker in color and have higher water holding capacities than do soils low in organic matter. The same amount of water was applied to each container (bottom photo).

Clay particles

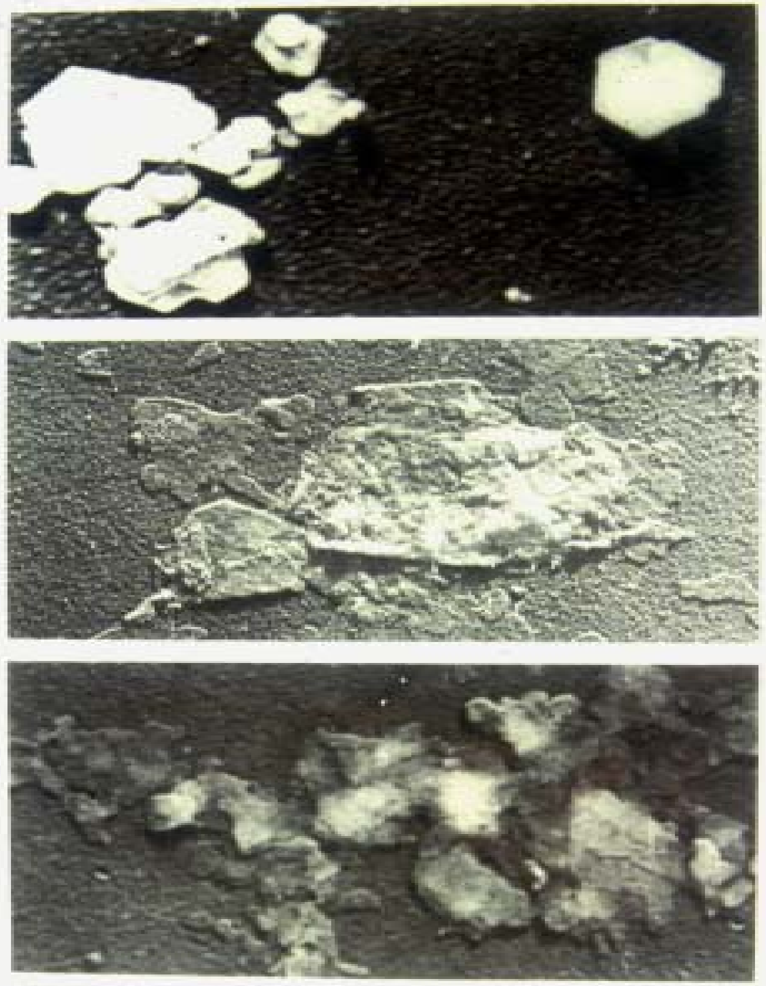
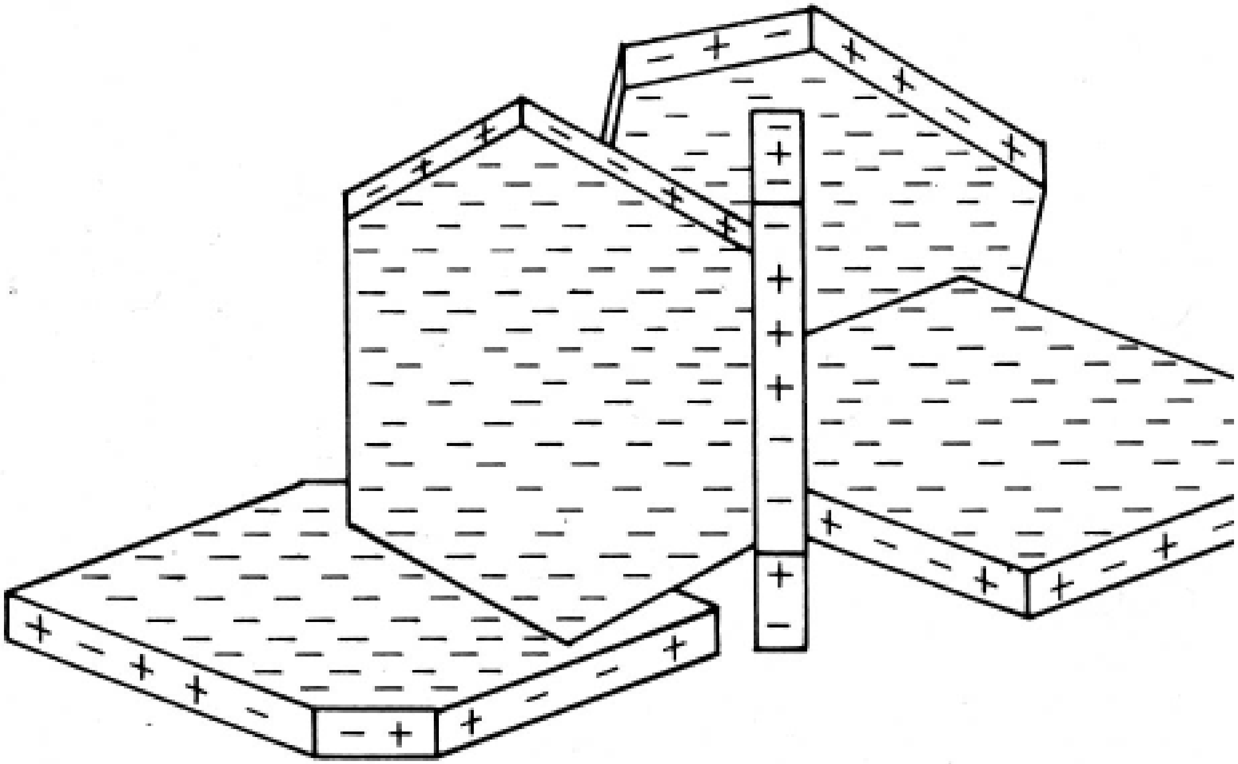


Figure 4:1. *Crystals of kaolinite (upper), montmorillonite (center), and hydrous mica (illite), as pictured by the electron microscope. Note their crystalline nature and mica-like shape. The kaolinite crystals are characteristically six-sided, while the others are irregular flakes. Magnification is 38,000 for both kaolinite and montmorillonite, and 45,000 for illite. (Illite and kaolinite from work of M. L. Jackson and J. A. Kittrick, University of Wisconsin; montmorillonite by B. M. Siegel, Cornell University.)*

An idealized cluster of clay particles



Clay crystal with adsorbed cations

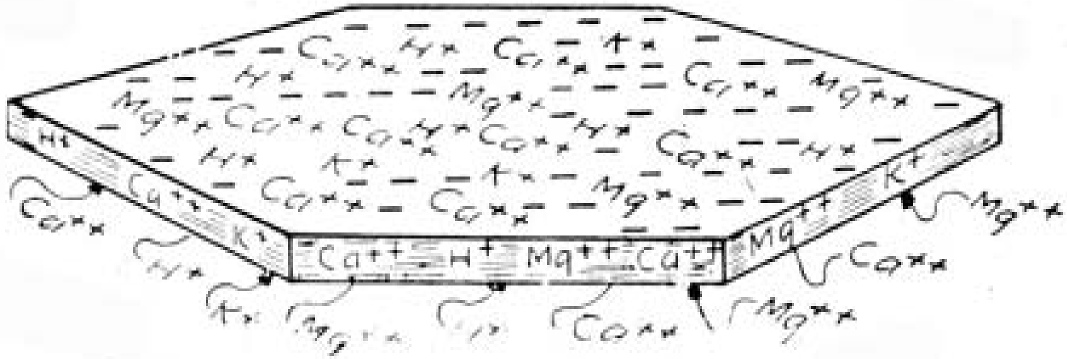


Figure 4:3. Diagramatic representation of a colloidal clay crystal (micelle) with its sheetlike structure, its innumerable negative charges, and its swarm of adsorbed cations. Note that Ca ions are dominant, but that some H, K, and Mg, and Na ions are present. No attempt has been made to show the adsorption of cations within the crystal (that is, between the platelike crystal units) or the numerous molecules of water that are held by the crystal surfaces and by the individual cations (hydrated ions).

Cation exchange capacity (CEC)

- A measure of the number of negatively charged sites on soil particles that attract exchangeable cations.
- Factors that influence the CEC include clay content, kinds of clay, humus content, and pH.

Base saturation

- Base saturation is the percent of the exchange sites that are occupied by exchangeable bases (Ca^{++}, Mg^{++}, K^{+}), which are important plant nutrients.

Percentage base saturation

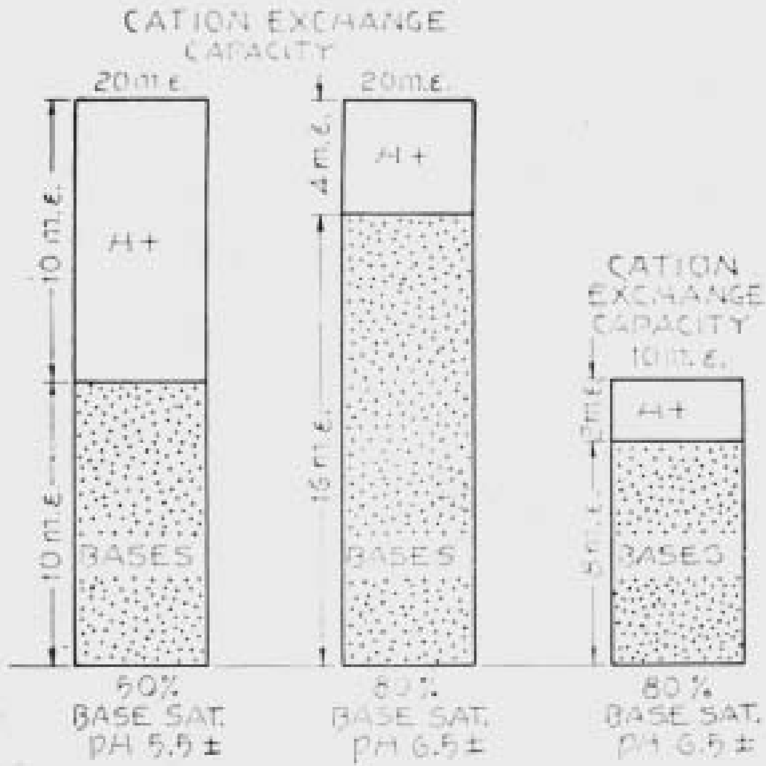


Figure 4:10. *Diagrams explanatory of percentage base saturation. Three soils are pictured with percentage base saturations of 50, 80, and 80 respectively. The first is a clay loam; the second, the same soil satisfactorily limed; and the third, a sandy loam with a cation-exchange capacity of only 10 m.e.*

Note especially that soil pH is correlated more or less closely with percentage base saturation. Also note that the sandy loam (right) has a higher pH than the acid clay loam (left) even though the latter contains more exchangeable bases.

Relationship between soil pH, cation exchange capacity, and base saturation

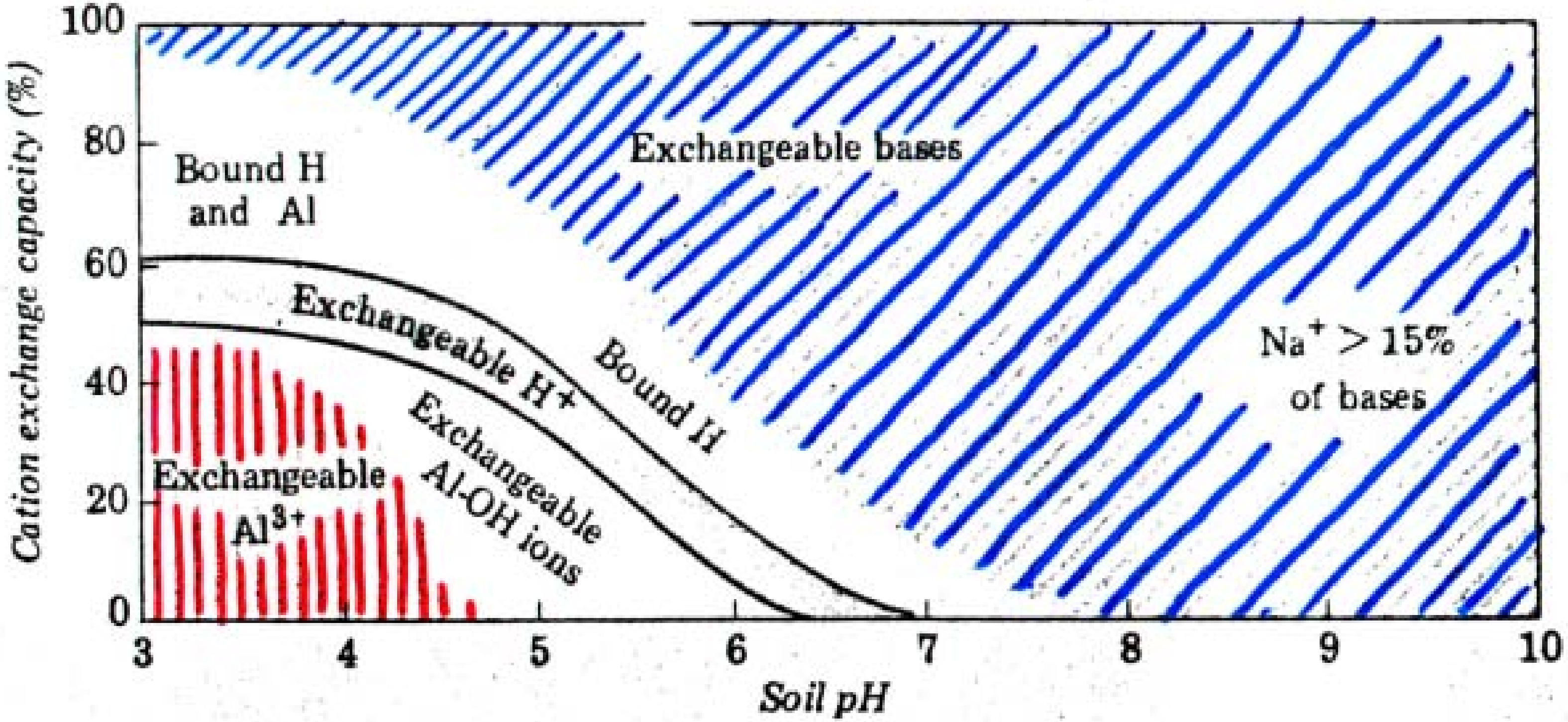


Fig. 1-9 General relationship between pH and exchangeable cations. Precise values vary from soil to soil for many reasons. Bound H^+ is that H^+ held so tightly to colloid surfaces that little of it is exchangeable. (Taken mostly from Buckman and Brady,[15] Fig. 14.1, © 1969, The Macmillan Co.)

Range of pH in soils

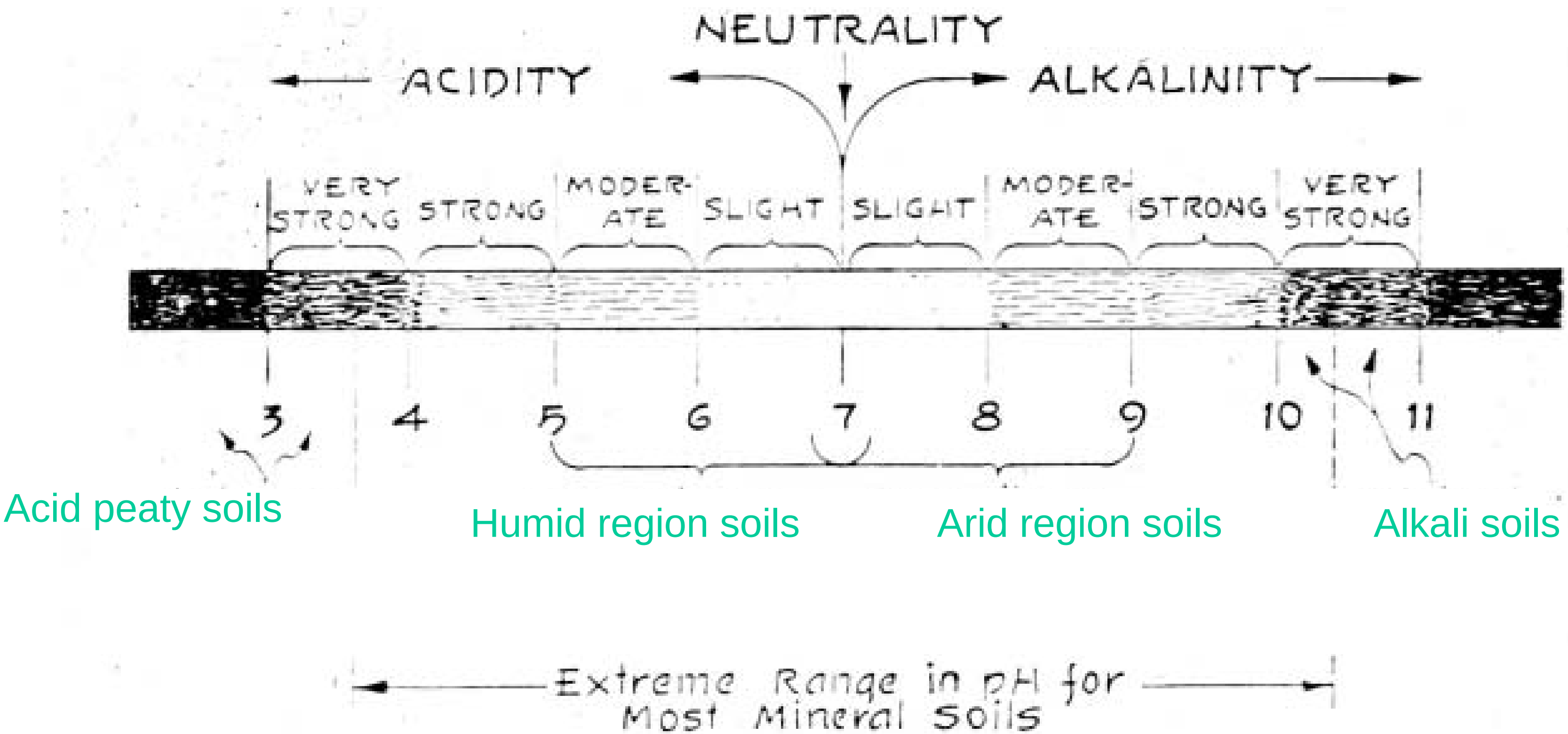
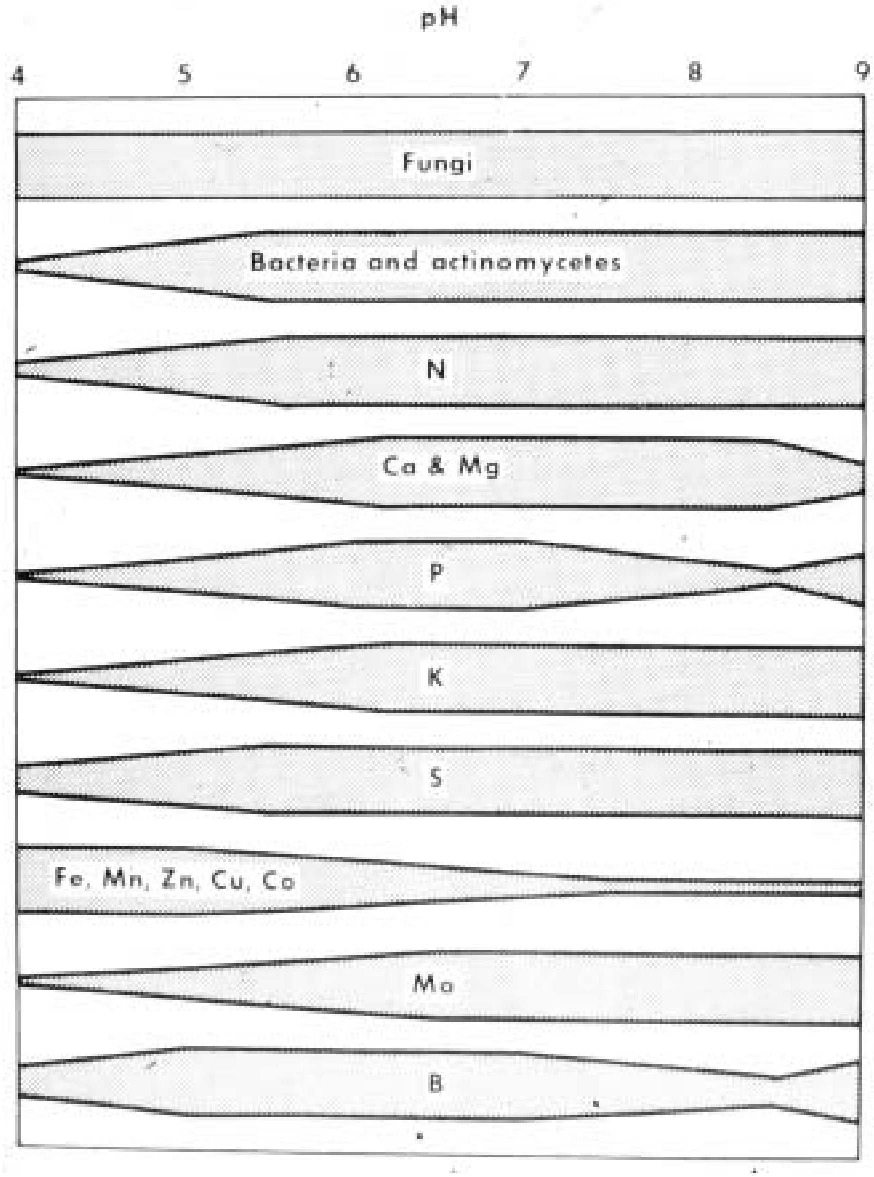
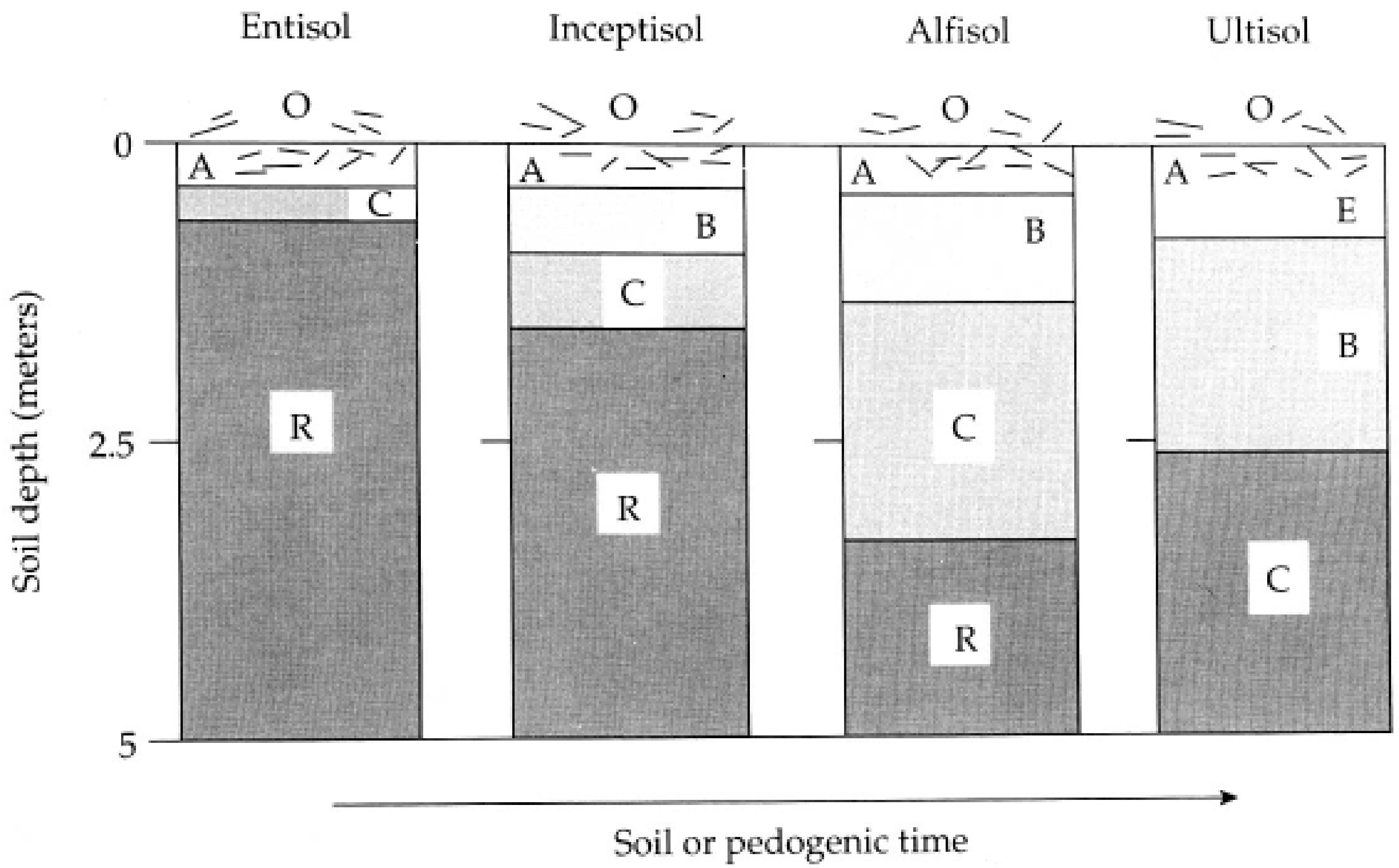


Figure 2:6. Diagram showing the extreme range in pH for most mineral soils and the range commonly found in humid-region and arid-region soils respectively. The maximum alkalinity for alkali soils is also indicated, as well as the minimum pH likely to be encountered in very acid peat soils.

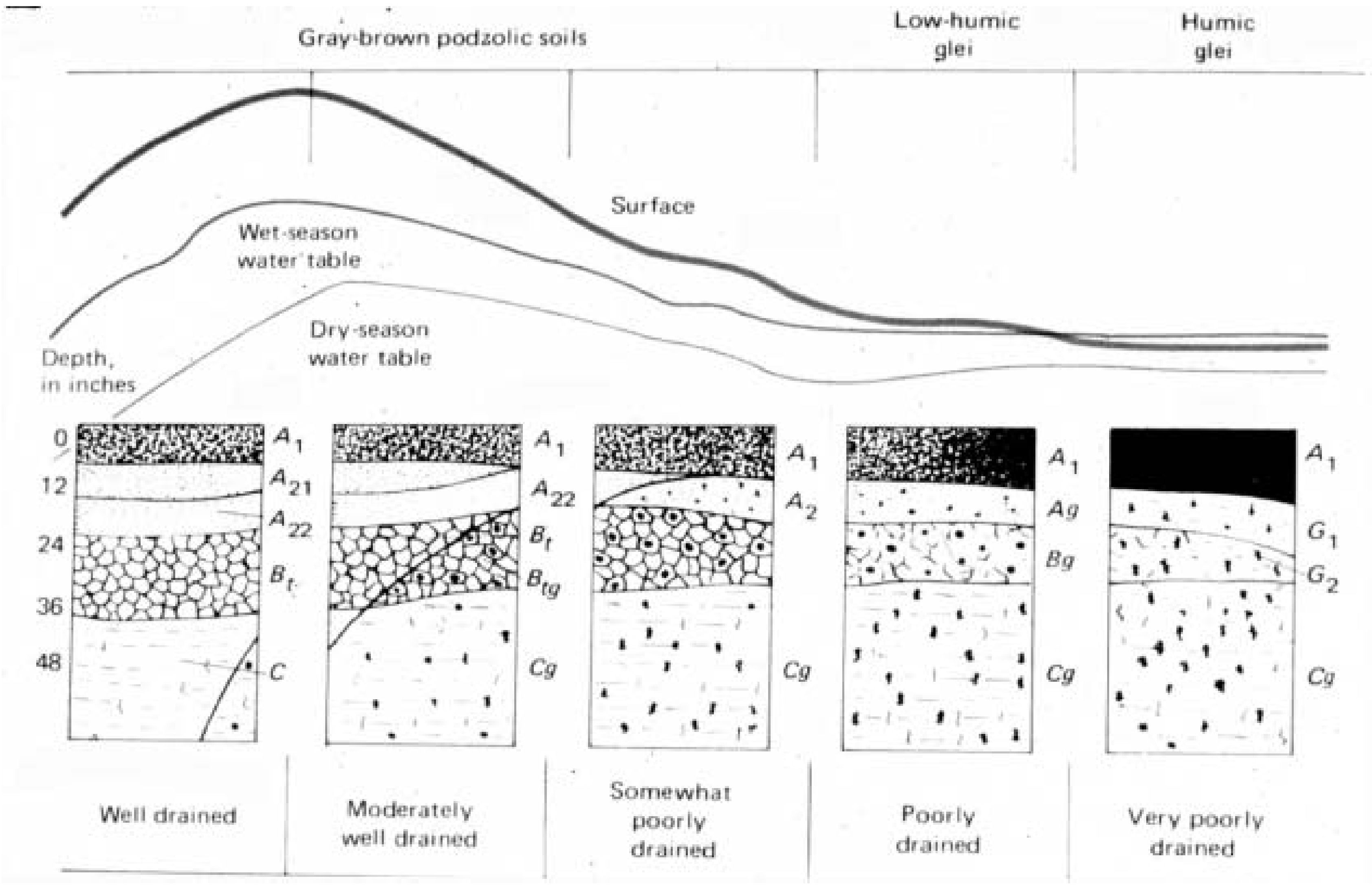
Relationship between pH and selected plant nutrients and the activity of soil fungi and bacteria



Soil genesis through time: Chronosequence



Toposequences



General trends in soil properties downslope

- Increasing
  - Depth of O horizon
  - Depth of the A horizon
  - Percent clay in the B horizons
  - Soil moisture
  - pH
  - Soil nutrients

Soil taxonomy

- The names of the soil units impart a great deal of information about the soil.
- The U.S. Soil Taxonomy is a highly systematic system that is now used in many parts of the world.
- It is similar to vegetation classification in that gradual changes from one type to another may be partitioned into discrete types despite the gradient.

Great soil groups in the U.S. soil taxonomy

Young soils

Entisols: “new soils with little horizon development (e.g., soils on floodplains, sand dunes, mountain tops).

Inceptisols: shallow moderately developed soils on new, very cold, or very wet substrates (e.g., many tundra soils).

Histosols: organic soils, peats.

Grassland soils

Mollisols: prairie soils and soils with dark surface horizons, high in organic mattter and high base saturation.

Deciduous forest soils

Spodosols: highly leached soils with a distinct bleached (E) horizon (e.g., podzols of northern humid forests).

Alfisols: well developed, soils common in many midwestern deciduous forest.

Desert and Tropical Soils

Vertisols: soils high in clay and salts that crack deeply when dried (many desert soils)

Aridisols: red desert soils, highly oxidized.

Ultisols: intensely leached soils of warm climates, with strong clay translocation, and low base content (e.g., some laterites, red-yellow podzols).

Oxisols: high weathered soils of the tropics with high oxides.

Formative elements of the names of soil orders

Table 17-7 Formative elements in the names of soil orders. Modified from *National Soil Survey Handbook 1997*, http://www.statlab.iastate.edu/soils/nssh/. Courtesy of the U.S. Department of Agriculture, Natural Resource Conservation Service.

Name of order	Formative element in name of order	Derivation of formative element	Pronunciation of formative element	Typical vegetation on soils of order
Alfisol	Alf	Al and Fe, symbols for aluminum and iron	Ped*alfer*	Deciduous forest
Andisol	And	J. *ando*, "dark"[a]	*And*esite	Many types
Aridosol	Id	L. *aridus*, "dry"	Ar*id*	Desert scrub
Entisol	Ent	Meaningless syllable	Rec*ent*	Many types
Gelisol[b]	El	L. *gelid*, "cold"	G*el*atine	Tundra
Histosol	Ist	Gr. *histos*, "tissue"	*Hist*ology	Marsh
Inceptisol	Ept	L. *inceptum*, "beginning"	Inc*ep*tion	Cool grassland
Mollisol	Oll	L. *mollis*, "soft"	*Moll*ify	Grasslands
Oxisol	Ox	F. *oxide*, "oxide"	*Ox*ide	Tropical rain forest
Spodosol	Od	Gr. *spodos*, "wood ash"	*Od*d	Coniferous forest
Ultisol	Ult	L. *ultimus*, "last"	*Ult*imate	Forest
Vertisol	Ert	L. *verto*, "turn"	In*vert*	Many types

[a]J. meaning Japanese

[b]Gelisols, a new order (soils with permafrost), added in 1998.

Common soil physical properties analyzed in the laboratory

- **Soil moisture**
- **Soil particle size - texture**
- **Bulk density**
- **Color**
- % organic matter
- Soil water retention properties
  - Field capacity - 1/3 atm
  - Wilting point - 15 atm
  - Hygroscopic water - 30 atm
  - Available water = field capacity - wilting point

Common soil chemical properties analyzed in the laboratory

- **pH**
- Cation exchange capacity - total amount of cations (including H^+) that can be displaced
- Base saturation - the percent of the cation exchange complex occupied by exchangeable bases (mostly plant nutrients such as Ca, Mg, Na, K, etc.)
- Nutrients - amounts of macronutrients and micronutrients