Introduction to Soils and Pedology

- Coined in mid 19th Century by French scientist
- Derived from Greek: pedon=ground, logia = discourse
- "The study, in situ, of the biogeochemical processes that form and distribute soils"
- An observational, vs. an experimental, science - *nature is the laboratory*
- Origins attributed to two centers: Russia (Dokuchaev) and Berkeley (Hilgard)

Definition of Soils

- Many definitions
- Soil is part of a continuum of materials at earth' surface
  - Soil vs. non-soil at bottom and top
  - Different soils laterally
- Need to divide continuum into systems, or discrete segments, for study
- Hans Jenny (1930's) conceptualized soils as physical systems amenable and susceptible to physical variables (STATE FACTORS)

Ecological functions of soil

- Supports plant growth
- Recycles nutrients and waste
- Controls the flow and purity of water
- Provides habitat for soil organisms
- Functions as a building material/base

Role of Pedology in Scientific and Societal Problems

- **Carbon and nitrogen cycles**
  - Are soils part of an unidentified sink for CO_2?
  - What is the effect of agricultural on soil C (and atm CO_2)?
  - Will soils store excess N from human activity?
- **Chemistry of natural waters**
  - How do soils release elements with time and space?
- **Earth history**
  - 'Paleosols' and evolution of land plants, atmospheric CO_2 records, human evolution
  - Soils and archaeology
- **Biodiversity**
  - Is soil diversity analogous to, and complementary to, biodiversity
  - Microorganisms in soil represent unknown biodiversity resources

Soils as a Physical System

- System is open to surroundings (exchange energy and matter)

System Properties = f (initial state, external surrounding, time)

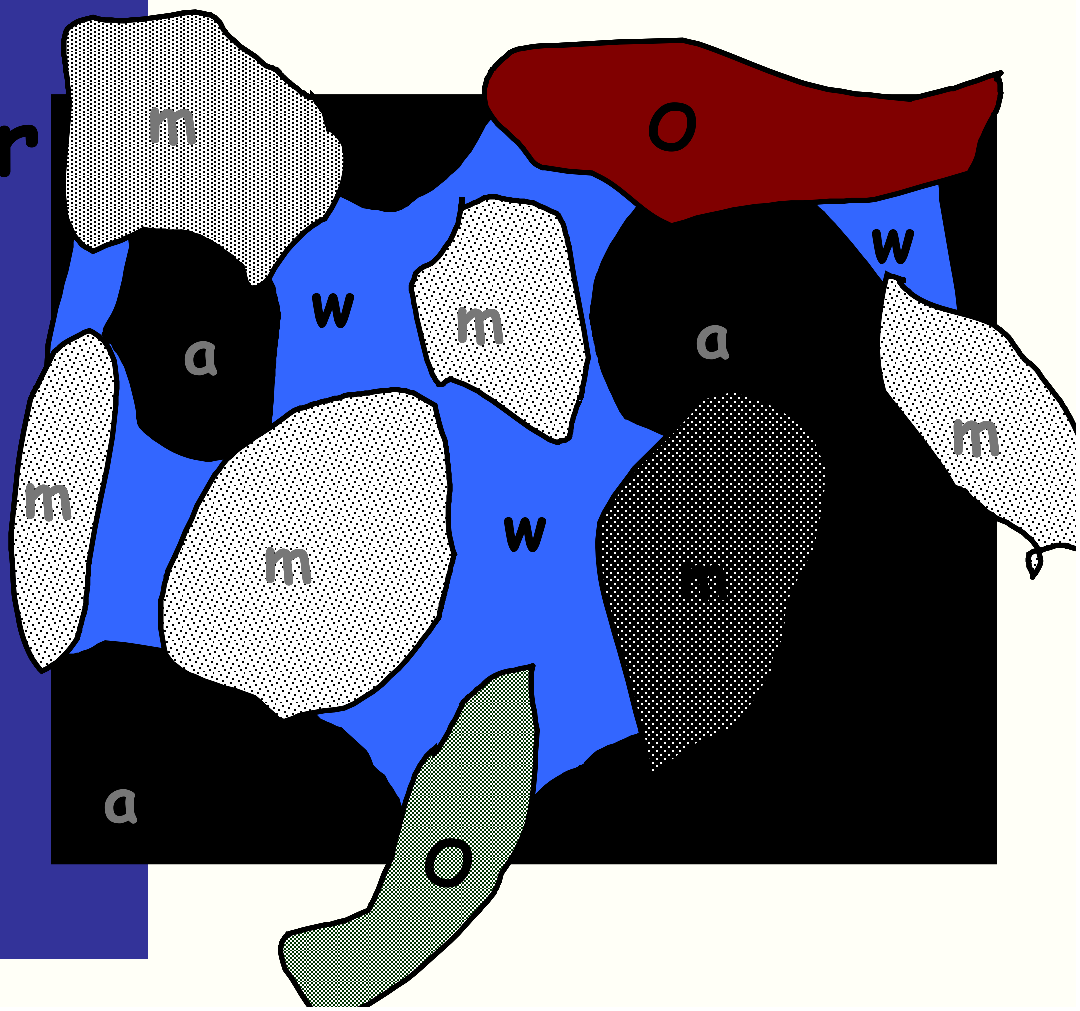
- "*Soil is those portion's of the earth's crust whose properties vary with soil forming factors*"

What Determines Soil Type

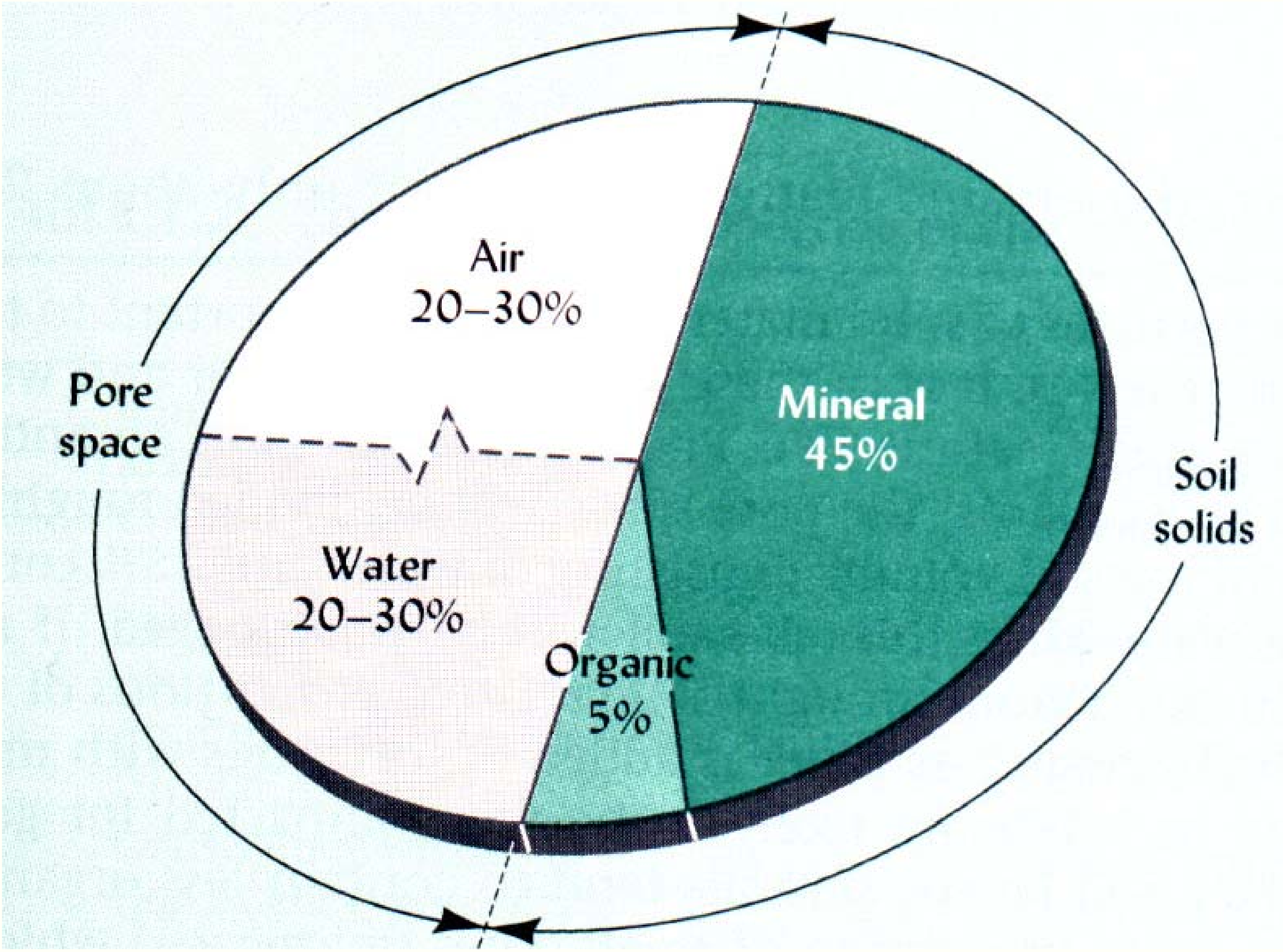
- Climate
- Vegetation
- Topography
- Time
- Parent Material
- Human Activities

Soil Composition

- Minerals
- Organic matter
- Water
- Air

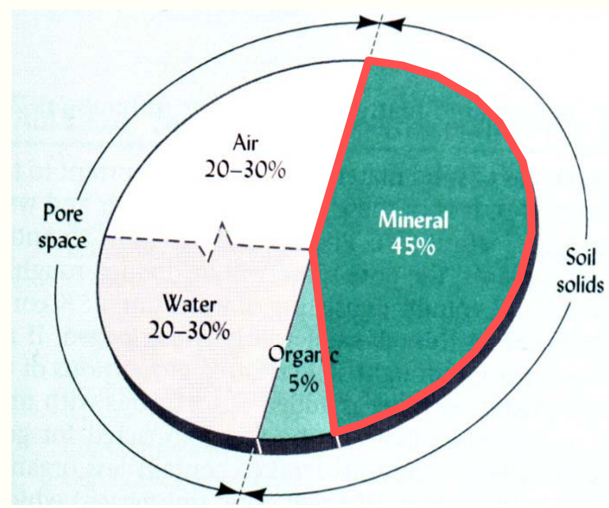


The four components of soil:



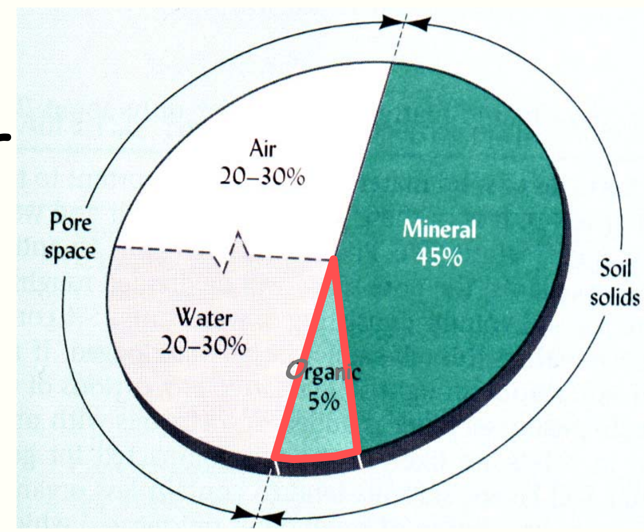
Mineral component

- Makes up less than 50% of a "soil"
- Varies in chemical composition
- Contains particles of several size ranges (small to really really small)
- Depends on the underlying geology/bedrock



Organic matter

- Small constituent by weight, but huge influence on soil properties
- Made up of partially decomposed plant & animal residues + organic compounds synthesized by soil microbes
- A TRANSITORY component of soils



Functions of Organic Matter

1. Stabilizes soil structure, making soil easily managed

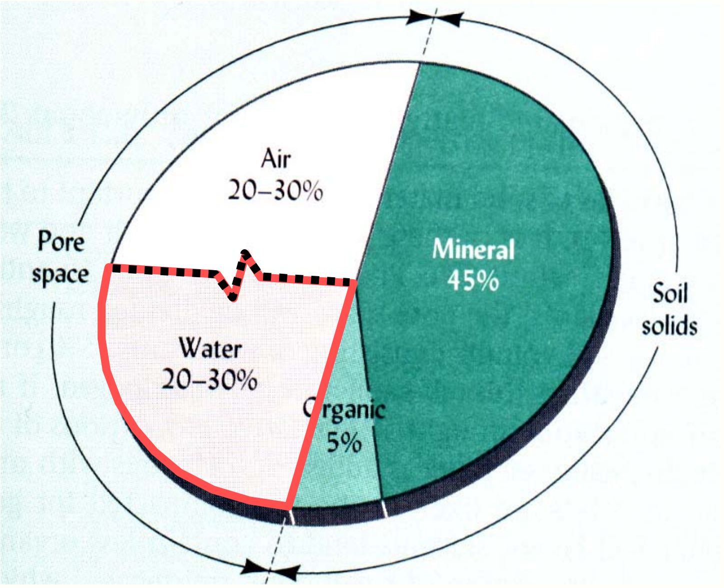
2. Increases the amount of water a soil can hold (and availability of the water)

3. Major source of plant nutrients

4. Main food/energy for soil organisms

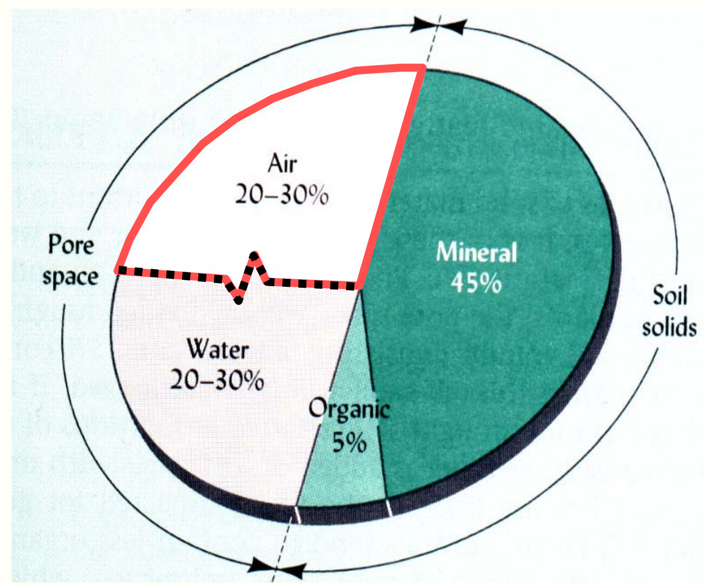
Soil Water

1. Held to varying degrees depending on amount of water and pore size
2. Not all soil water is available to plants



Soil Air

1. High spatial variability
2. High temporal variability
3. High moisture content (Rh ≈100%)
4. High CO_2 content
5. Low O_2 content



Conditioning Variables

- Jenny (1941, 1980) "Factors of Soil Formation" $S=f_{(cl,o,r,p,t\ldots)}$
- Climate
- Vegetation
- Relief
- Time
- Parent Material

Soil Starts with Weathering

Chemical Alteration

- Solution & Leaching
- Biological Action
- Hydration

Mechanical

- Impact
- Wedging: Frost, Plant Roots, Salt Crystal Growth, Expansion of Hydrated Minerals

Transfers

Leaching from Surface

- K, Mg, Na
- Ca
- Si
- Al, Fe

Accumulation beneath Surface

- Al, Fe in Humid Climates
- Ca in Arid Climates

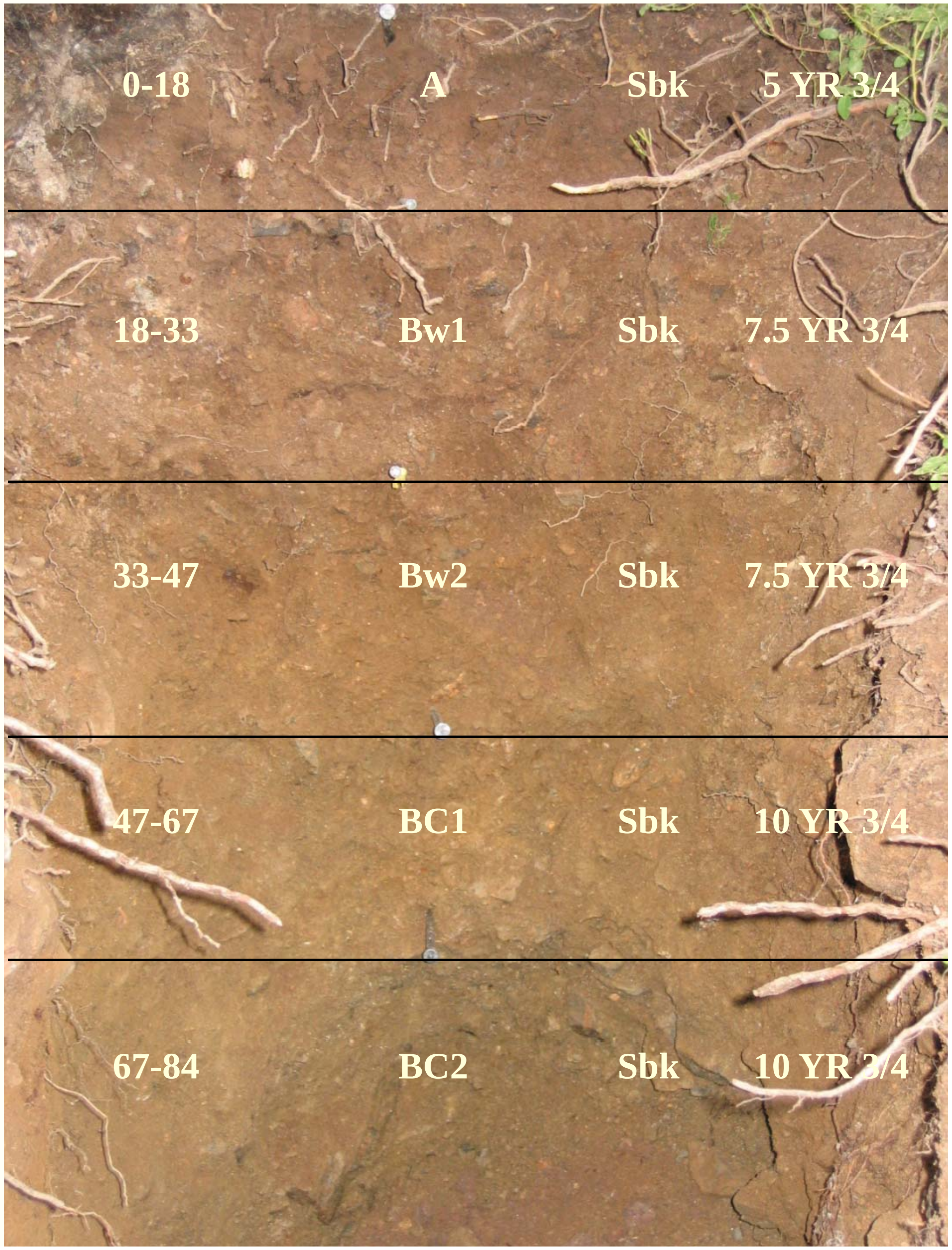
Characterization of Soils

- Morphological
- Physical
- Chemical
- Hydrological

Soil Morphology

- Major terms and concepts:
  - **Soil profile:** *2d vertical exposure of soil vs. depth* ***(pedon is 3D)***
  - **Soil horizons:** *roughly horizontal bands of soil that form from soil forming processes*

Field Pedon Description



Field Pedon Description

Depth (cm)	Horizon	Color (Moist)	Texture	Clay (%)	Gravel (%)	Structure	Effervescence	pH
6-4	Oi							
4-0	Oe							
0-18	A	5 YR 3/4	sl	13	>50	2 m sbk	eo	5.1
18-33	Bw1	7.5 YR 3/4	sl	12	>50	2 c sbk	eo	5.1
33-47	Bw2	7.5 YR 3/4	sl	8	>50	2 m gr	eo	5.4
47-67	BC1	10 YR 3/4	sl	8	>50	2 f-m sbk	eo	5.4
67-84	BC2	10 YR 3/4	sl	6	>50	2 f sbk	eo	5.5

Morphological Properties of Soils

- Major terms and concepts:
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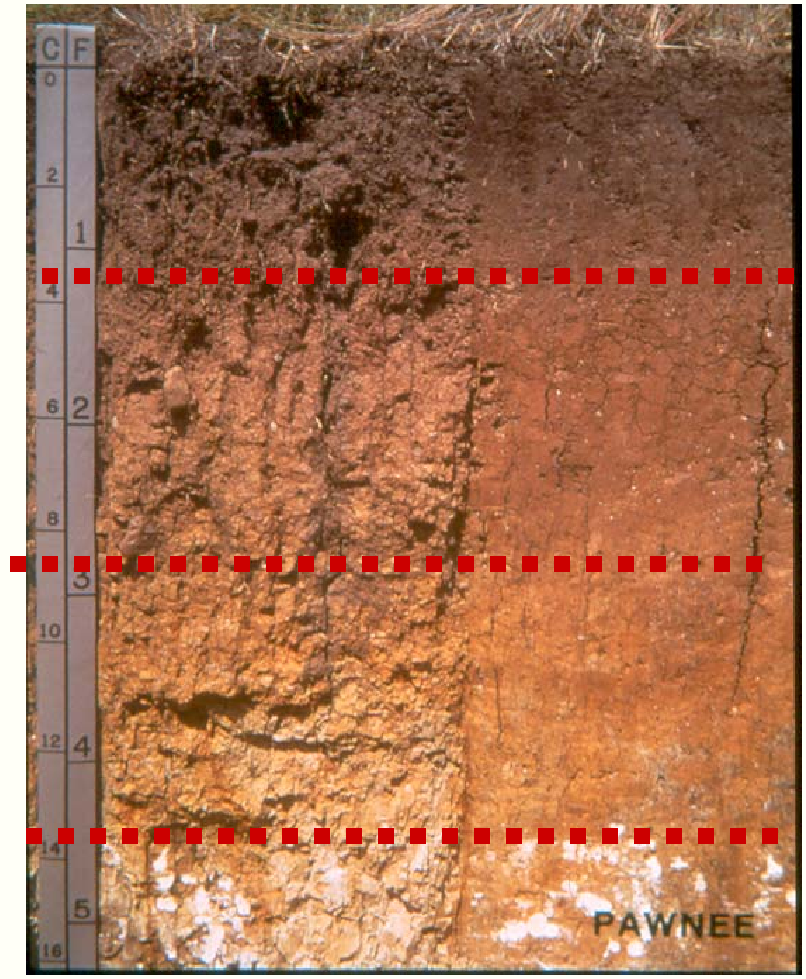
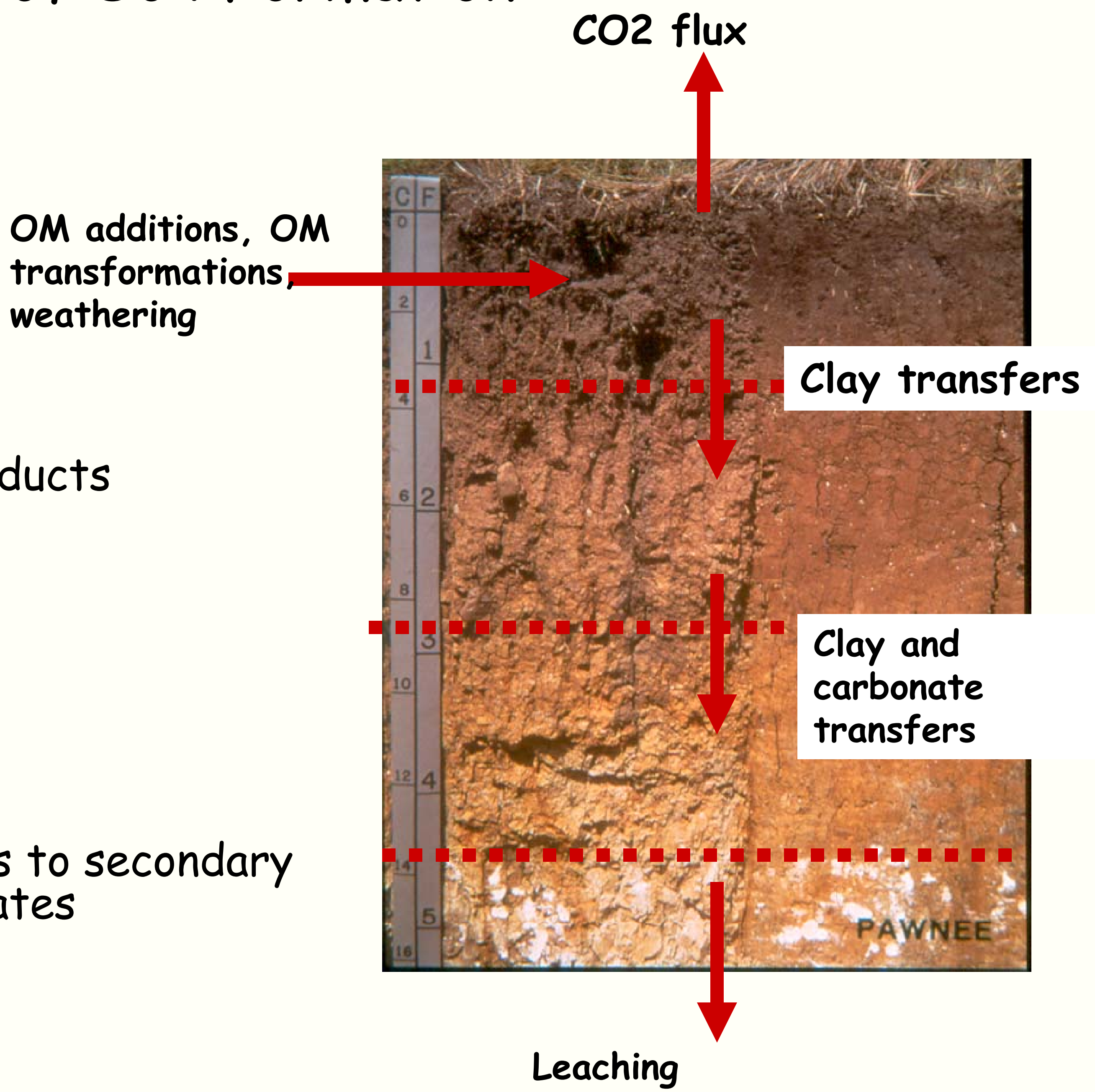


Key Processes of Soil Formation

- Additions
  - –Organic C
  - –Dust
- Removals
  - –CO2
  - –Weathering products
- Transfers
  - –Clay
  - –Organic matter
  - –Carbonate
- Transformations
  - –Plants to SOM
  - –Primary silicates to secondary silicates, carbonates

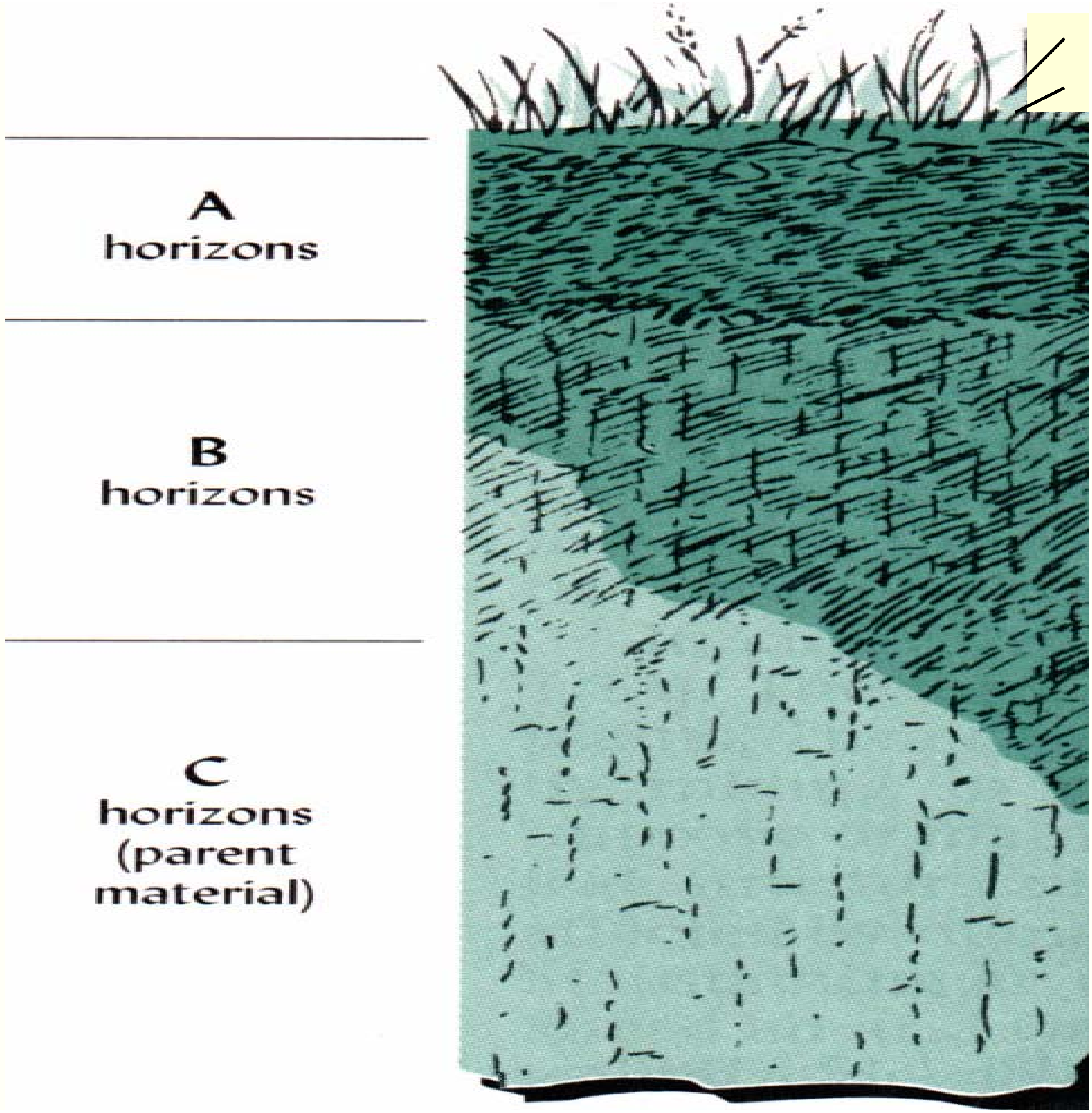


Soil Horizon Nomenclature

- Based on interpretation of dominant soil forming processes affecting that horizons
  - Names based on presumed changes relative to parent material (t=0)
- Universal with some variance
- Originated by Russians in 19th Century

The "Master" horizons

- O surface horizon made of Organic matter
- A surface horizon, mineral soil high in organic matter
- E subsurf. horizon light in color due to leaching, site of Eluviation processes
- B subsurf horizon, site of illuviation processes
- C least weathered (and deepest) of all the soil horizons
- R bedrock


A
horizons
B
horizons
C
horizons
(parent
material)

Subscripts: Processes occurring in these Horizons

O horizon

- Oi identifiable (recognizable) material
- Oe Intermediate (even balance?)
- Oa highly decomposed (almost all gone)

A horizon

- Ap plowed surface
- Ab buried surface

More Subscripts

B horizons

- t clay accumulations (terra cotta)
- g "gleying" (very wet climates)
- k karbonates (dry zones– really spelled with a "c")
- s sesquioxide accumulations (think iron, aluminum, red/yellow)

- h humus (high organic content)
- w "weak" development, distinctive colorations
- o residual oxides – red color, "tropical soils"
- ss "slickensides" of clay

Rules for naming

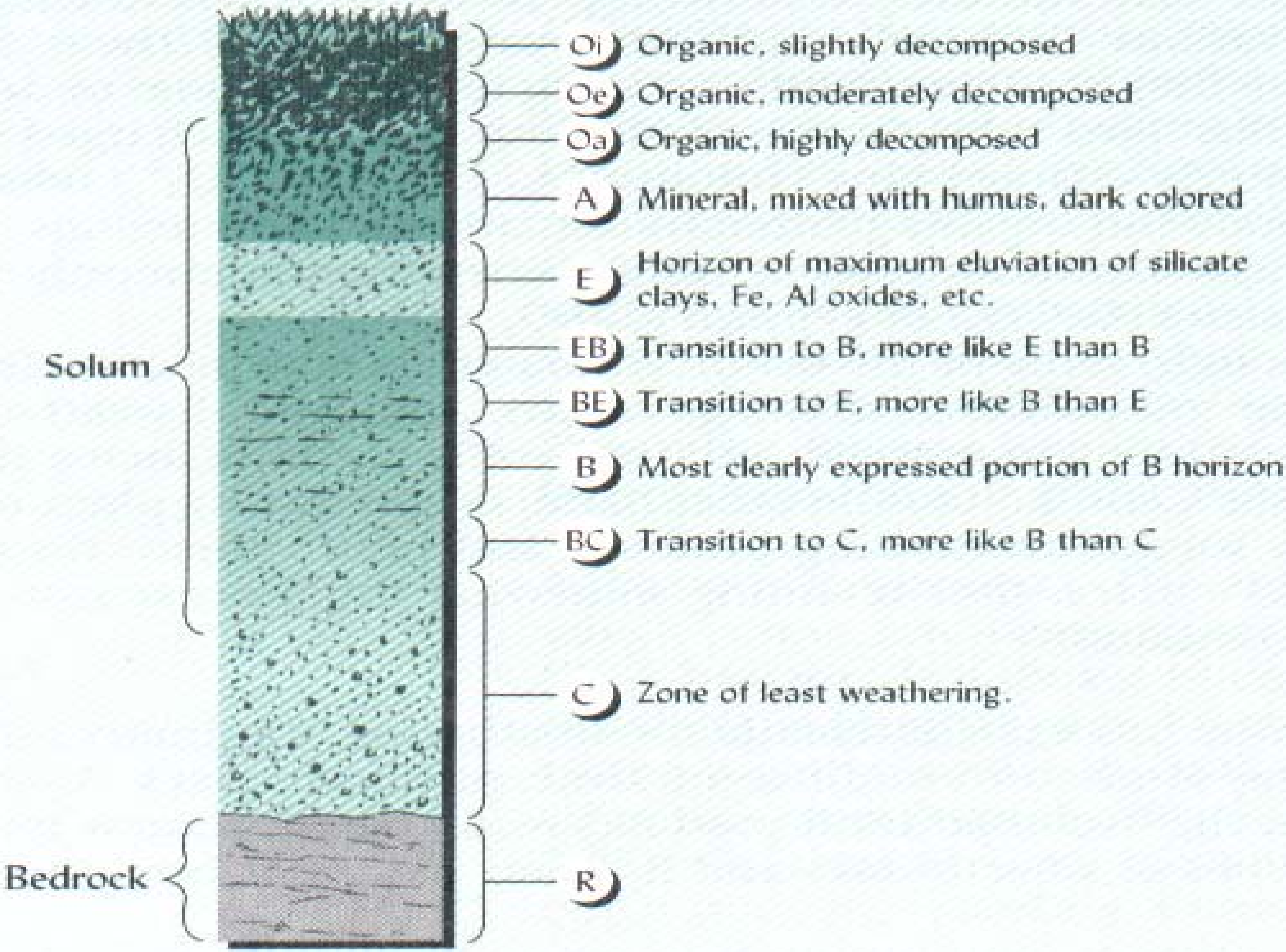
- C horizon
  - r (highly weathered rock) “saprolite”
  - k (carbonates)

- Subscript Rules
  - rarely use more than three
  - t (almost) always first

  Examples:

  Btg, Cr, Bw, Ap, . . .

Transition horizons and subdivisions within master horizons



Master Horizon Subdivisions

Lower Case Modifiers of Master Horizons	*Definitions (relative to soil parent material)*
a	Highly decomposed organic matter (O horizon).
b	Buried soil horizon
c	Concretions or nodules of rion, aluminum, manganese or titanium.
d	Non-cemented, root restricting natural or human made (plow layers, etc.) root restrictive layers.
e	Intermediate decomposition of organic matter (O horizon).
f	Indication of presence of permafrost
g	Strong gleying present in form of reduction or loss of Fe and resulting color changes.
h	Accumulation of illuvial complexes of organic matter which coat sand and silt particles.
i	Slightly decomposed organic matter (O horizon).
j	Presence of jarosite (iron sulfate mineral) due to oxidation of pyrite in previously reduced soils.
k	Accumulation of calcium carbonate due to pedogenic processes.
m	Nearly continously cemented horizons (by various pedogenic minerals)
n	Accumulation of exchangeable sodium
o	Residual accumulation of oxides due to long-term chemical weathering.
p	Horizon altered by human related activities
q	Accumulation of silica (as opal)
r	Partially weathered bedrock
s	Illuvial accumulation of sesquioxides
ss	Presence of features (called slickensides) caused by expansion and contraction of high clay soils
t	Accumulation of silicate clay by weathering and/or illuviation
v	Presence of plinthite (iron rich, reddish soil material)
w	Indicates initial development of oxidized (or other) colors and/or soil structure
x	Indicates horizon of high firmness and brittleness
y	Accumulation of gypsum
z	Accumulation of salts more soluble than gypsum (e.g. Na_2CO_3, etc.)

Soil Profile Description Data Forms

FIELD SHEET FOR RECORDING SOIL CHARACTERISTICS

No. 56 CA-10-

Soil Type Auberry coarse sandy loam

Location ½ mi W New Auberry on N Fork Rd. (NW¼, NE¼ Sec 6, 10 S, 23 E: MDB+M

Geographical Landscape rolling upland

Elevation 2150 ft. Slope 9% Aspect NE Erosion none

Groundwater deep Drainage Well Alkali none

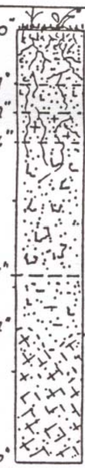
Mode of Formation primary (residual) Parent Material Tonalite (Qtz Diorite)

Climate Subhumid mesothermal MAP = 25"; MAT = 59°F

Natural Cover ann. grasses, forbs, blue oak, shrubs Soil Region VIII

Profile Group VII Higher Categories fi-lo, mix, therm. Ultic Haplox...

Genetically Related Soil Series Ahwahnee, Sierra



PROFILE SKETCH		COLOR	TEXTURE	STRUCTURE	CONSISTENCE	REACTION	MISC: Roots, Pores, Clay films, Concretions
0"	O	Lt gr br	Grass + forb litter;		loose-dry; matted-moist		thickness ~ ¼"
0"–7"	A	10YR 5/2 D 10YR 3/3 M	cosl	2f-mgr	sh fr so po	6.2	3f (roots) 3ft (pores) cs
7"–12"	AB	10YR 6/3 D 10YR 4/2 M	cosl	1m-fsbk	h fr so po	6.0	1f-m (roots cs
12"–16"	BAt	10YR 5/3 D 10YR 4/3 M	sl+	1m sbk	h fr so po	6.0	1f-m (roots) 1ft (pores) 1n po, br cs
16"–35"	Bt	10YR 5/3 D 10YR 4/4 M	scl−	2c-vc abk	vh fi ss p	5.3	1f-m (roots 1ft (pores) 2mk pf as
35"–42"	BC	10YR 6/3 D 10YR 5/4 M	cosl	1m-fsbk	sh fr ss p	5.6	highly micaceous 1n pf aw
42"–60"	Cr	V. pa. br., peppered w/ dk gr - dry Varied ye. br + dk. gr. - moist	Granitic rock-grus → (crushes) to lcos	(rock structure) or fabric"	—	6.6	strongly weathered tonalite (qtz. diorite); easily excavated

Natural Land Division E3

Soil Rating (Storie index) 67 X 80 X 90 X 95 = 46 Soil Grade 3

Land Use Capability Unit IVe-1 (18)

Present Use rangeland

Suitability: Irrigated Crops fair (pasture) Range fair (winter-spring)

Nonirrigated Crops fair (hay, barley) Timber not suited

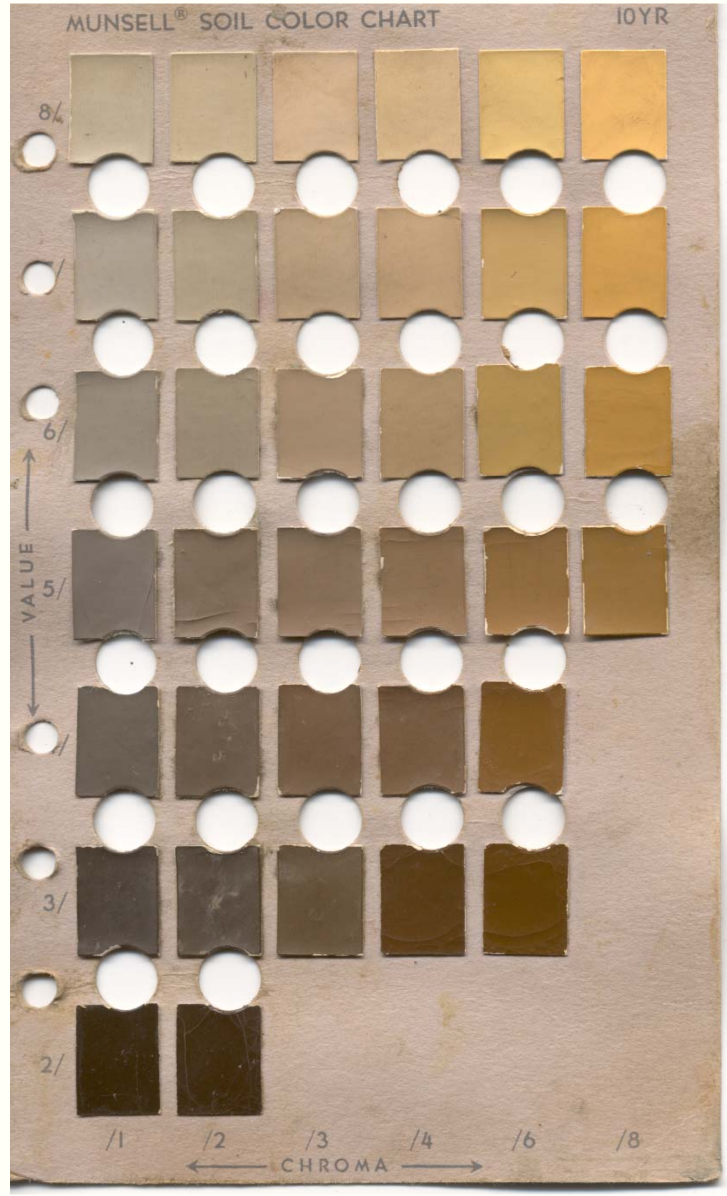
Soil Management Forage responds to N and P. Legumes respond to S

Remarks Erosion hazard moderate – avoid overgrazing

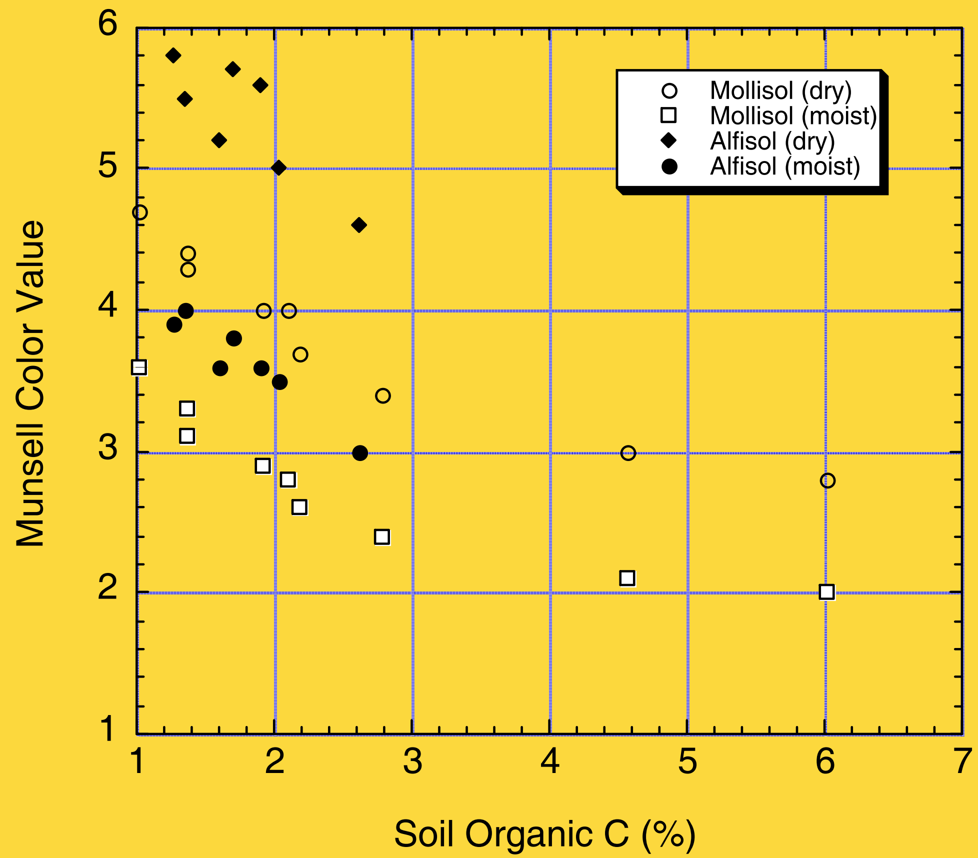
Form SoNDA 68 Rev. S&PS · ttd

Soil Color

- Hue: *Dominant spectral color*
  - Reflects pm/age/climate
  - Unoxidized silicate rocks are yellowish, soil formation forms FeO that is red
- Value*: Relative lightness or darkness*
  - Reflects OM content
- Chroma: *Brightness (oxidation)*
  - Reflects age/degree of Fe oxidation



Soil Value Related to Organic Carbon Content



Soil Structure

- Aggregation of mineral grains and OM into multi-particle structures
  - Soil structure exists at scales from micron to cm scale
  - We are concerned about field-scale observable strucuture (macro)

- Key controls on 'macro' structure
  - Clay content (clay shrinking and swelling align soil particles into plates (very near surface), blocks (common near surface) or prisms (deeper in soil)
  - Organic matter (polysaccrides) important for near surface particle aggregation (granular)
  - Clay + Na^+ very important for formation of columnar structure.

Types of Soil Structure

Commonly A horizons

Commonly B horizons

COMMON TYPES OF SOIL STRUCTURE

The term "structure" is used when considering the arrangement of soil particles into various sizes and shapes. This transparency illustrates the principal kinds of structures found in Illinois soils.

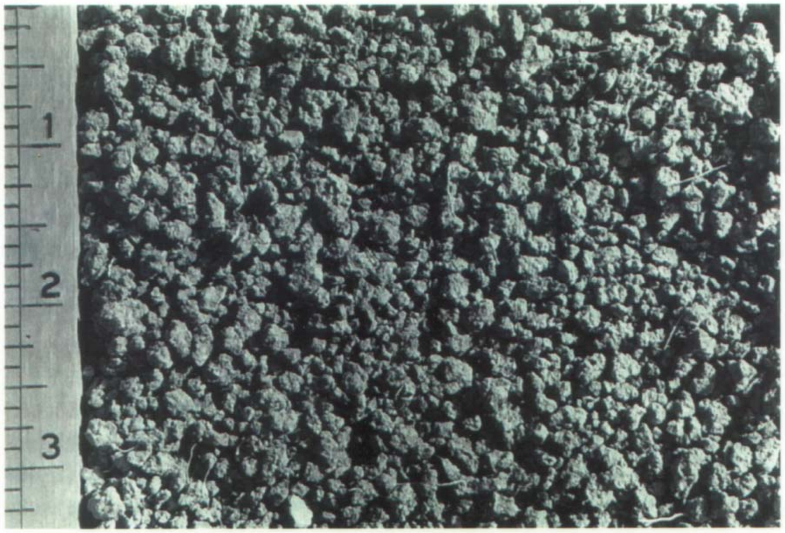
Kind of structure	Description of aggregates (clusters)		Horizon
Crumb	Aggregates are small, porous, and weakly held together	Nearly spherical, with many irregular surfaces	Usually found in surface soil or A horizon
Granular	Aggregates are small, non-porous, and are strongly held together		
Platy	Aggregates are flat or plate-like, with horizontal dimensions greater than the vertical. Plates overlap, usually causing slow permeability		Usually found in subsurface or A2 horizon of timber and claypan soil
Angular blocky or cube-like	Aggregates have sides at nearly right angles, tend to overlap	Nearly block-like, with 6 or more sides. All 3 dimensions about the same	Usually found in subsoil or B horizon
Subangular blocky or nut-like	Aggregates have sides forming obtuse angles, corners are rounded. Usually more permeable than blocky type		
Prismatic	Without rounded caps	Prism-like with the vertical axis greater than the horizontal	
Columnar	With rounded caps		
Structure lacking Single grain	Soil particles exist as individuals such as sand and do not form aggregates		Usually found in substratum or C horizon
Massive	Soil material clings together in large uniform masses, as in loess		

E or A horizon of desert soils

Structure near surface

‘Clods” : lack of soil structure

Granular Structure: OM interaction with mineral grains



Subsurface Structure

- Platey Structue: near surface due to shrinking/swelling or compaction

- Prismatic Structure: subsurface in moderate clay content with seasonal water

Subsurface Structure

Columnar: combination of clay and Na^+

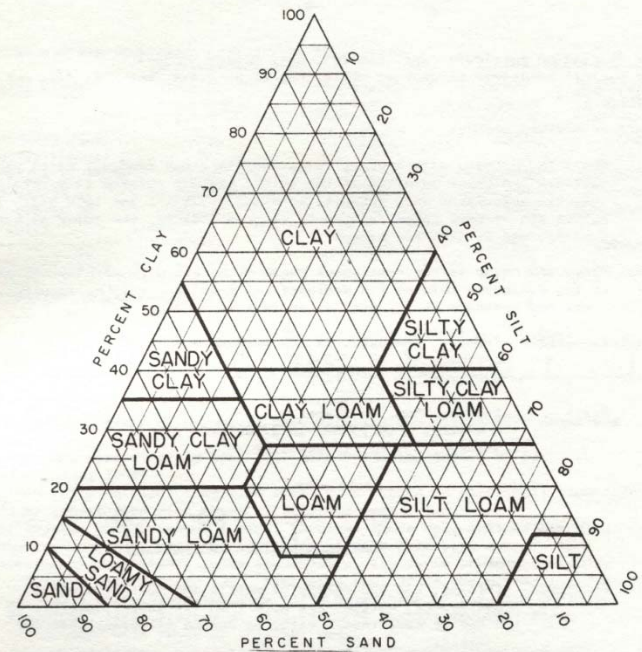
Soil Texture

- Relative proportion of sand, silt, and clay
  - Sand: 0.05 to 2 mm
  - Silt: 0.002 to 0.05 mm
  - Clay: < 0.002 mm (2 microns)

- Particle distribution determined by sedimentation

- Textural classes (textural triangle) based on long-term practical experience
  - Reflects large influence of clay on soil characteristics
  - Clay (to be discussed later) has impact on water, physical processes, etc.

-7-



.SOIL TEXTURAL CLASSES

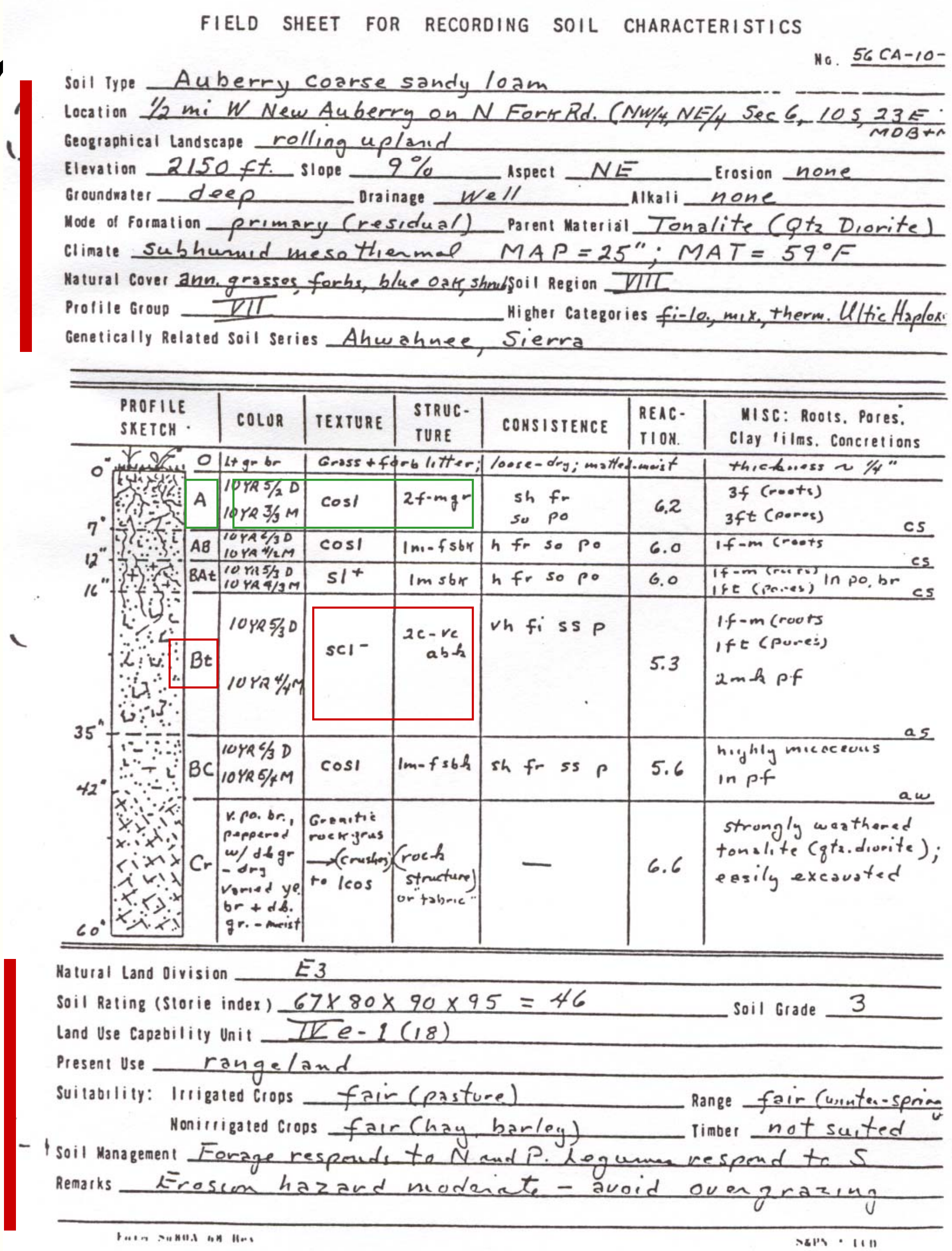
The following textural abbreviations and modifiers will be used:

st	-	stones and stony
cob	-	cobbles and cobbly
g	-	gravel and gravelly
vcos	-	very coarse sand
cos	-	coarse sand
s	-	sand
fs	-	fine sand
vfs	-	very fine sand
lcos	-	loamy coarse sand
ls	-	loamy sand
lfs	-	loamy fine sand
cosl	-	course sandy loam
sl	-	sandy loam
fsl	-	fine sandy loam
vfsl	-	very fine sandy loam
l	-	loam
si	-	silt
sil	-	silt loam
scl	-	sandy clay loam
cl	-	clay loam
sicl	-	silty clay loam
sc	-	sandy clay
sic	-	silty clay
c	-	clay

Review of Descr

Factors of Soil Formation:

Practical or mgt concerns



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Location: 1/2 mi W New Auberry on N Fork Rd. (NW1/4, NE1/4 Sec 6, 10S, 23E MDB+M
Geographical Landscape: rolling upland
Elevation: 2150 ft. Slope: 9% Aspect: NE Erosion: none
Groundwater: deep Drainage: well Alkali: none
Mode of Formation: primary (residual) Parent Material: Tonalite (Qtz Diorite)
Climate: subhumid mesothermal MAP = 25"; MAT = 59°F
Natural Cover: ann. grasses, forbs, blue oak, shrub Soil Region: VIII
Profile Group: VII Higher Categories: fi-lo, mix, therm. Ultic Haplox[illegible]
Genetically Related Soil Series: Ahwahnee, Sierra

Profile Sketch (depth)	Horizon	Color	Texture	Structure	Consistence	Reaction	Misc: Roots, Pores, Clay films, Concretions
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60"	Cr	v. po. br., peppered w/ dk gr - dry; varied ye br + dk. gr. - moist	Granitic rock-grus (crushes) to lcos	(rock structure or fabric)	—	6.6	strongly weathered tonalite (qtz. diorite); easily excavated

Natural Land Division: E3
Soil Rating (Storie index): 67 X 80 X 90 X 95 = 46 Soil Grade: 3
Land Use Capability Unit: IVe-1 (18)
Present Use: rangeland
Suitability: Irrigated Crops: fair (pasture) Range: fair (winter-spring)
Nonirrigated Crops: fair (hay, barley) Timber: not suited
Soil Management: Forage responds to N and P. Legumes respond to S
Remarks: Erosion hazard moderate - avoid overgrazing

Soil Physical Properties

- Soil Texture - provides general information regarding the amounts of sand, silt and clay
- Bulk Density - mass of dry soil per unit bulk volume, including the air space (pores)
- Depth to Bedrock - influences the depth to which roots may penetrate the soil

Physical properties (continued)

- Aggregate Stability - determines soil structure and is very important to hydrological properties and aeration.
- Soil Color - measured in terms of hue, value and chroma, reflects organic matter content and oxidizing or reducing soil conditions

Physical properties (continued)

- Aggregate Stability - determines soil structure and is very important to hydrological properties and aeration.
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Soil Chemical Properties

- Organic Matter Content - provides a generalized indication of the relative fertility status of the soil; promotes greater water retention, aeration, fertility
- Soil pH - an index of the relative acidity or alkalinity of the soil; often considered a master variable in determining the nutrient availability of a soils

Chemical Properties (Continued)

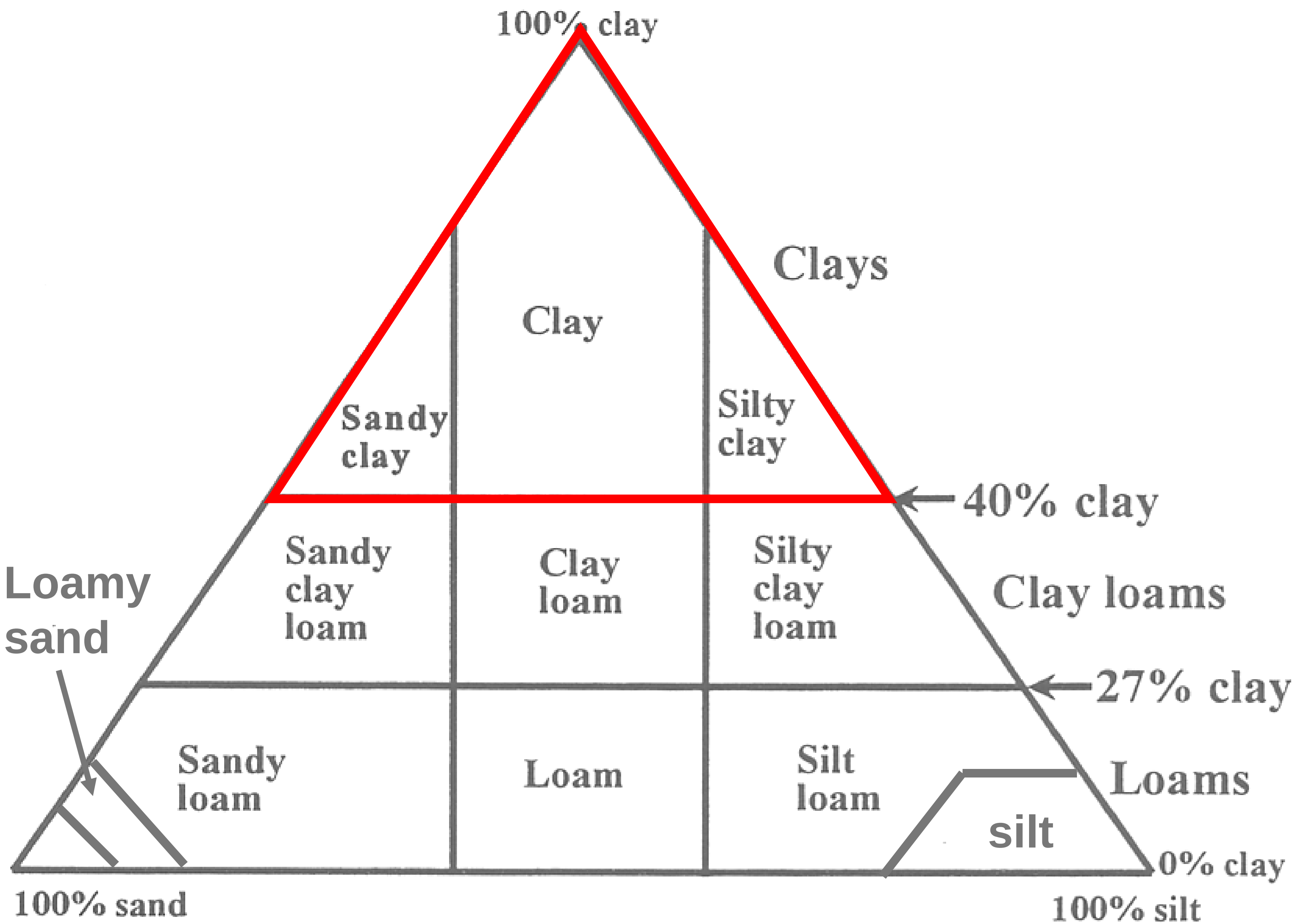
- Soil Salinity Range - an index of salt content; salts in large quantities may inhibit the plant's ability to extract water and nutrients from the soil
- Cation Exchange Capacity - relative measure of the soil's potential to retain added nutrients; soils with high CEC have a greater nutrient retention potential than soils with a low CEC

Soil Hydrological Properties

- Drainage - provides and estimate of the amount of water that remains in soil after wetting
- Plant available water content - an index that relates to the amount of soil water available for plant use immediately after wetting
- Soil infiltration rate - rate at which water enters the soil surface; is highly dependent on soil physical properties such as soil texture.

Hydrological Properties (Continued)

- Permeability - the ability of the soil to transmit water through and below the rooting zone
- Water table depth - provides a generalized estimate of the depth to standing water over a small geographic area


100% clay
Clays
Clay
Sandy clay
Silty clay
40% clay
Sandy clay loam
Clay loam
Silty clay loam
Clay loams
Loamy sand
27% clay
Sandy loam
Loam
Silt loam
Loams
silt
0% clay
100% sand
100% silt

Soil Colloids

- "Organic and inorganic matter with very small particle size and a correspondingly large surface area per unit mass" ("Soil bank")

- Four categories:
  - Crystalline silicate clays (phyllosilicates)
  - Noncrystalline silicate clays
  - Iron and aluminum oxide clays
  - Organic matter (humus)

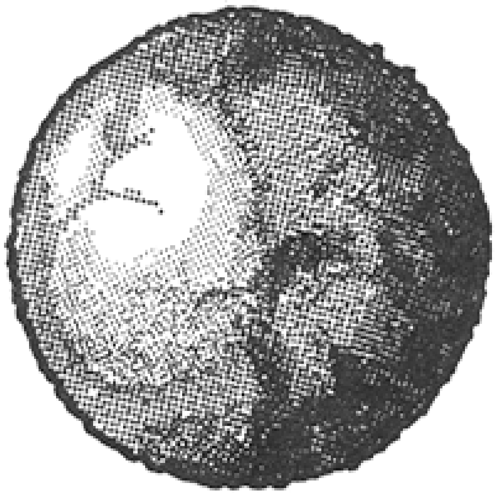
"Clay" is . . .

- A particle size class (<0.002 mm)

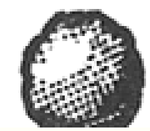
- A mineral type with specific properties and characteristics **(secondary mineral)**

Relative Size Comparison of Soil Particles

Sand
.05 to 2mm
feels gritty



Silt
.002 to .05 mm
feels smooth



Clay
less than .002 mm
feels sticky

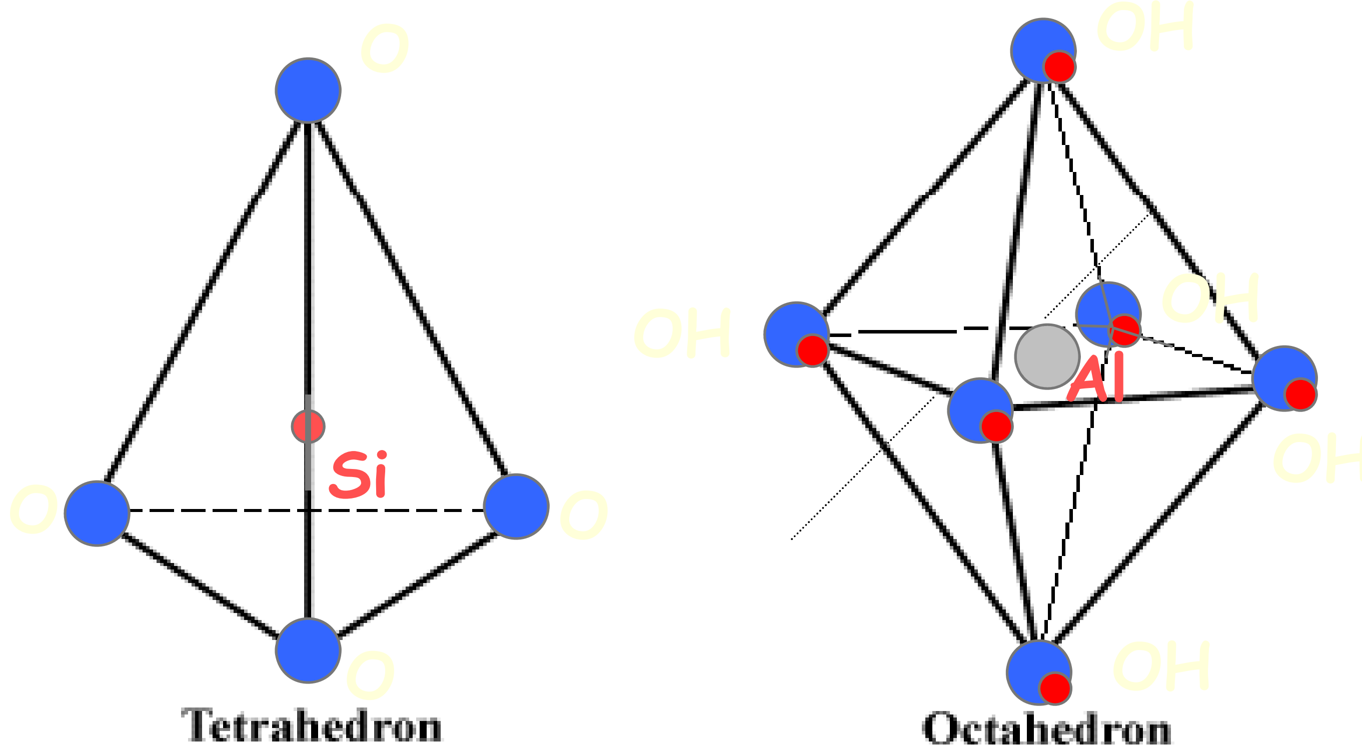
"Big" → smaller → really small

Sand → silt → clay

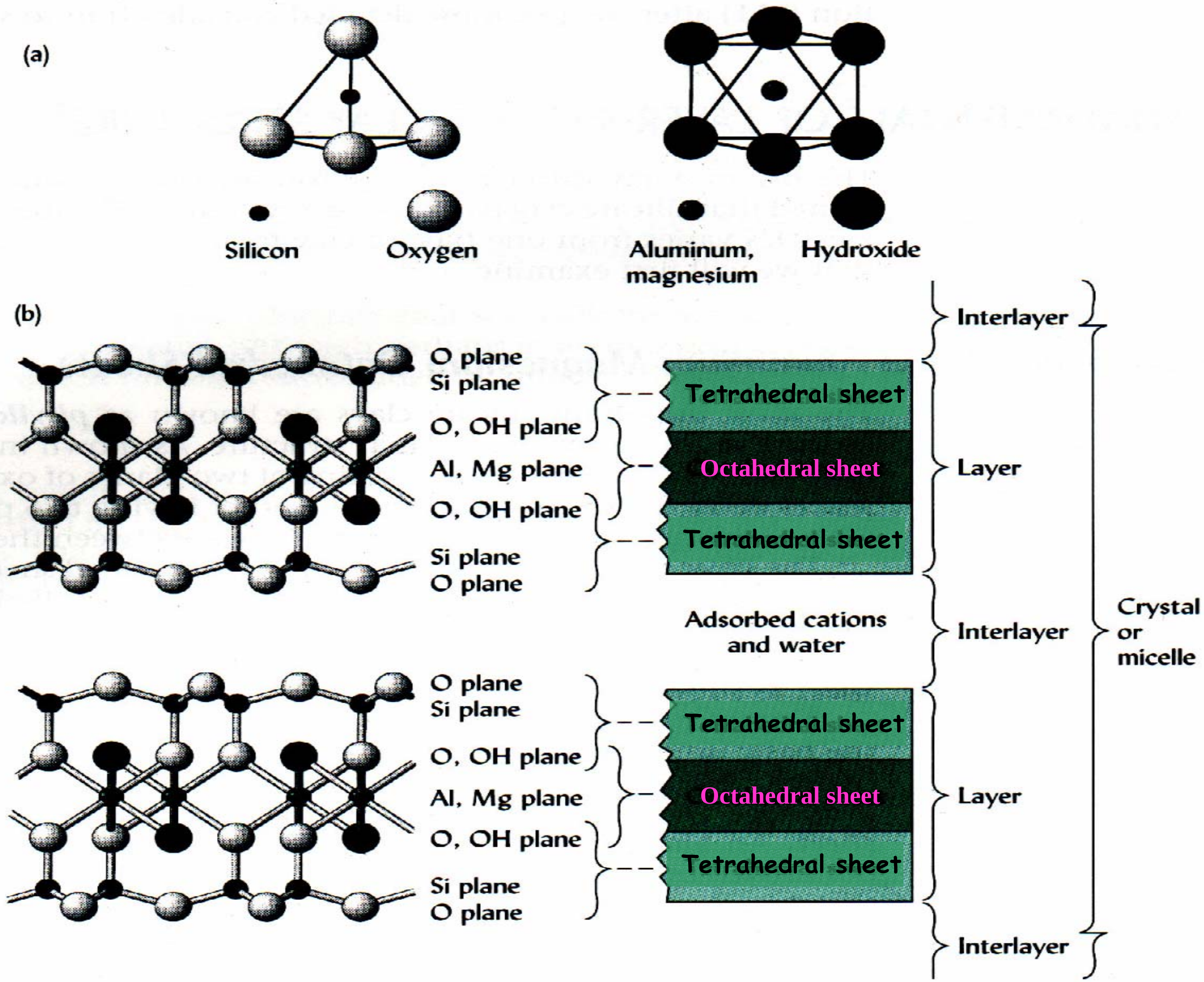
Fundamentals of clay mineralogy

- 2 basic building blocks: the silica (Si) tetrahedron and the aluminum (Al) octahedron
- These building blocks form sheets: "silicate layer clays"

Shape of silicon tetrahedron and aluminum octahedron



Source: Kohnke, 1968


(a)
Silicon
Oxygen
Aluminum, magnesium
Hydroxide
(b)
O plane
Si plane
O, OH plane
Al, Mg plane
O, OH plane
Si plane
O plane
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Adsorbed cations and water
O plane
Si plane
O, OH plane
Al, Mg plane
O, OH plane
Si plane
O plane
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Interlayer
Layer
Interlayer
Layer
Interlayer
Crystal or micelle

Isomorphous substitution

Equal shape/size (ionic radii)

- The replacement of one ion for another of similar size within the crystalline structure of the clay
- This changes the total charge and location of the charge on the mineral (greatly affecting the properties of the clay)

Isomorphic Substitution in **tetrahedral** sheet

$(+4) \times 2 = +8$

Si_2O_4

$(-2) \times 4 = -8$

neutral

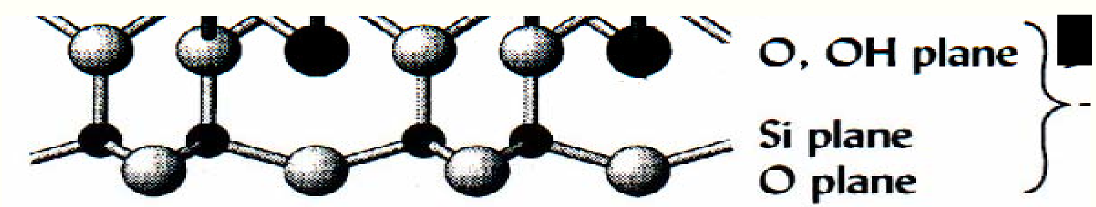
→

$(+4) + (+3) = +7$

$SiAlO_4$

-8

net negative charge



Tetrahedral sheet

Isomorphic Substitution in **octahedral** sheet

$(-1) \times 2 = -2$

$(-2) \times 2 = -4$

-6

$(OH)_2Al_2O_2$ → $(OH)_2AlMgO_2$

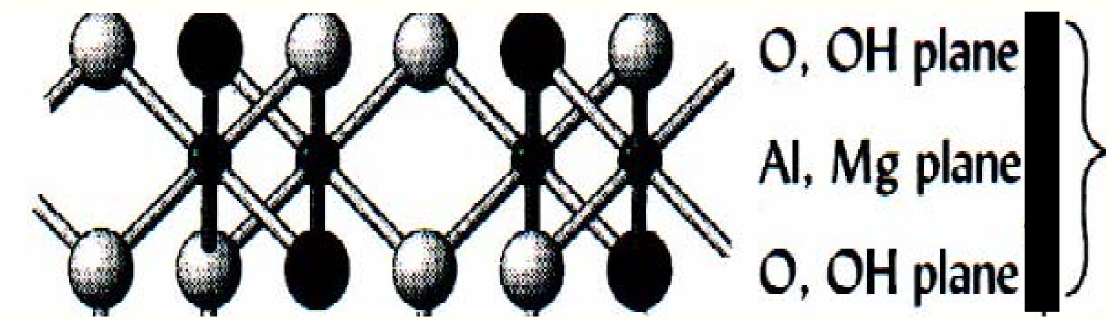
$(+3) \times 2 = +6$

neutral

$(-2) + (-4) = -6$

$(+3) + (+2) = +5$

net negative charge



Octahedral sheet

Ionic Radii of elements in silicate clays
– Tetrahedral & Octahedral sheets

Note that Al, Fe, O, and OH can fit in either.

Ion	*Radius, nm*[a]	*Found in*
Si^{4+}	0.042	
Al^{3+}	0.051	Tetrahedral sheet
Fe^{3+}	0.064	
Mg^{2+}	0.066	Octahedral sheet
Zn^{2+}	0.074	Exchange sites
Fe^{2+}	0.070	
Na^{+}	0.097	
Ca^{2+}	0.099	
K^{+}	0.133	
O^{2-}	0.140	Both sheets
OH^{-}	0.155	

[a] 1 nm = 10^{-9}m.

Types of clay minerals

- Based on **numbers and combinations of structural units** **(tetrahedral and octahedral sheets)**
- Number of **cations** in octahedral sheet
- Size and **location of layer charge** **(due to isomorphic substitution)**
- Absence or presence of **interlayer cations**
- Two general categories: **1:1, 2:1**

Clay minerals

1:1 clays
(one tetrahedral sheet for each octahedral sheet)

Kaolinite nacrite, dickite, halloysite, etc.

2:1 clays
(two tetrahedral sheets for each octahedral sheet)

[redacted]

Montmorillonite ,beidellite, saponite, etc.

[redacted]

Illite, muscovite , biotite, etc.

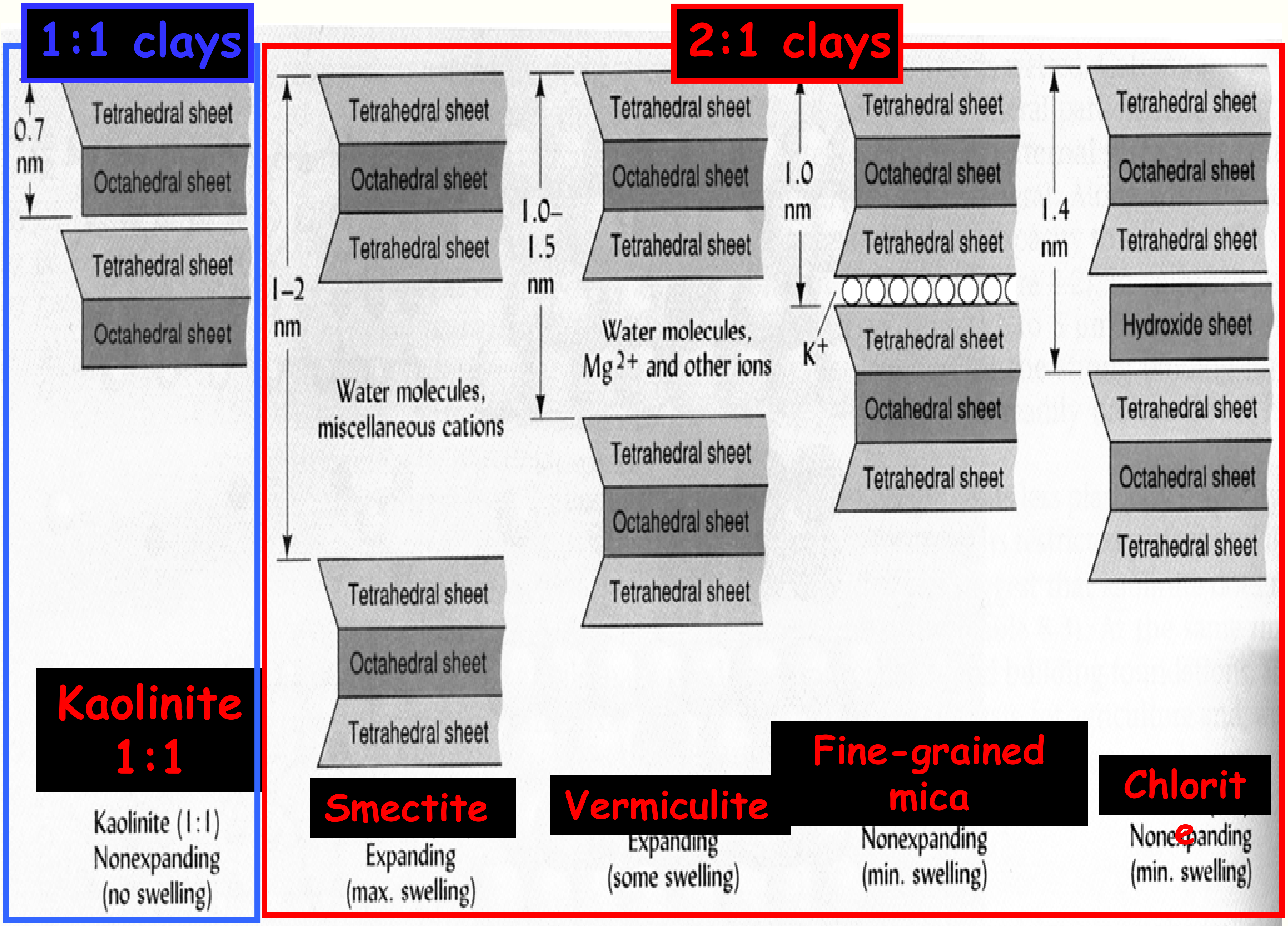
[redacted]

Tri- or di- vermiculit e

Weird-o, not truly 2:1

Cookeite, chamosite ETC

Visual comparison of common silicate clays



1:1 Silicate Clays

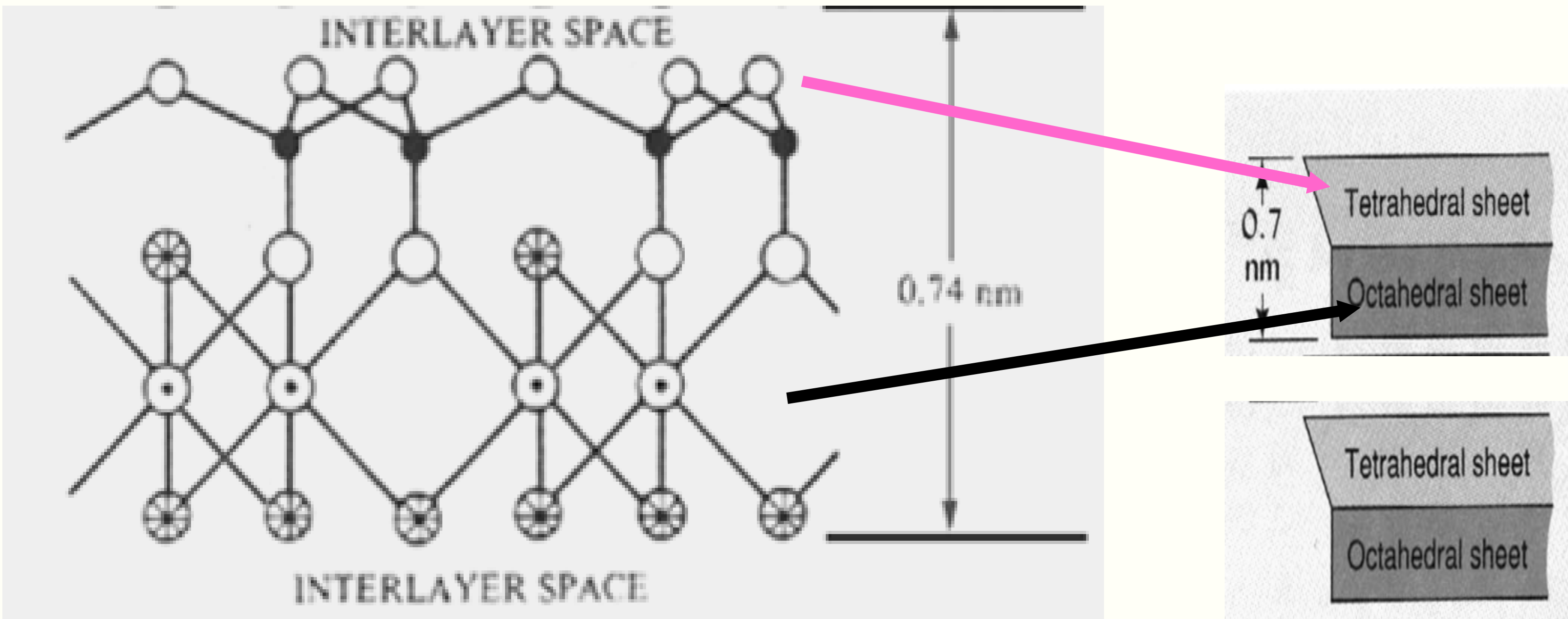
- Layers composed of **one tetrahedral** sheet bound to **one octahedral** sheet
- Kaolinite: one of the most widespread clay minerals in soils; most abundant in warm moist climates
- Stable at low pH, **the most weathered of the silicate clays**
- Synthesized under equal concentrations of Al^{3+} and Si^{4+}

Kaolinite

- A 1:1 clay
- **<u>Little or no isomorphous substitution</u>**
- "nutrient poor"
- No shrink-swell (stable because of H-bonding between adjacent layers)
- A product of acid weathering (low pH, common in soils of the SE USA

Structure of Kaolinite

NO ISOMORPHOUS SUBSTITUTION!!!



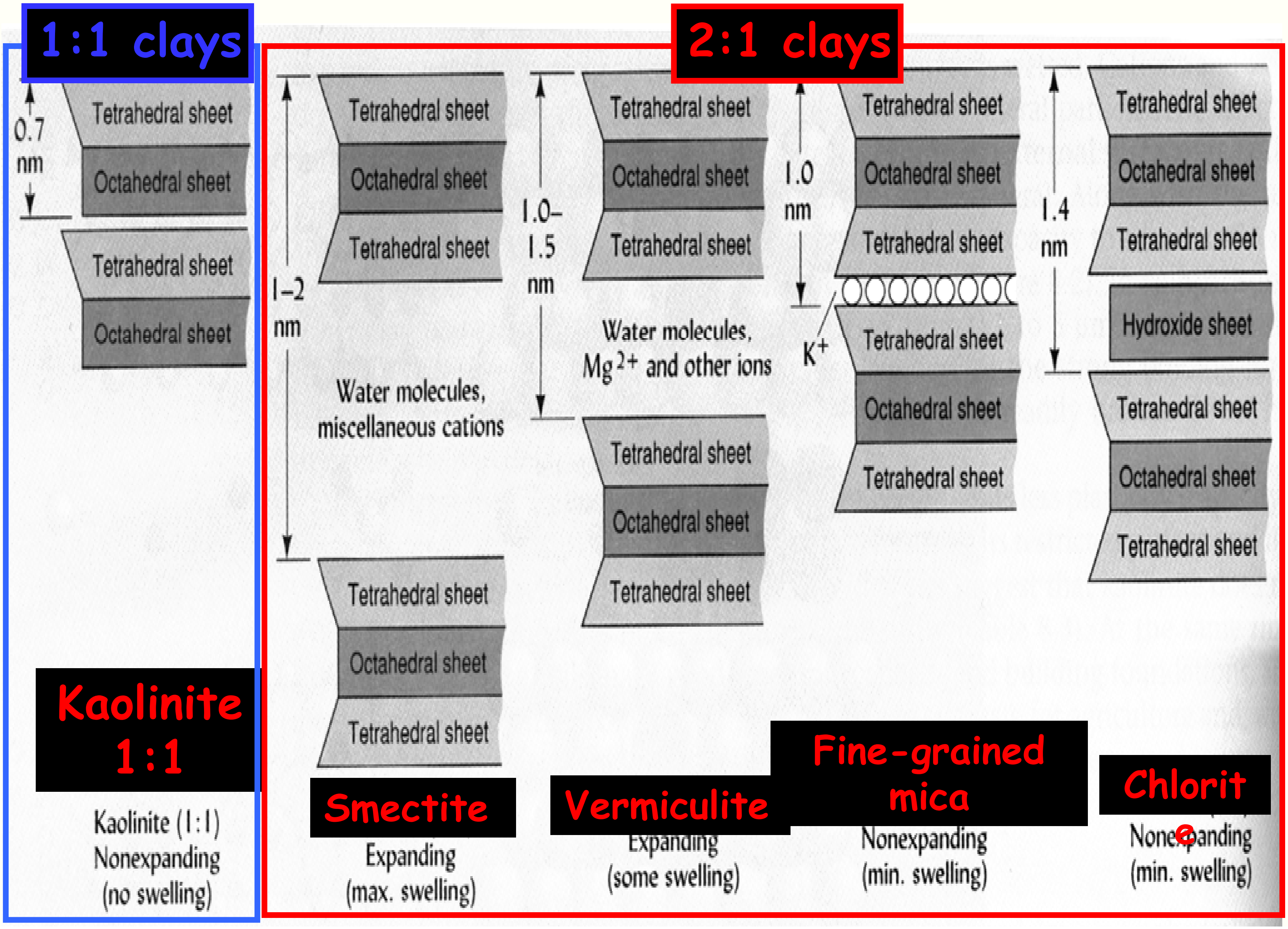
Sheets of silicon tetrahedra and aluminum octahedra linked by shared oxygen atoms.

Kaolinte under low pH

$$Al{-}OH \quad + \quad H^+ \quad \leftrightarrow \quad Al{-}OH_2^+$$

No charge   positive charge

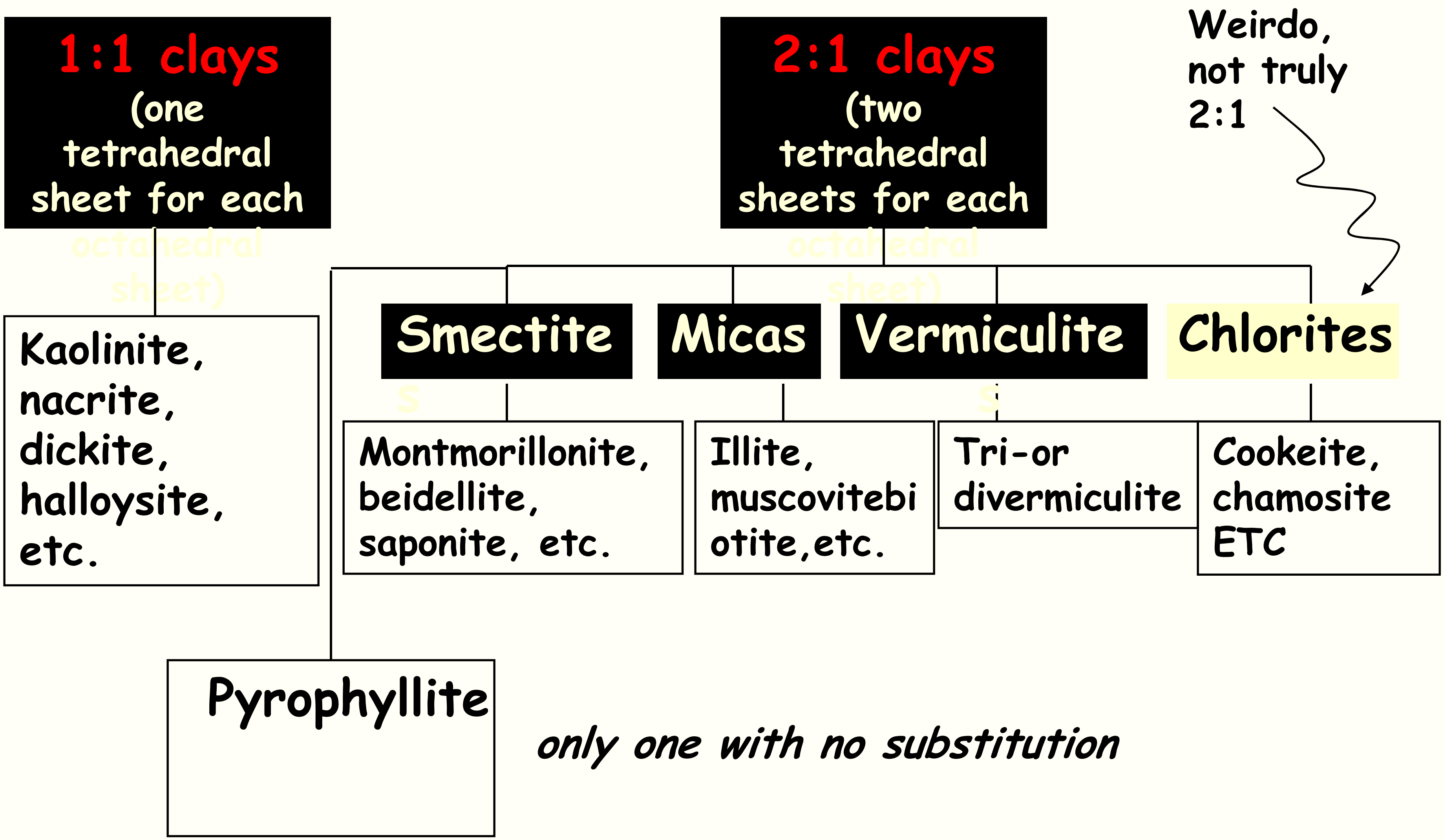
Visual comparison of common silicate clays



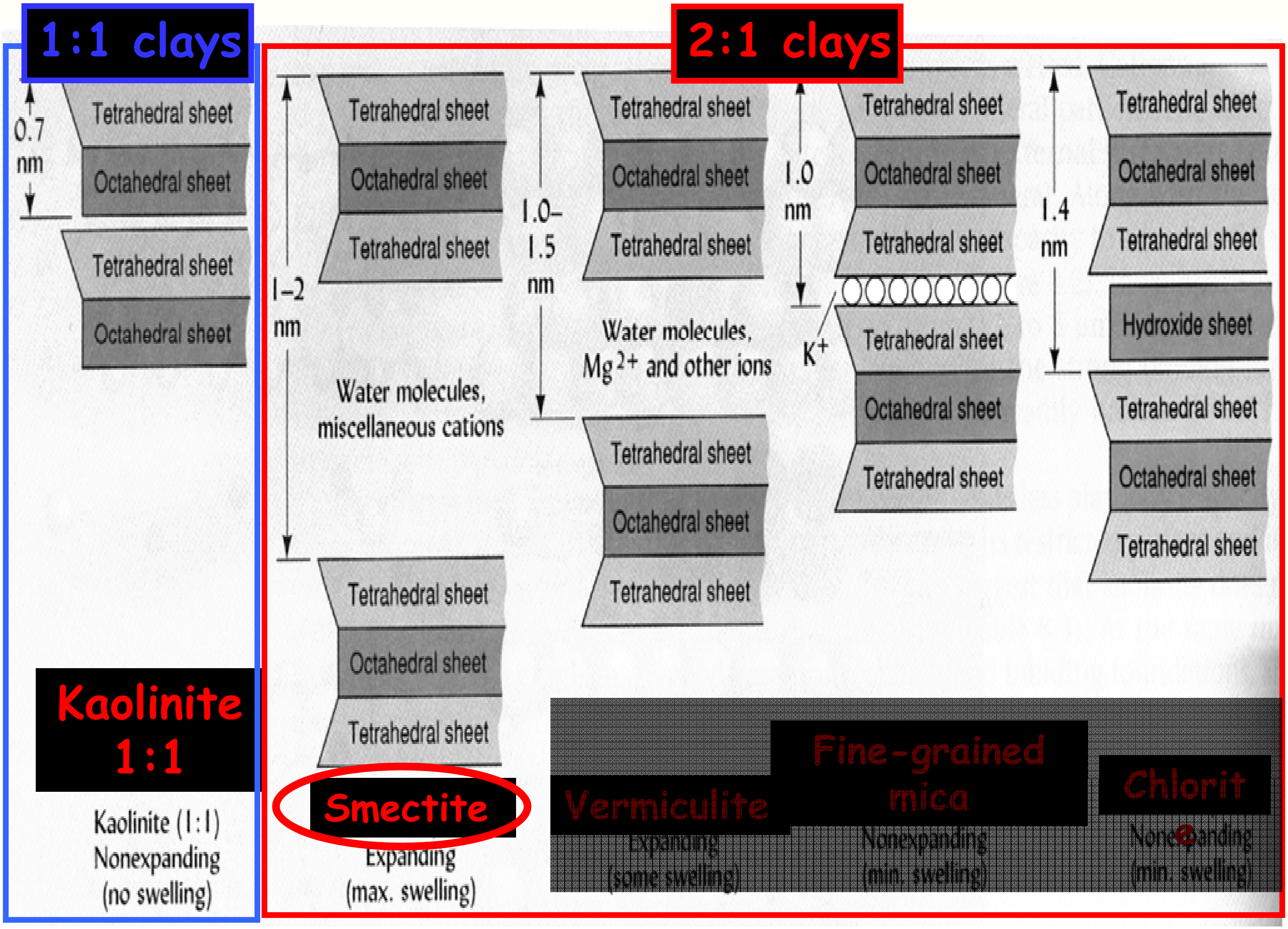
2:1 Silicate Clays

- **Two silica tetrahedral sheets** linked to **one aluminum octahedral sheet**
- Three key groups:
  - **Smectites** (e.g., montmorillonite)
  - **Vermiculites**
  - **Micas** (e.g., illite)
- And one weirdo (the **chlorites**)

Clay minerals



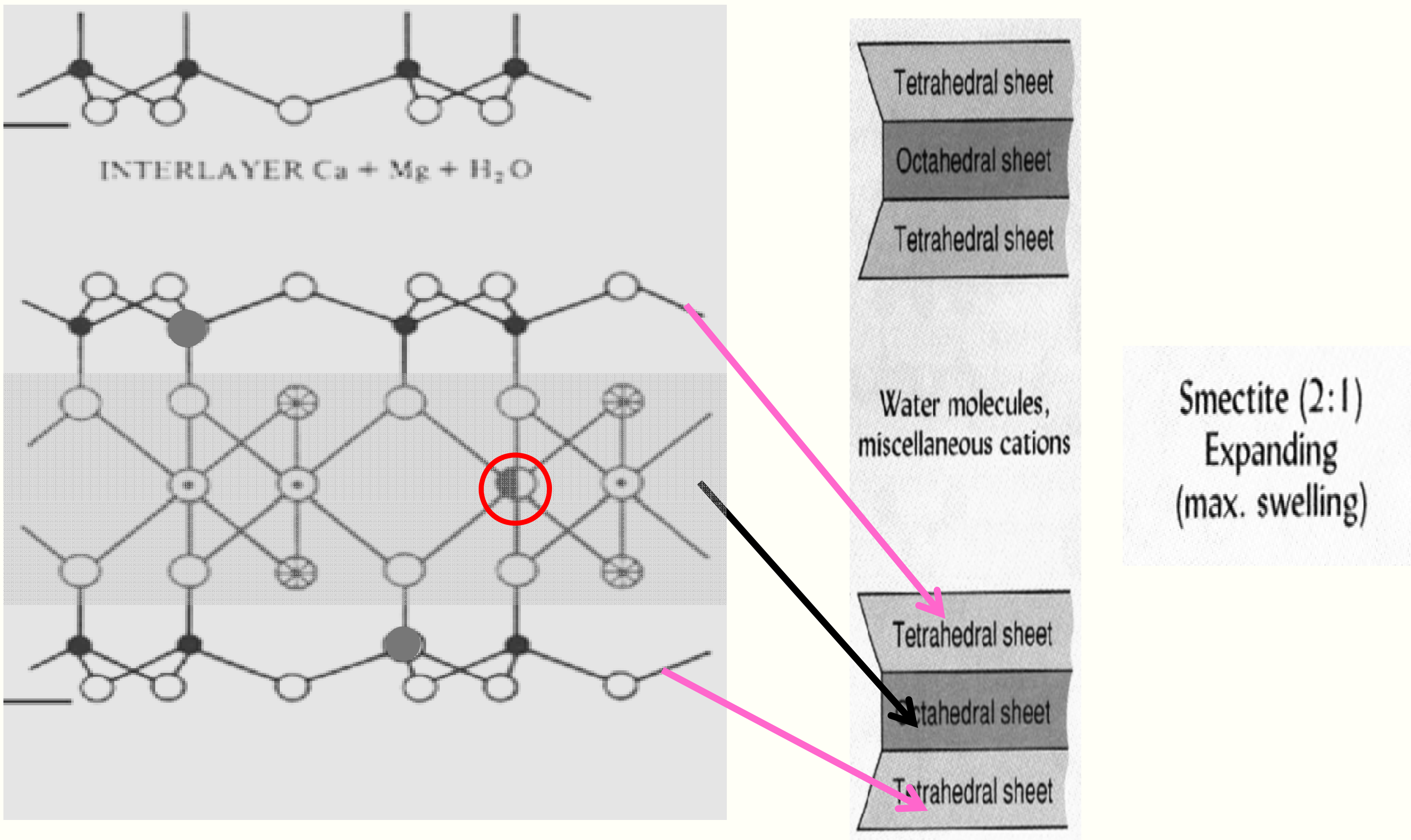
Visual comparison of common silicate clays



Smectite (2:1, Montmorillonite)

- Layer charge originates from the substitution of **Mg^{2+} for Al^{3+}** in the octahedral sheet
- Unstable (weathers to something else) under low pH and high moisture
- Most swelling of all clays
- "Nutrient rich"

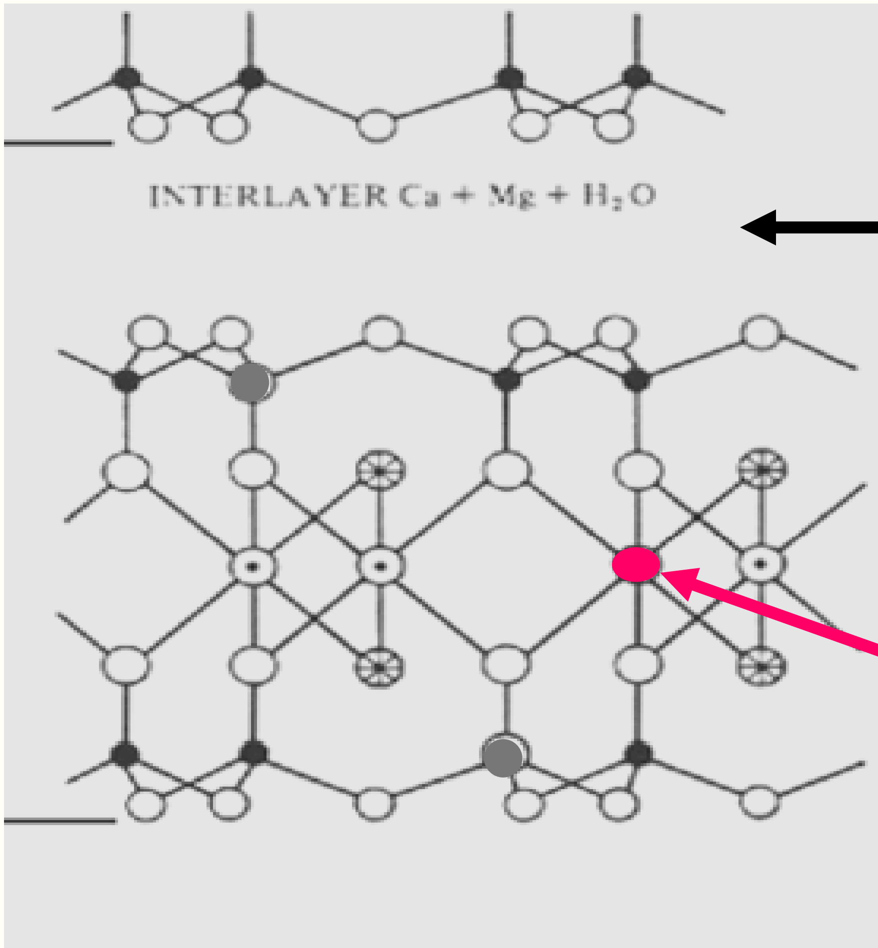
Structure of basic Smectite
(Montmorillonite)



Structure of montmorillonite (a smectite): it is built of two sheets of silicon tetrahedra and one sheet of aluminum octahedra, linked by shared oxygen atoms.

Structure of basic Smectite

(Montmorillonite)

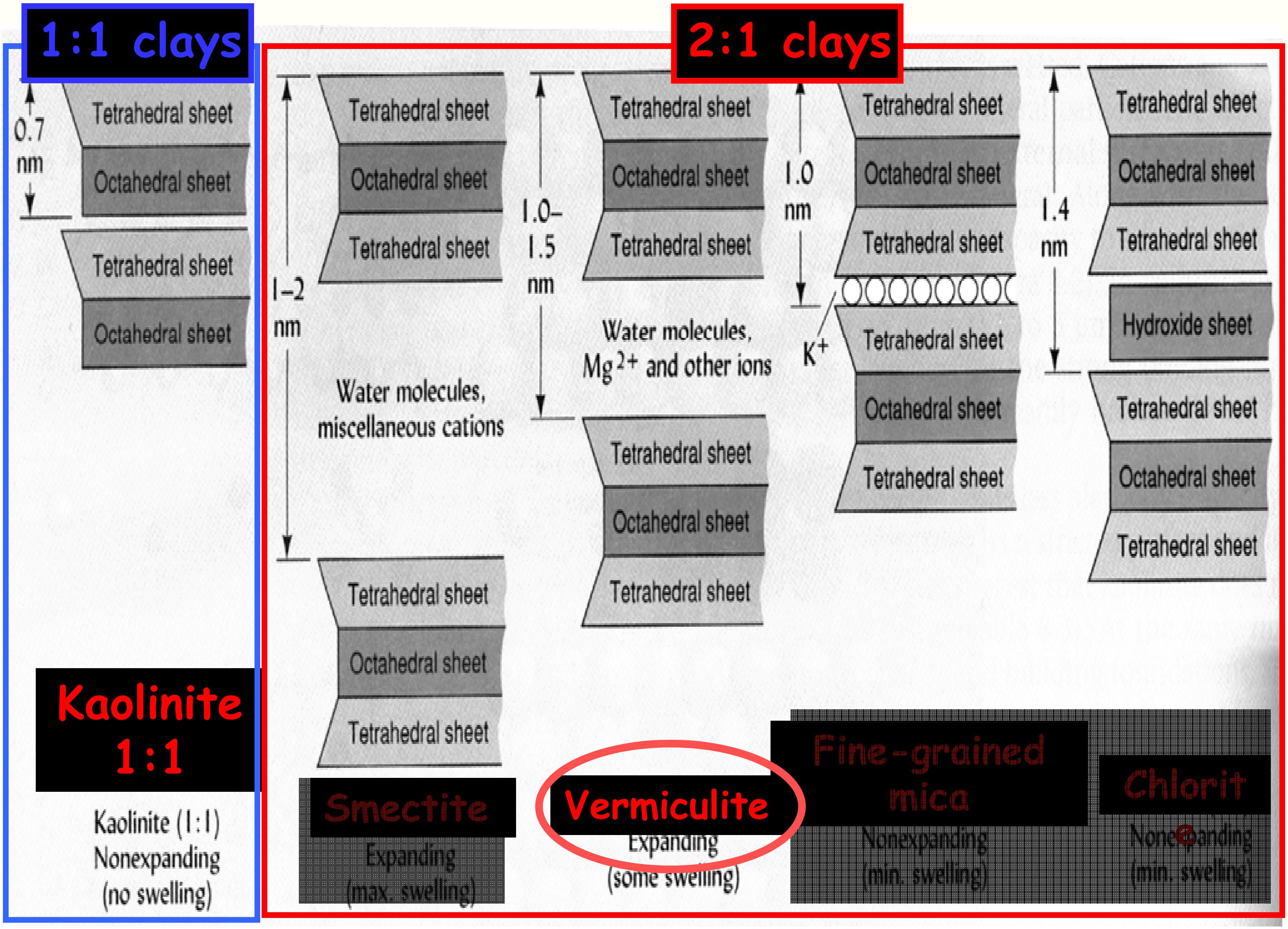


Causes cations to move into the interlayer space, where they can be replaced by other cations

Isomorphous substitution in the octahedral sheet

= Mg (this slide only)

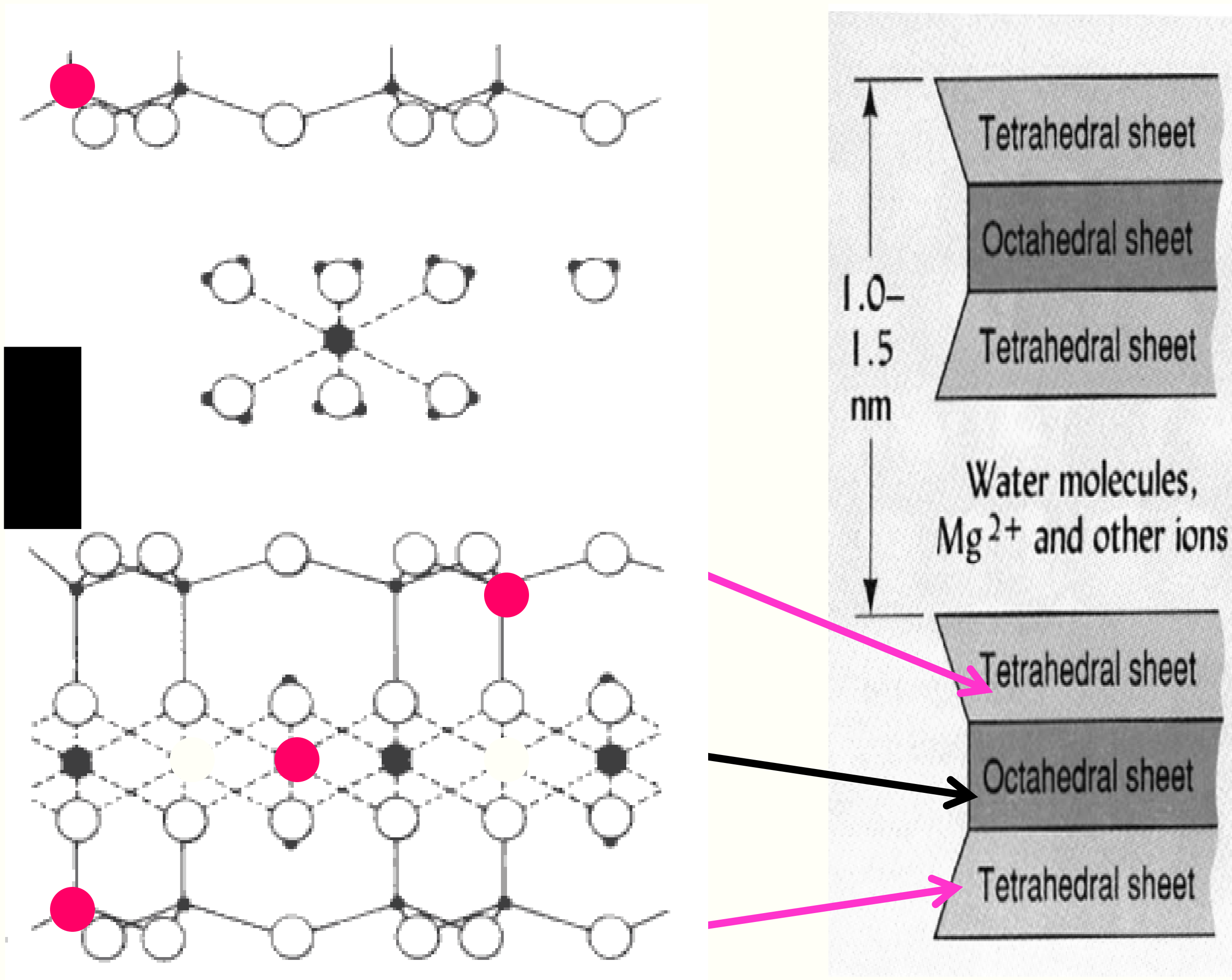
Visual comparison of common silicate clays



Vermiculites (2:1)

- Alteration product of micas (rock form)
- Formed from loss of K^+
- Interlayer K^+ of mica replaced with Mg^{2+}
- **Limited shrink-swell** …
  - **High layer charges: Isomorphic substitution in BOTH tetrahedral & octahedral sheets**
  - **"nutrient rich!" (the most)**
  - **Stable under moderate to low soil pH, high Mg, Fe**
  - **Common in midwestern US**

Structure of Vermiculite



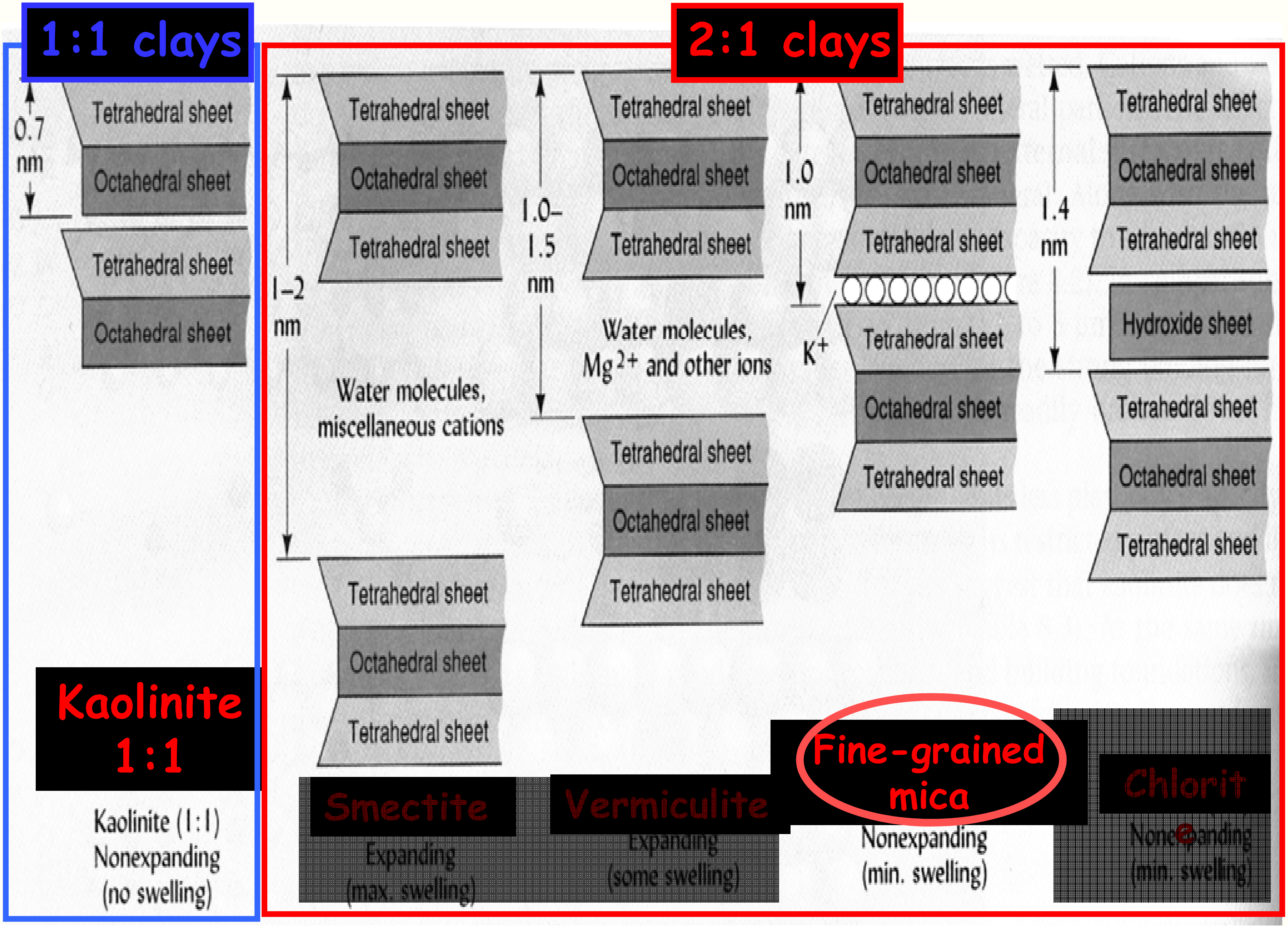
Lots of charge imbalance, <u>both sheets</u>:

High nutrient supply capacity

● = Al (this slide only!)

⬬ = Mg (this slide only!)

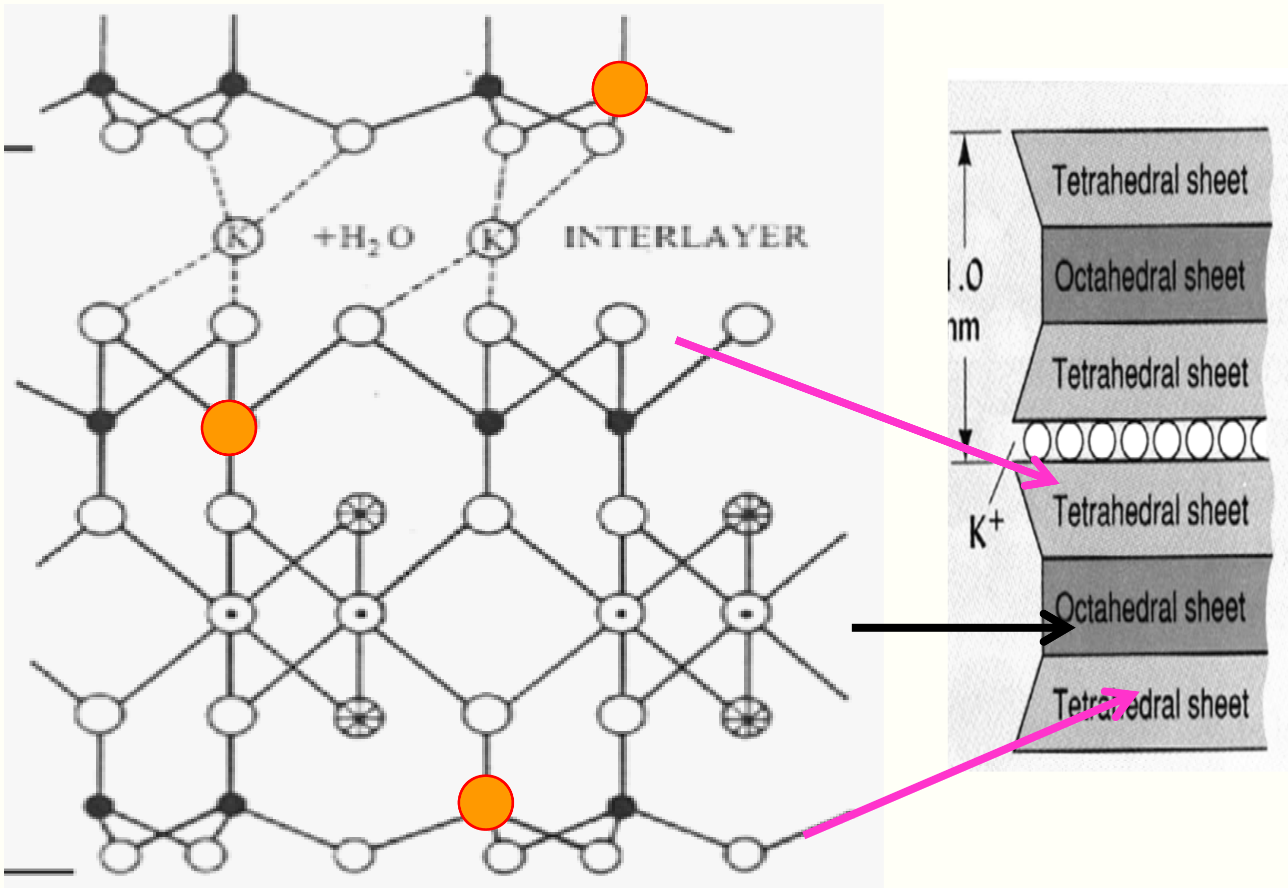
Visual comparison of common silicate clays



(2:1, Fine-grained Mica: Illite)

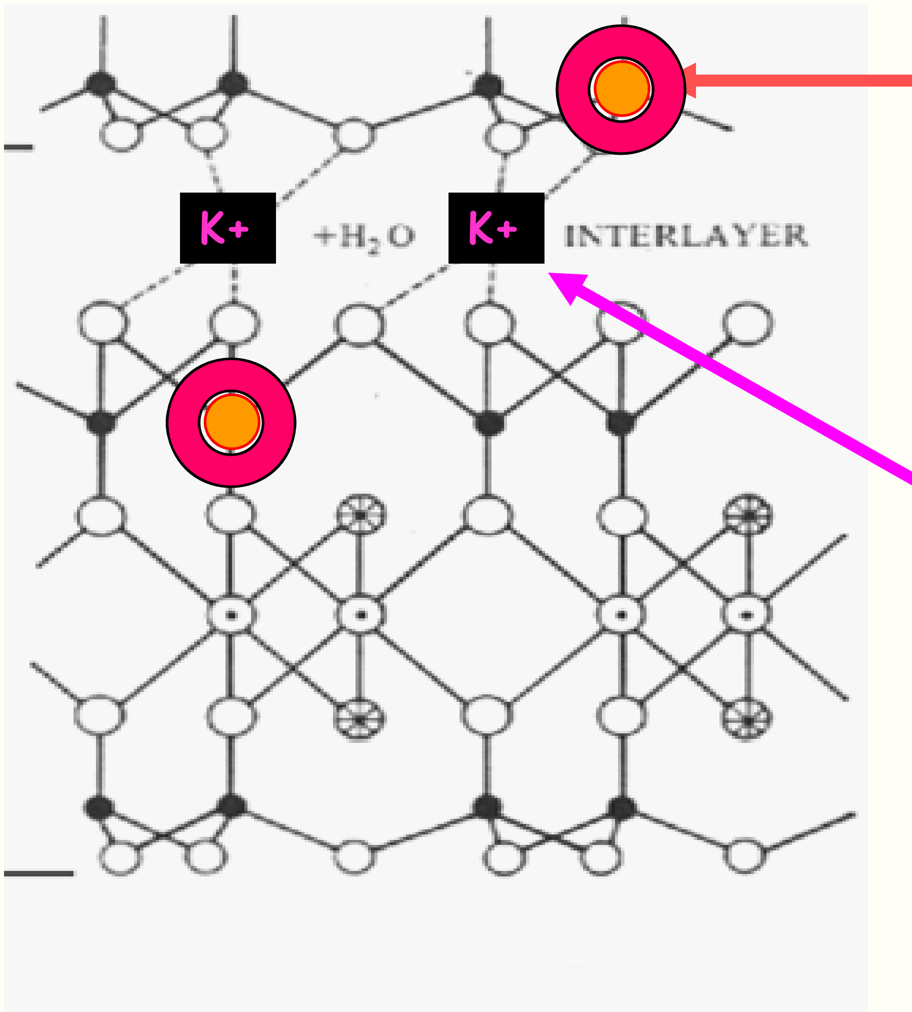
- Al^{3+} **substitution** for Si^{4+} **on the tetrahedral sheet**
- Strong surface charge
- "fairly nutrient poor"
- Non-swelling, only moderately plastic
- Stable under moderate to low pH, common in midwestern US

Structure of Illite



Fine-grained mica (2:1)
Nonexpanding
(min. swelling)

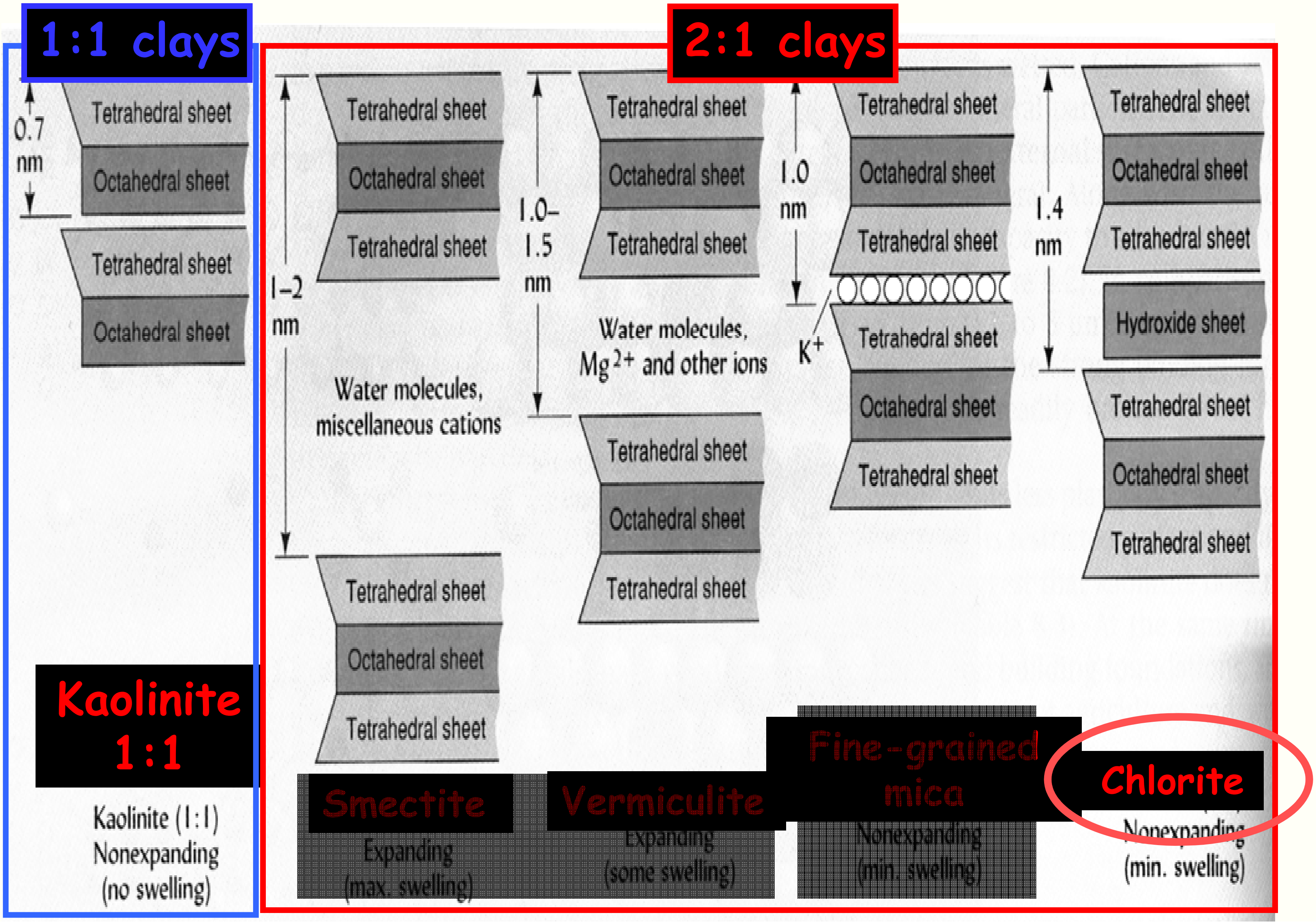
Structure of Illite



1. Isomorphous substitution is in the tetrahedral sheets

2. K+ comes into the interlayer space to satisfy the charge and "locks up" the structure

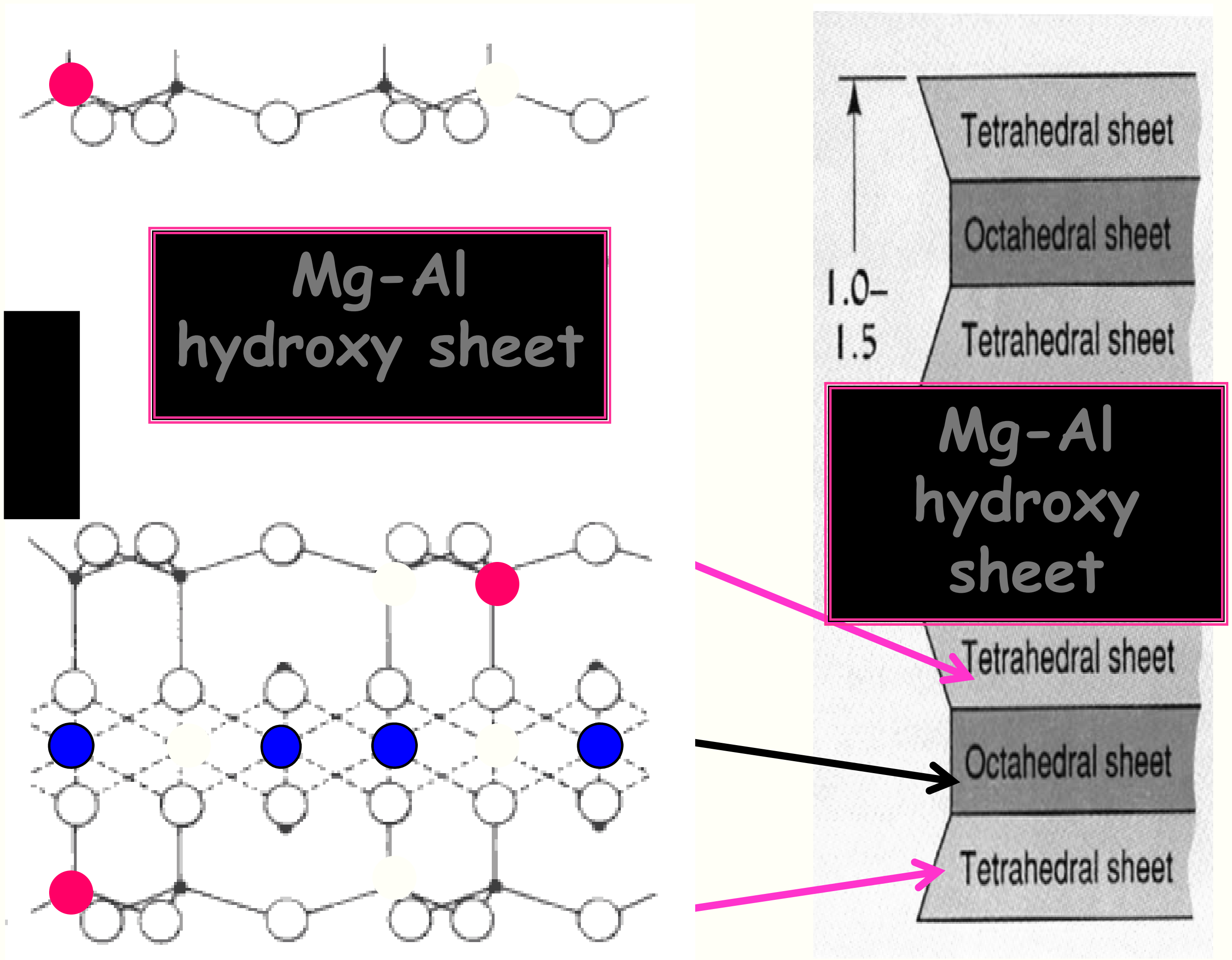
Visual comparison of common silicate clays



Chlorites (2:1:1)

- Hydroxy sheet in the interlayer space
- Restricted swelling
- “Nutrient poor”
- Common in sedimentary rocks and the soils derived from them
- **Isomorphic substitution in both tetrahedral and octahedral sheets**

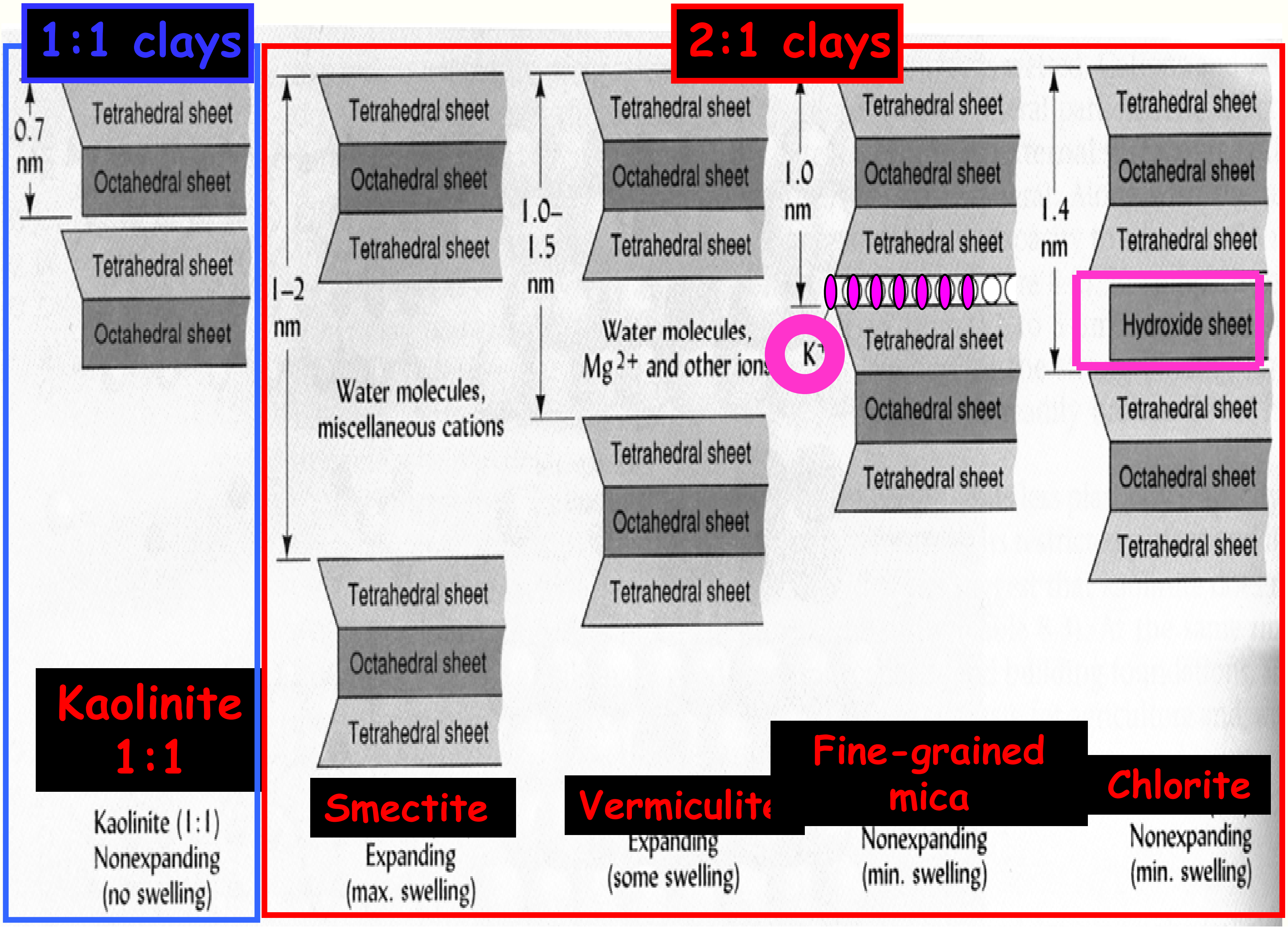
Structure of Chlorite



1. Iron-rich
2. "locked" structure
3. Low nutrient supply capacity

= Al = Fe = Mg

Visual comparison of common silicate clays



Comparison of common silicate clays

Property	Kaolinite	Smectite	Fine-grained mica
Swelling	**Low**	**High**	**Low to none**
Bonding	**Hydrogen (strong)**	**Van der Waal's (weak)**	**Potassium ions (strong)**
Net negative charge (CEC)	**Low: 2-5 $cmol_c/kg$**	**High: 80-120 $cmol_c/kg$**	**Mod: 15-40 $cmol_c/kg$**
Charge location	Edges only – NO isomorphic substitution	Octahedral sheets	**Tetrahedral sheets**
General class	**1:1 (TO)**	**2:1 (TOT)**	**2:1 (TOT)**

Total Elemental Analyses

Sample Preparation

- Typical methods of sample preparation include extraction, dissolution, or acidification and should result in a solution free of particulates. Typical acid matrices include 10% HCl (1 volume of concentrated HCl in 10 volumes of solution), 25% HNO3, and 1% HNO3.
- Samples be at least 10ml in volume, but can generally get by with 5ml samples.

Analyses

- ICP, Inductively Coupled Plasma
- ICAP-OES, Inductively Coupled Plasma Optical Emission Spectrometer
- Provides total elemental analysis of acidic solutions of soil extracts

Total Elemental Analyses

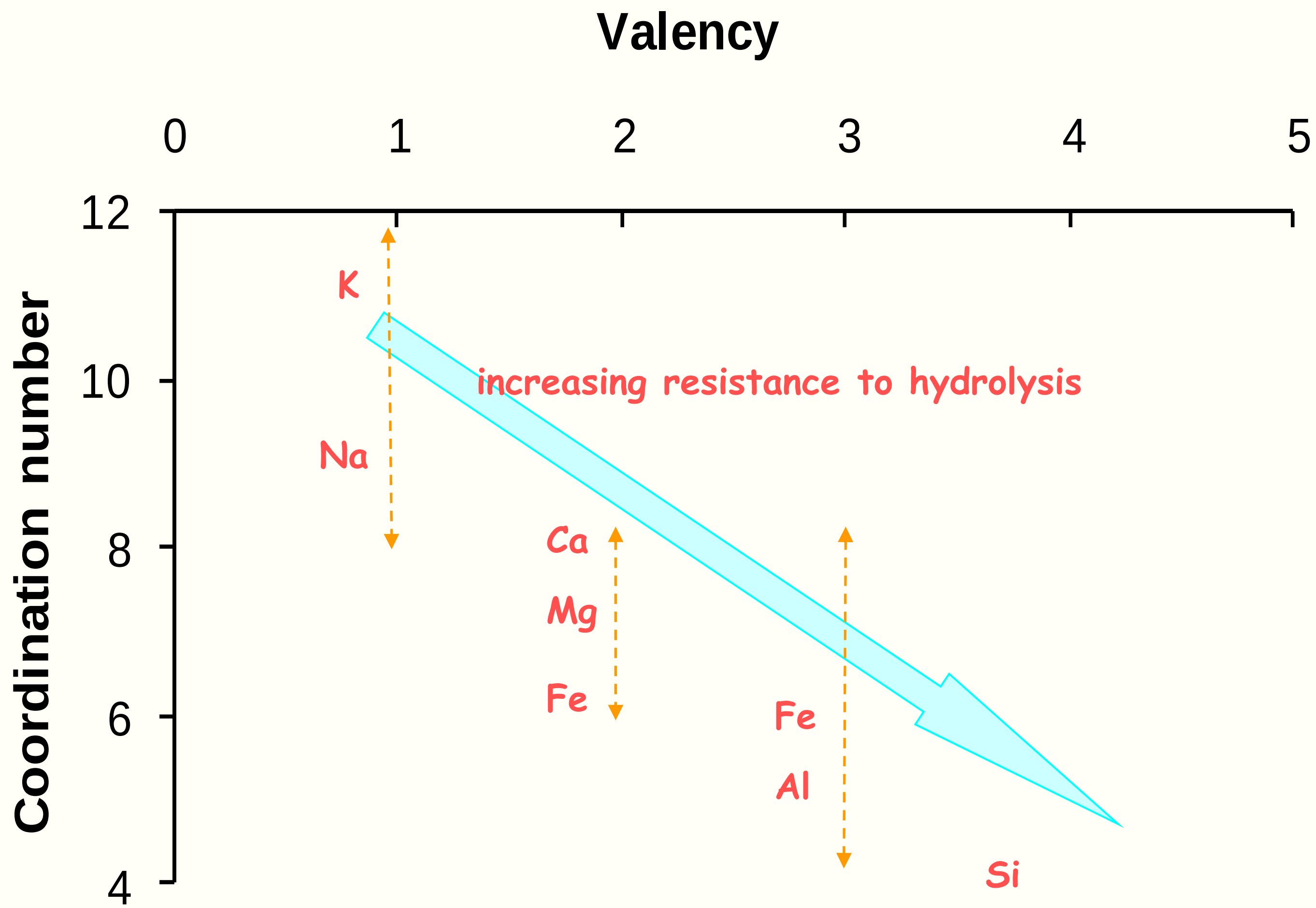
Methods

- A nebulized mist is injected from a liquid into the center of an argon plasma. A plasma is created from a flow of gas within a high energy field which ionizes the gas and causes intense heating. Temperatures inside an ICP plasma reach 10000 K
- The intense heat causes the dissociation of most chemical compounds, and the energy that the component atoms absorb causes them to undergo excitation and ionization energy transitions. The transitions produce spectral emissions characteristic of the elements being excited.
- The spectra produced by the plasma is broken down into individual spectral lines by the ICP's spectrometer, and the ICP's computer translates the spectral lines into concentrations for a specified suite of elements.

Interpreting Results

- Data values are expressed on an atomic weight basis (not as molecular species) and are reported in ppm
- To convert elemental values to other forms you need to factor in the atomic weight of the element as a fraction of the molecular weight of the species in question.

Elemental Weathering



Paton et al., 1995

Mass Balance

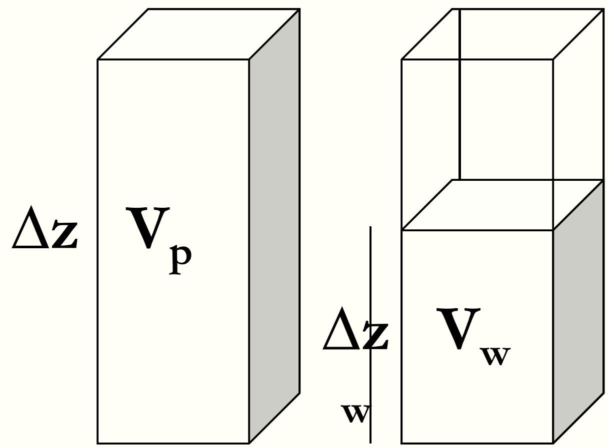
Goal

- To interpret the effects of weathering and pedogenesis quantitatively
- To merge pedologic and hydrochemical environments by assessing elemental and mineralogical gains and losses from the soil system

Mass Balance

What is mass balance?

- A physical and chemical model and mathematical tool used to quantify net gains and losses of material/mass in and out of soil horizons (mass transfers) during pedogenesis

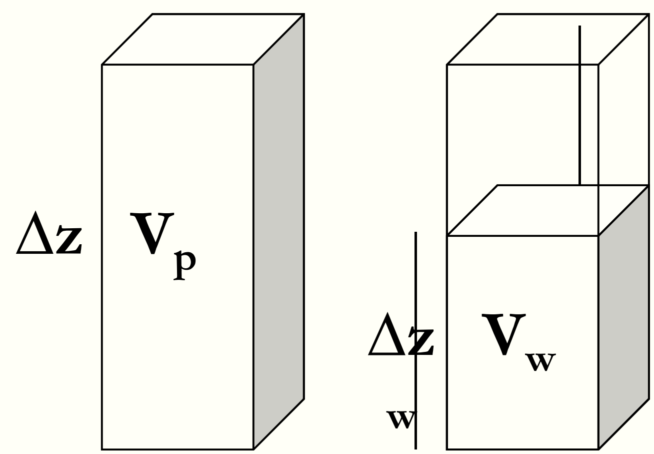


- Comparison of bulk density, volume, and chemical composition between soil horizons and their respective parent material

Mass Balance

What does mass balance do?

- Accounts for the fate of elements during weathering
- Accounts for mineral neoformation
- Accounts for leaching



Mass Balance

Conservation of Mass

$$\frac{V_p \rho_p C_{j,p}}{100} + m_{j,flux} = \frac{V_w \rho_w C_{j,w}}{100} \qquad \frac{cm^3 * \frac{g}{cm^3} * \frac{g}{100g}}{100}$$

- The volume, density and concentration of the parent material (+) or (-) what has been added or removed contributes to the volume, density, and concentration of that element in the soil.

- The units combine to give the mass of element j in grams. So…the mass of the element in the soil is a product of the new volume (original volume (+) or (-) what has been removed), BD, and concentration.

Mass Balance

Strain

- To observe strain based on the volume change due to weathering:

$$\varepsilon_{i,w} = \frac{V_w - V_p}{V_p} = \frac{V_w}{V_p} - 1$$

- This is strain or volume change determined by use of an immobile element like Ti or Zr due to weathering

- Don't assume isovolumetric weathering (an initial volume may dilate or collapse during soil evolution)

  – So…the volume change relative to an immobile element determined by the density and concentration loss of a mobile element

$$\varepsilon_{i,w} = \frac{\rho_p C_{i,p}}{\rho_w C_{i,w}} - 1$$

Mass Balance

Strain

"a change in bulk density that is not compensated by an inversely proportional change in the concentration of the immobile element"

(Chadwick et al.,1990)

- Collapse- negative strain due to mineral dissolution and element mobility
- Dilation- positive strain due to elemental additions

Mass Balance

Mass Gains and Losses

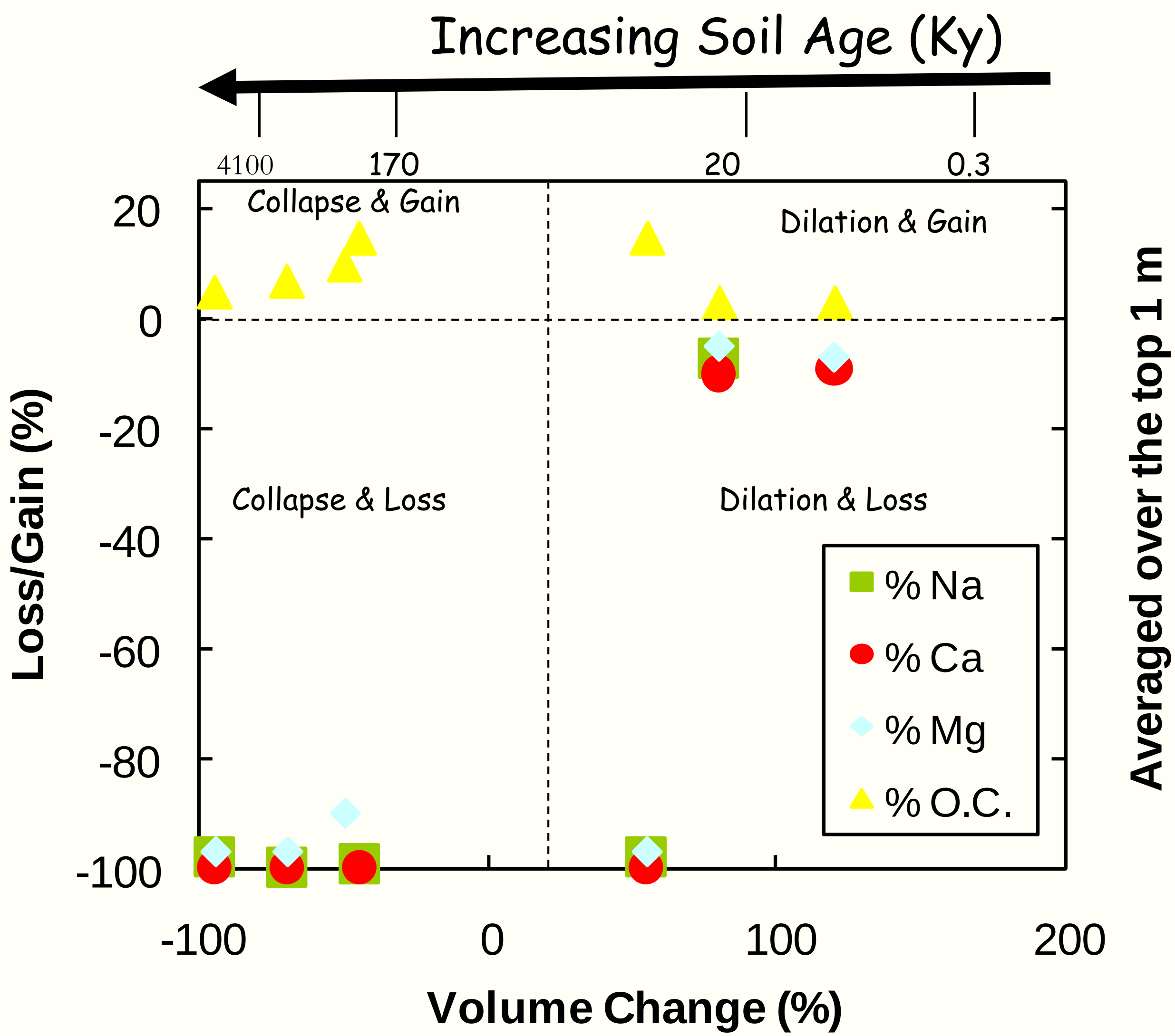
- Open System Mass-Transport Function: Mass Fractions Relative to the mass of element in parent material

$$\tau_{j,w} = \frac{100 m_{j,flux}}{V_p C_{j,p} \rho_p} = \frac{\rho_w C_{j,w}}{\rho_p C_{j,p}} (\varepsilon_{i,w} + 1) - 1$$

- Density, concentration and volume change are considered

- -1.0 = 100% of mass of element originally in parent material was extracted during weathering.
- 0.00 = element has been immobile

Mass Balance Theory



Mass Balance

Limitations

1. External sources are often unidentifiable
2. Determining accurate parent material is critical
   - In soils derived from sedimentary parent materials, the least weathered soil horizon is considered the parent material
3. Bulk density is difficult to determine for some textures (ie. gravelly)

Pedology: A Platform for Regional and Global Biogeochemical Studies

1) Why soils and pedology research matter.

- *Pedological Rules*
- *Pedology and biogeochemistry (Amundson, 2004)*

2) Regional Biogeochemical Research

- *C storage and variability in grassland systems*

Soils *reflect* and at the same time *affect* the environment

- Soils of any region *reflect* climatological, geological, biological, and topographical conditions.
- Soil properties that regulate water, gas exchange and nutrient status and influence plant growth have important *affects* on the environment.

Pedological Rules

- There is a pressing need to identify the extent to which we can extrapolate beyond individual study sites and model systems.
- Pedological rules are "general principles that underpin and create patterns" within and among ecosystems and strengthen our ability to generalize biogeochemistry more broadly (regionally and globally).
- Our investigations should allow us to probe the limits of these rules and potentially identify key contingent factors that may alter their manifestation

Elemental Distribution of Soil Versus the Earths Crust (Amundson, 2004)

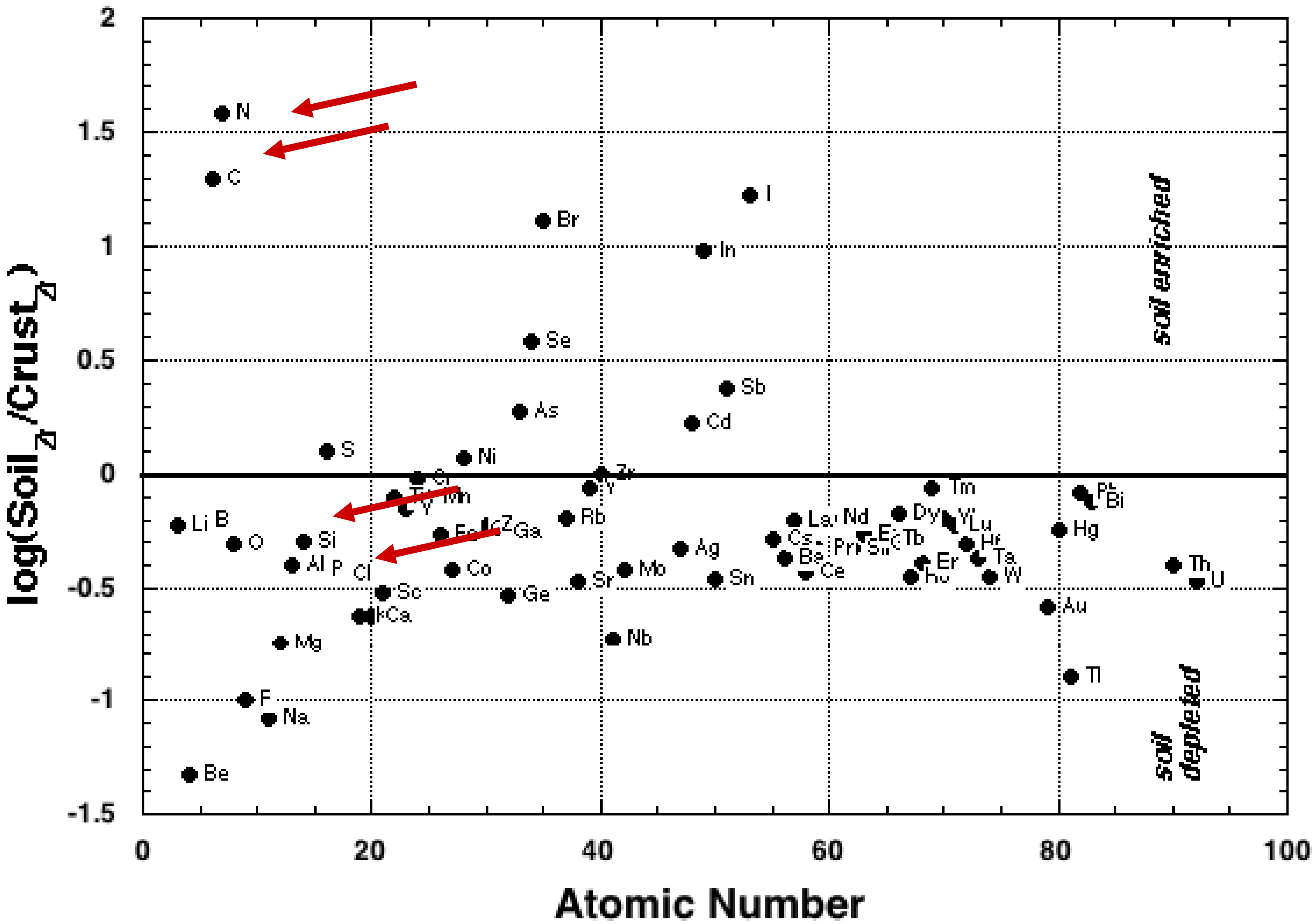


Figure 3.5

Elemental Distribution of Vegetation Versus the Earth's Crust (Amundson, 2004)

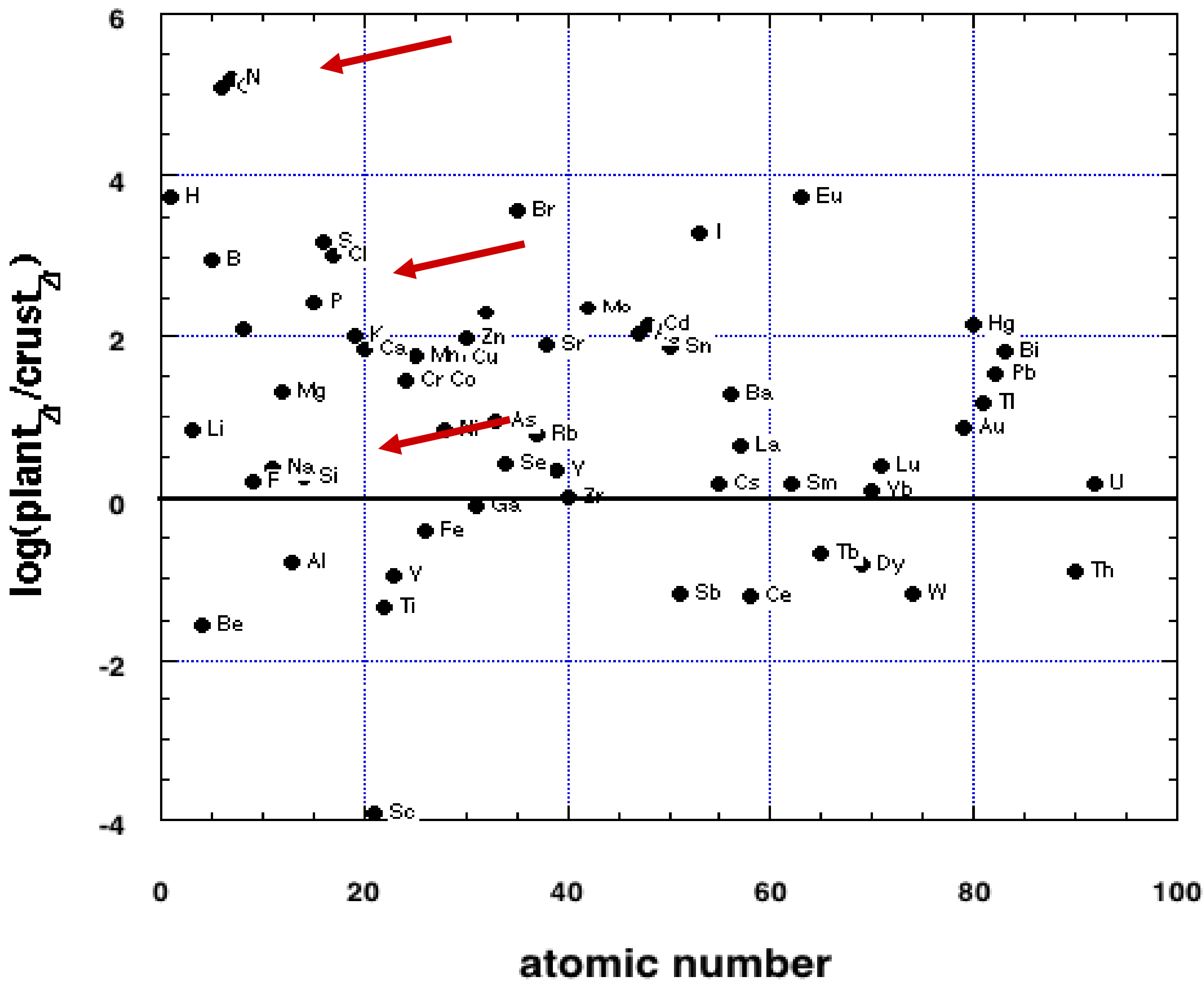


Figure 3.8

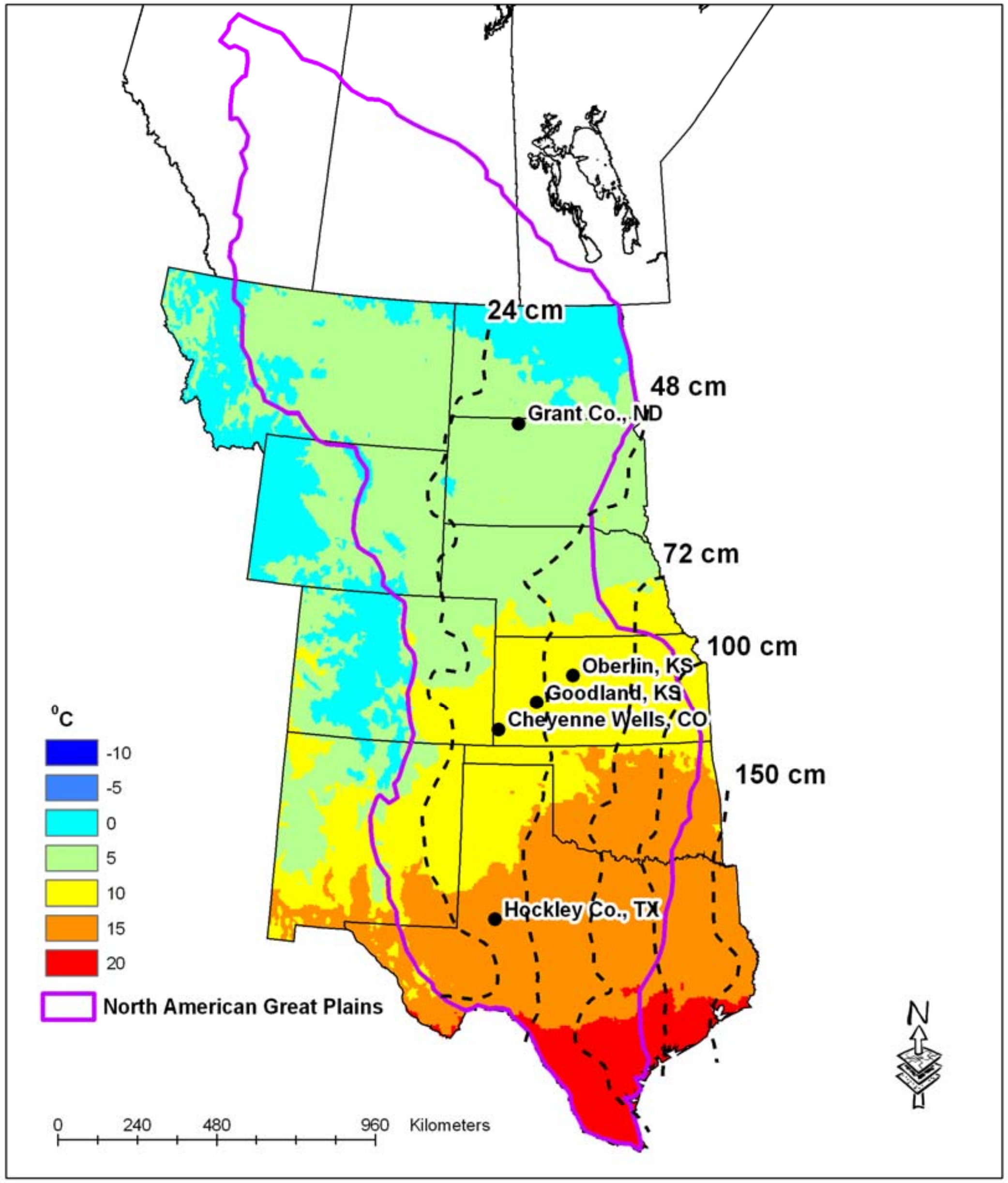
Scientific Approach

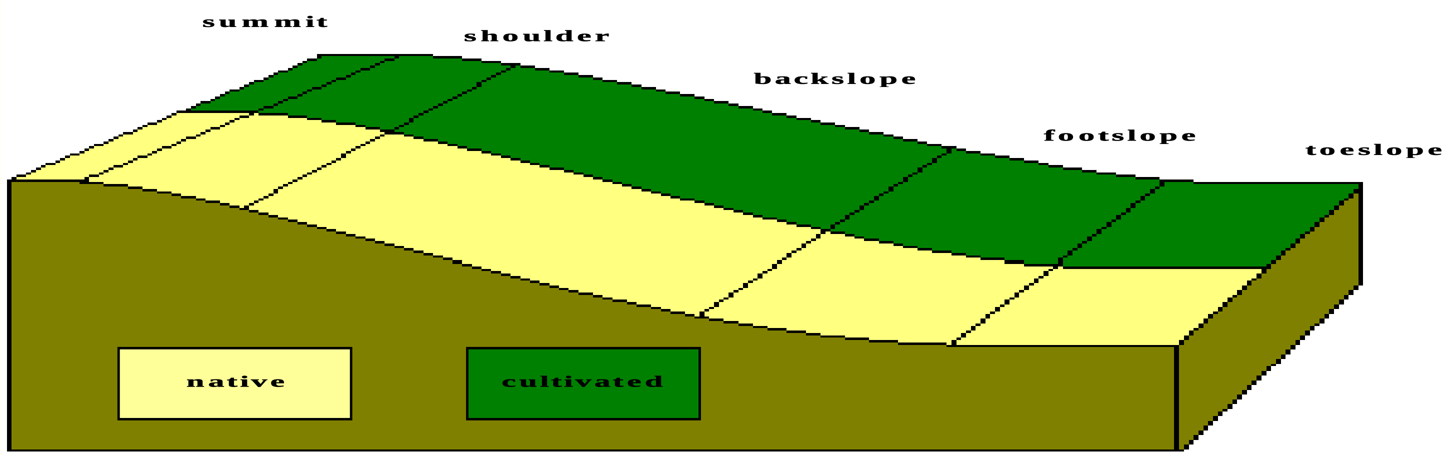
- Utilize environmental gradients to establish the range and variability in soil properties, processes and behavior that constrain regional and global biogeochemical models.
- State Factor Analyses (Jenny, 1941, 1980; Vitousek, 2004)
- Integrate geochemical, biochemical and mass balance approaches with traditional pedological measurements.

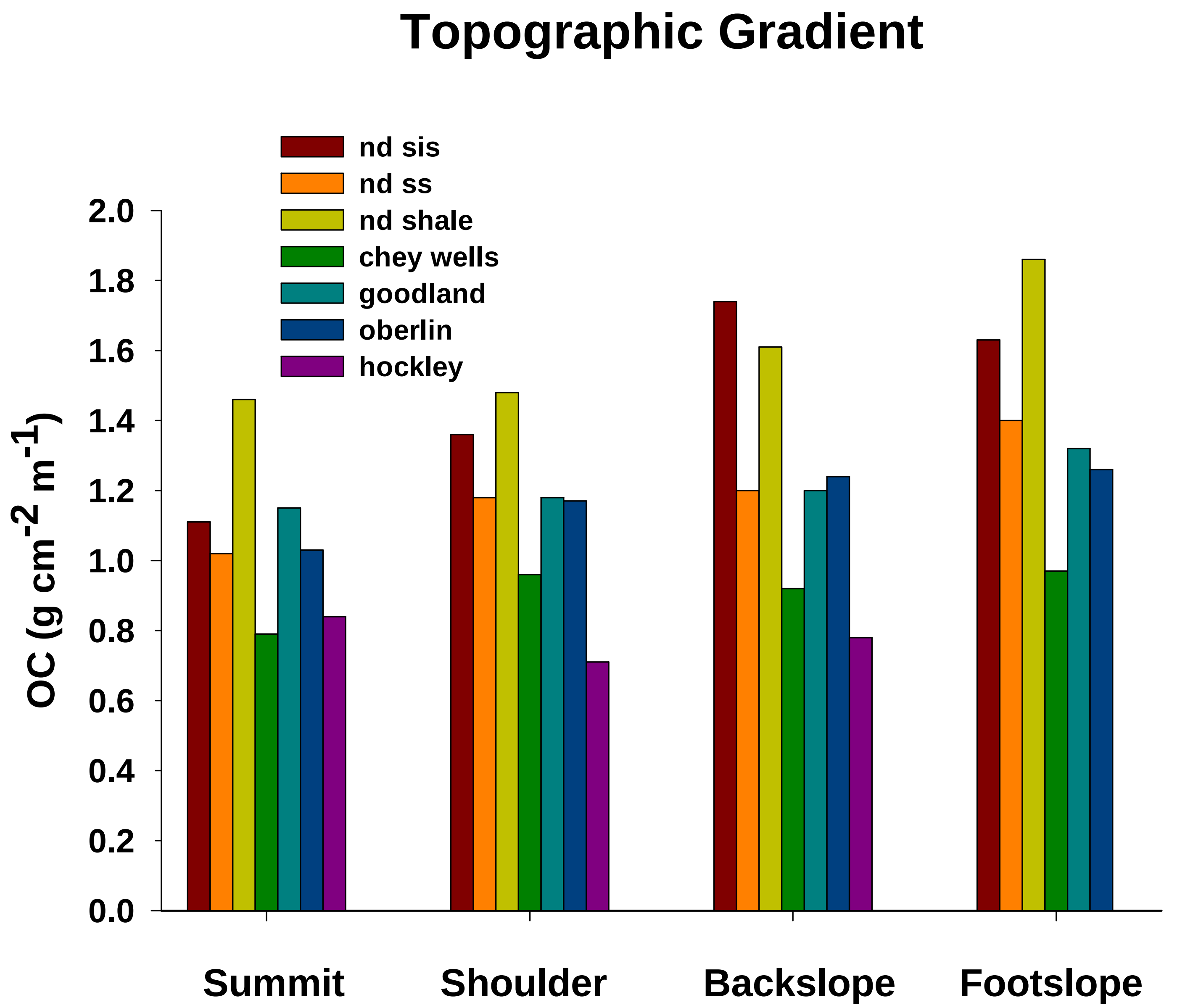
Carbon Storage and Variability in Grassland Systems

Environmental Gradients

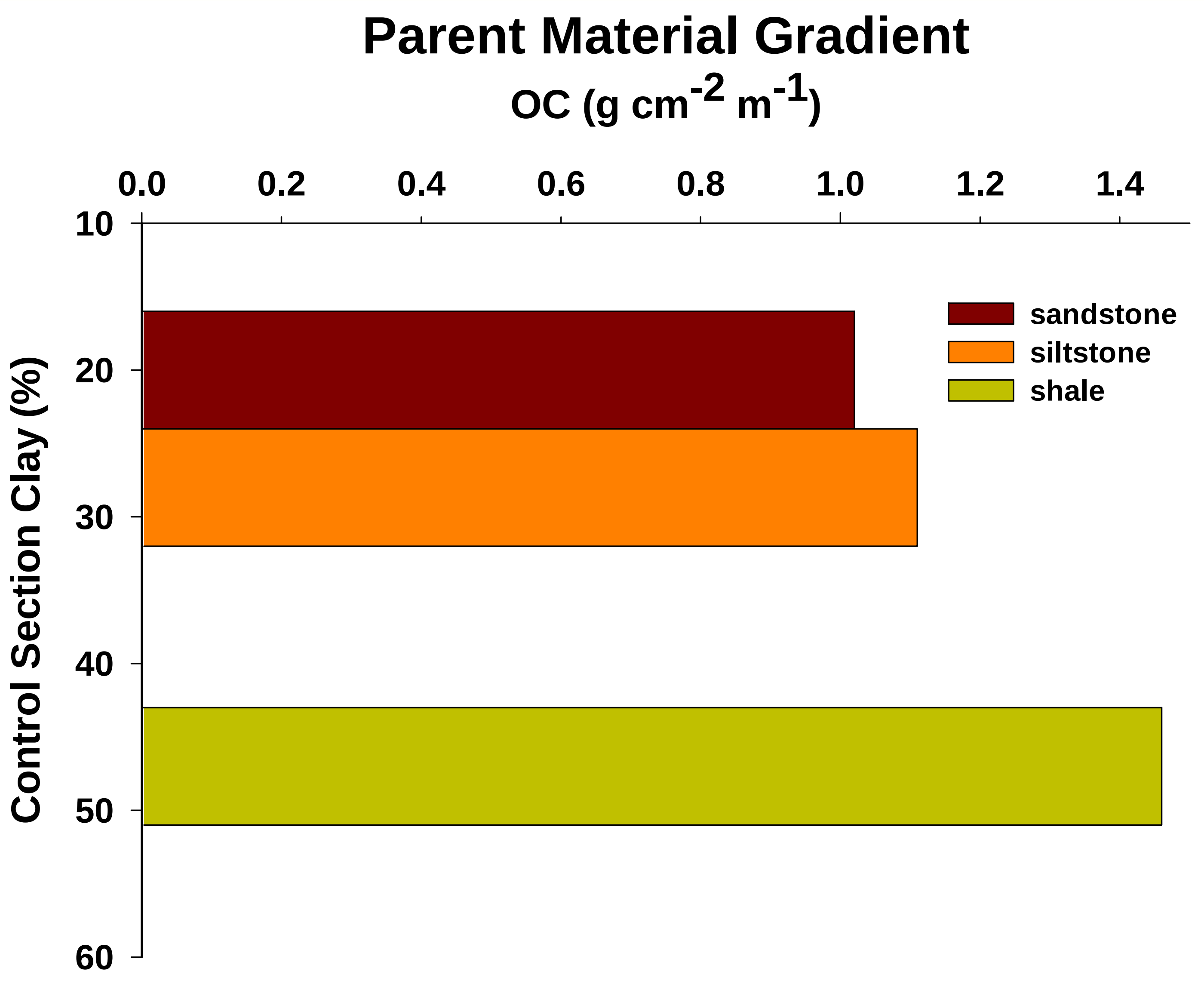
- Toposequences (Aguilar et al, 1988;Kelly et al, 1988)
- Lithosequences (Aguilar et al, 1988)
- Climosequences (Honeycutt et al, 1987; Kelly, 1989)


24 cm
48 cm
72 cm
100 cm
150 cm
Grant Co., ND
Oberlin, KS
Goodland, KS
Cheyenne Wells, CO
Hockley Co., TX
°C
-10
-5
0
5
10
15
20
North American Great Plains
0
240
480
960
Kilometers
N

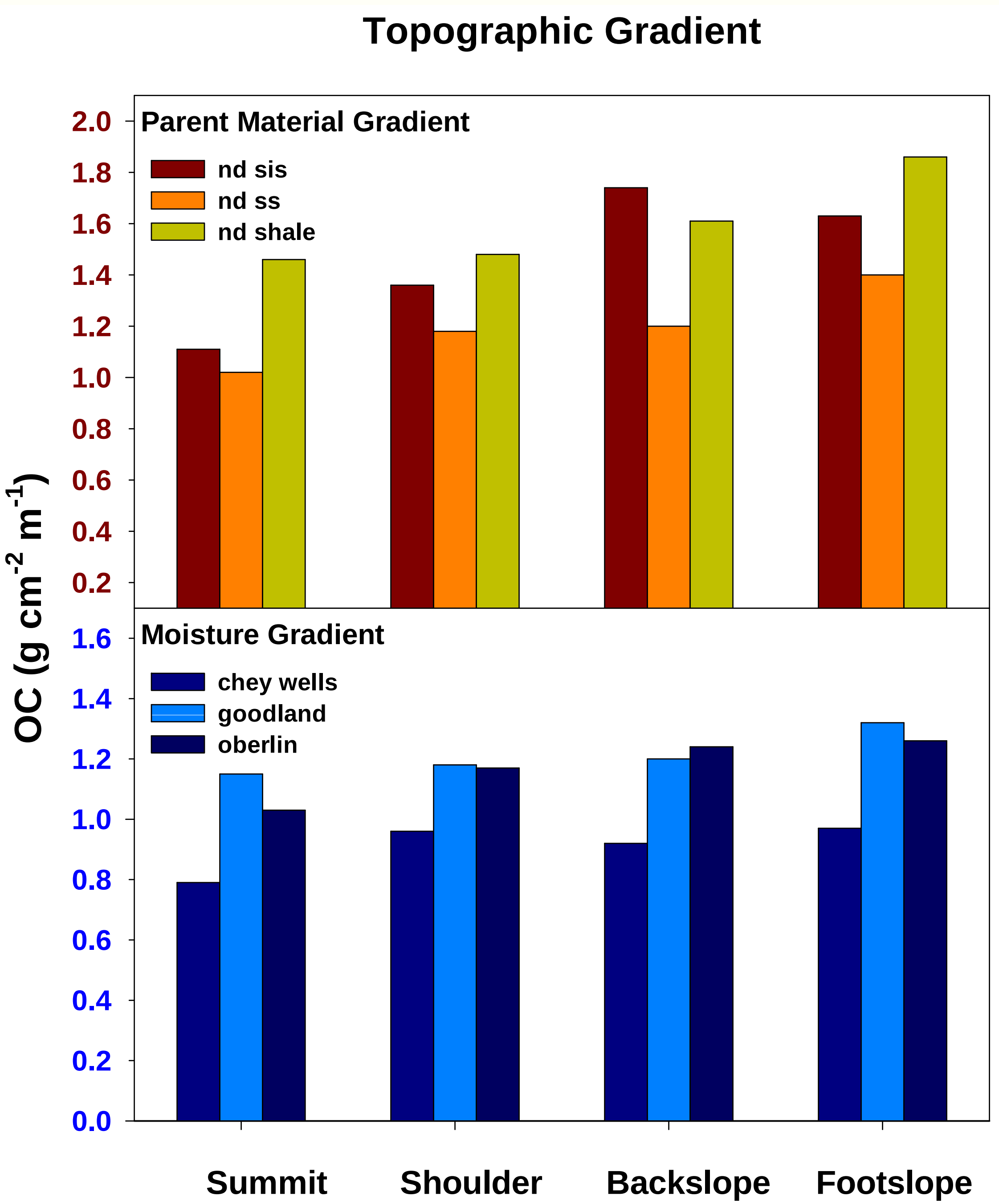

summit
shoulder
backslope
footslope
toeslope
native
cultivated

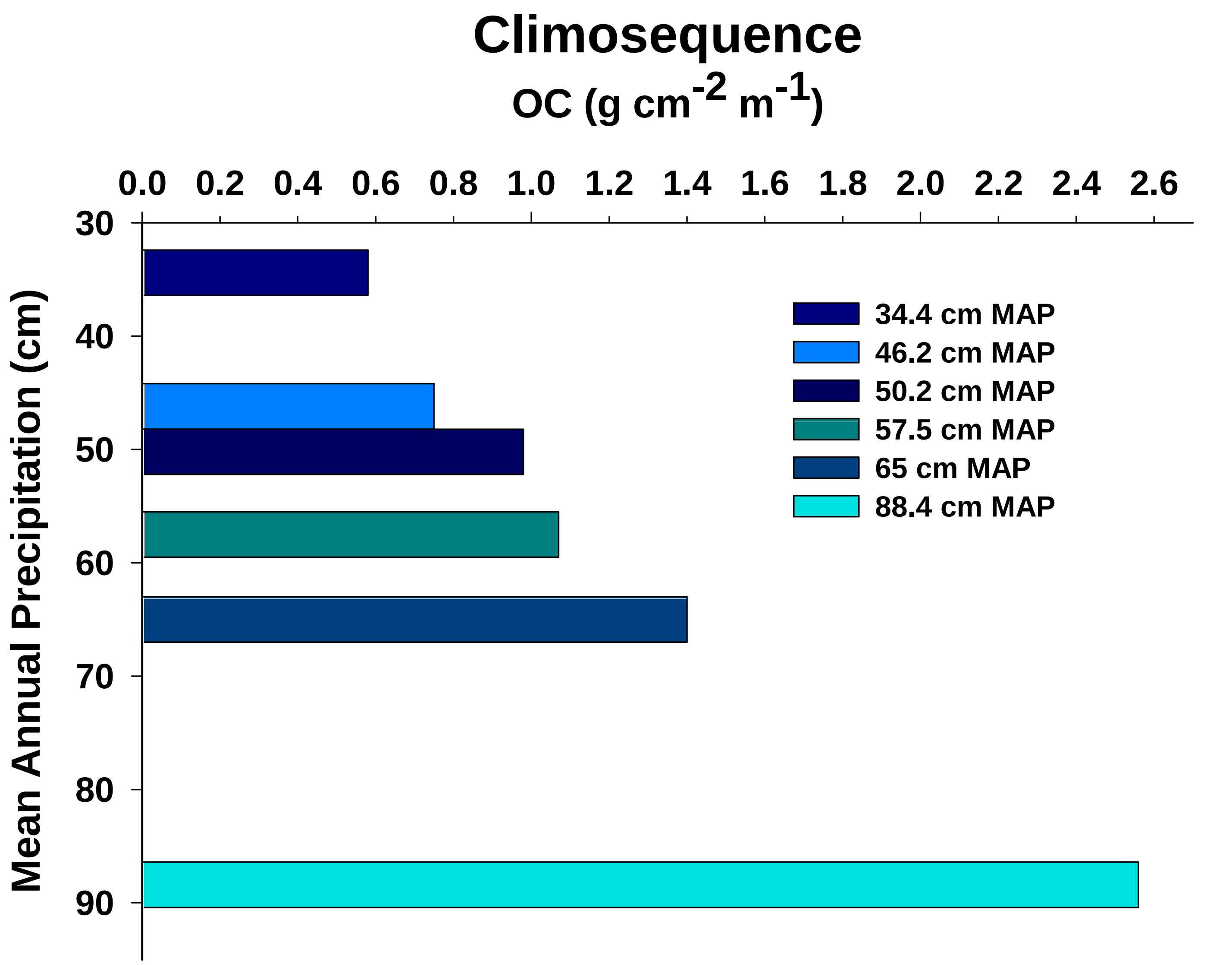


Topographic Gradient
nd sis
nd ss
nd shale
chey wells
goodland
oberlin
hockley
OC (g cm-2 m-1)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Summit
Shoulder
Backslope
Footslope



Parent Material Gradient
OC (g cm-2 m-1)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Control Section Clay (%)
10
20
30
40
50
60
sandstone
siltstone
shale


Topographic Gradient
Parent Material Gradient
nd sis
nd ss
nd shale
Moisture Gradient
chey wells
goodland
oberlin
OC (g cm-2 m-1)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Summit
Shoulder
Backslope
Footslope



Climosequence
OC (g cm-2 m-1)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Mean Annual Precipitation (cm)
30
40
50
60
70
80
90
34.4 cm MAP
46.2 cm MAP
50.2 cm MAP
57.5 cm MAP
65 cm MAP
88.4 cm MAP

Pedological Rules

- Grassland ecosystems vary systematically in C storage as a function of landscape position, bioclimatic and Edaphic conditions

- The relationship between conditioning variables and soil properties provide a potential avenue for extrapolating beyond site level and constraining regional studies.

Pedology & Biogeochemcial Research

- Earth Sciences are now at the forefront of research addressing biogeochemical questions at regional and global scales.

- Identify pedological processes that operate consistently, or at least change predictability, across similar ecosystems within and between regions ?

- There is a pressing need to identify those pedological processes that are predictive (quantifiable) rather than descriptive.

- Once established and tested the "Pedological Rules" can be utilized to help quantify the range and variability of biogeochemical responses to key drivers (climatic extremes and land use).