## Chemical Weathering and Soils

Fresh rocks and minerals that once occupied the outermost position reached their present condition of decay through a complex of interacting physical, chemical, and biological processes, collectively called ***weathering.***

**Chemical Weathering and Soils**

1. new minerals created by the weathering processes,
2. minerals that resisted destruction, and
3. organic debris added to the weathering zone.

## Chemical Weathering and Soils

***Functions of weathering***

- gives rock lower strength and greater permeability,
- produces minor landforms,
- releases minerals in solution,
- Is first step in soil formation.

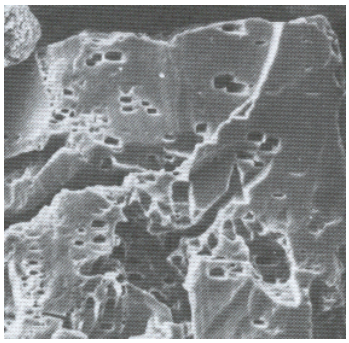
## Chemical Weathering and Soils

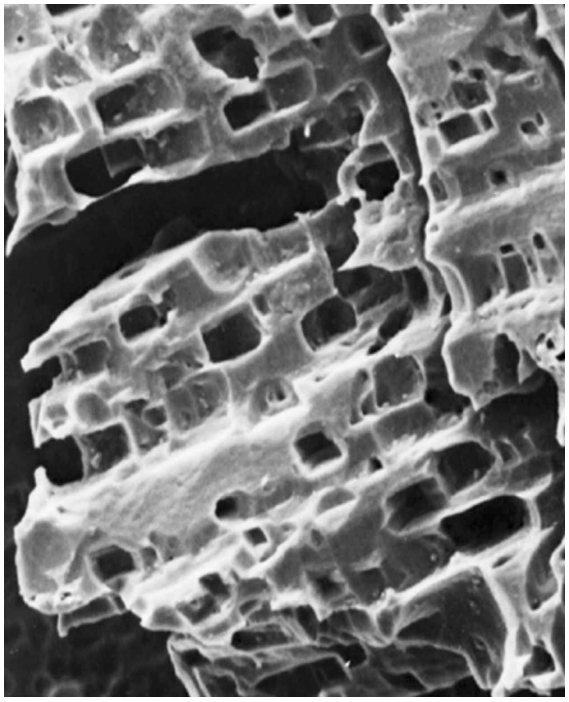
**Decomposition** - group of processes that attempt to create substances that are more nearly stable in that environment.

- Driving force for decomposition is water.

$$H_20 + CO_2 \Longleftrightarrow H_2CO_3$$

- How materials weather is related to how easily ions are released.
- sites of excess energy

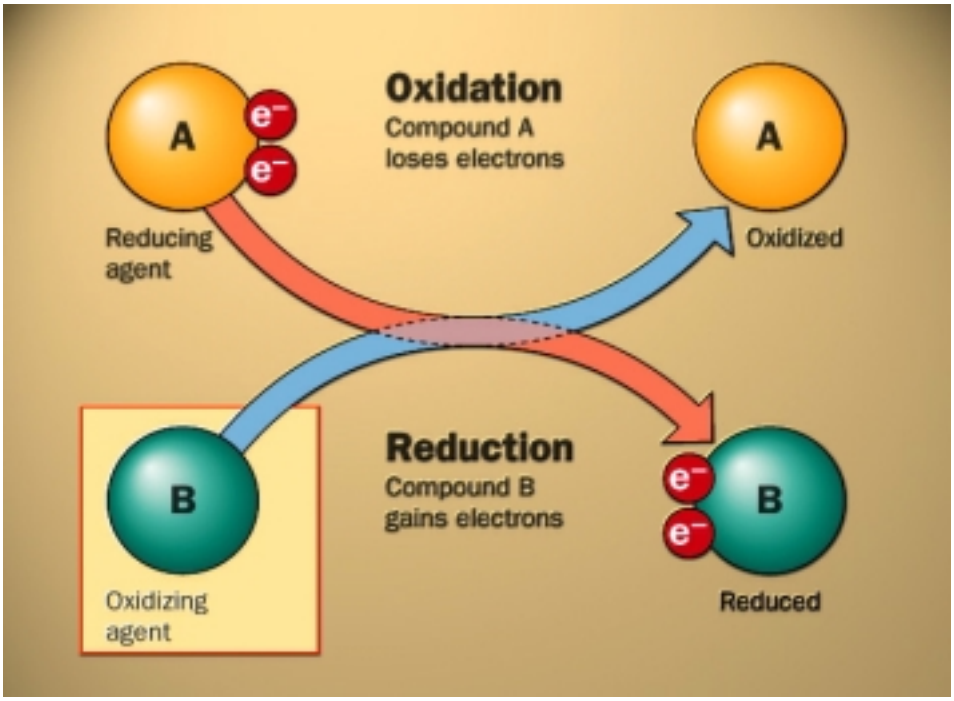




## Chemical Weathering and Soils

***Processes of Decomposition***

**Oxidation and Reduction**



## Chemical Weathering and Soils

***Processes of Decomposition***

**Oxidation and Reduction**

- iron is the most commonly oxidized mineral element $Fe^{+2}$ (ferrous iron) ——> $Fe^{+3}$ (ferric iron) or $2FeO + O_2$ ——> $Fe_2O_3$


Oxidized soil has turned red brown

## Chemical Weathering and Soils

***Processes of Decomposition***

**Solution -** when atoms are dissolved from a mineral, the structure becomes unstable.

$$CaCO_3 + H_2CO_3 \longrightarrow Ca^{+2} + 2HCO_{3-}$$

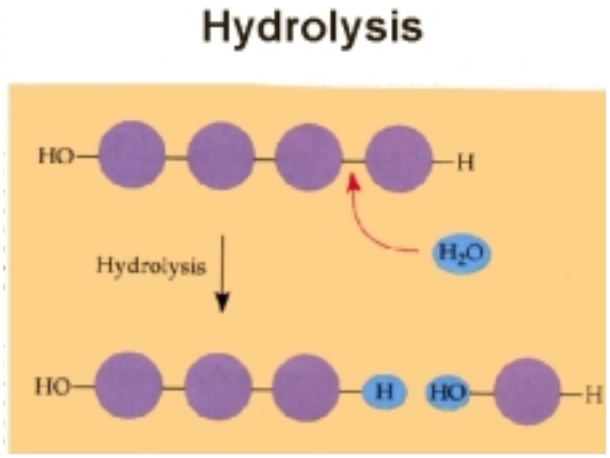
- bicarbonate represents the largest constituent of the dissolved load of most rivers

## Chemical Weathering and Soils

***Processes of Decomposition***

**Hydrolysis** - a reaction between a salt and water to produce an acid and a base.

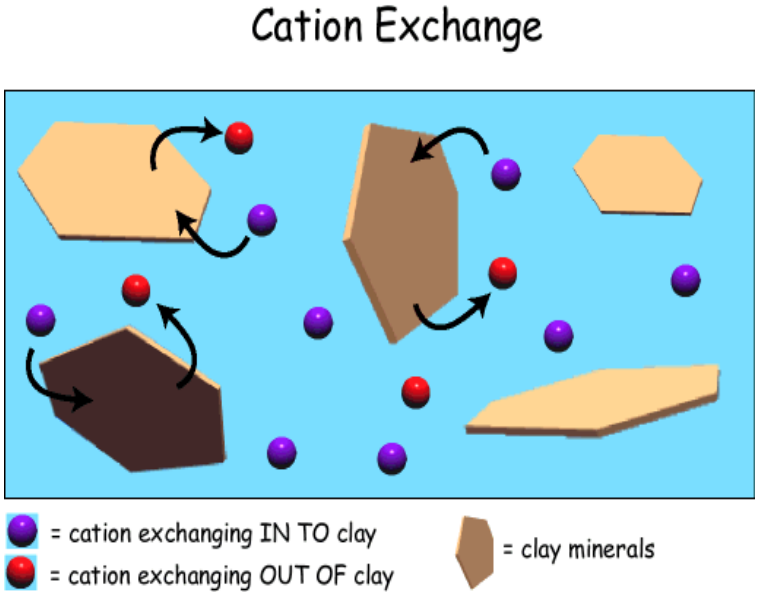
$CO_2 + H_2O \Longleftrightarrow H_2CO_3$ (carbonic acid) $\Longleftrightarrow H^+ + HCO_{3^-}$ (bicarbonate)



## Chemical Weathering and Soils

**Ion exchange** - is the substitution of ions in solution for those held by mineral grains - most effective in clay minerals.

***cation exchange capacity*** (c.e.c.) - exchange is governed by the composition and pH of the interstitial water as well as the type of ion in the exchangeable position.



## Chemical Weathering and Soils

**Representative Cation Exchange Capacities for Various Materials**

| *Material* | *Approximate cation exchange capacity (me/100 g dry weight)* |
|---|---|
| Organic matter | 150–500 |
| Kaolinite | 3–15 |
| Halloysite | 5–10 |
| Hydrated halloysite | 40–50 |
| Illite | 10–40 |
| Chlorite | 10–40 |
| Smectite | 80–150 |
| Vermiculite | 100–150+ |
| Palygorskite | 5–30 |
| Sepiolite | 20–45 |
| Allophane | 25–70 |
| Hydrous oxides of aluminum and iron | 4 |
| Feldspars | 1–2 |
| Quartz | 1–2 |
| Basalt | 1–3 |
| Zeolites | 230–620 |

(Taken from Carroll[15] and Grim[32]; palygorskite and sepiolite data from Weaver and Pollard.[71])

## Chemical Weathering and Soils

***Mobility of decomposed materials***

**Leaching**

- removes in solution the constituents that have been separated from minerals
- affects the pH of fluids surrounding minerals
- transfer mechanism

## Chemical Weathering and Soils

***Mobility of decomposed materials***

**Fixation and retardation** - mobility is considerably lower than might be expected.

**Chelation -** reaction between a metal ion and a complexing agent

- metallic ions that are extremely immobile under normal conditions can be mobilized by reacting with complexing agents

## Chemical Weathering and Soils

***Degree and rate of Decomposition***

- **End products**
- **Mineral stability**
- **Secondary minerals**
- **Estimates based on chemical analyses**

**Mean Lifetime of a 1 mm Crystal at 25°C and pH 5 (From Lasaga et al., 1994, Table 1 and References Therein).**

| *Mineral* | *Lifetime (years)* |
|---|---|
| Quartz | 34,000,000 |
| Kaolinite | 6,000,000 |
| Muscovite | 2,600,000 |
| Epidote | 923,000 |
| Microcline | 921,000 |
| Prehnite | 579,000 |
| Albite | 575,000 |
| Sanidine | 291,000 |
| Gibbsite | 276,000 |
| Enstatite | 10,100 |
| Diopside | 6,800 |
| Forsterite | 2,300 |
| Nepheline | 211 |
| Anorthite | 112 |
| Wollastonite | 79 |

## Chemical Weathering and Soils

### Soils

The vertical arrangement of the layers constitutes a diagnostic property of soils known as the ***soil profile*.**

Relationship between bedrock and soil profile

Soil Profile

Bedrock

## Chemical Weathering and Soils

***Fundamental concepts of soil genesis (pedogenesis)***

- Present day processes operate through space and time,
- Distinct regimes of soil processes produce distinct soils,
- Soil and its vegetation cover modify processes of land degradation,
- Clay is produced within the soil,
- Organo-mineral complexes are produced in the soil,

## Chemical Weathering and Soils

***Fundamental concepts of soil genesis (pedogenesis)***

- In the course of pedogenesis, soil succession occurs,
- Complexity is more common than simplicity
- Little of the soil continuum is older than Tertiary and most no older than Pleistocene times,
- A knowledge of the Pleistocene is pre-requisite to understanding soils.

## Chemical Weathering and Soils

***The soil profile***

O horizon

A horizon

E horizon (eluvial)

B horizon (illuvial)

C horizon

Bedrock

## Chemical Weathering and Soils

***The soil profile***

**O Horizons** – layers dominated by organic material.

## Chemical Weathering and Soils

***The soil profile***

**A horizons** – Mineral horizons that formed at the surface or below an O horizon, that exhibit obliteration of all or much of the original rock structure and show one of  more of the following:

## Chemical Weathering and Soils

***The soil profile***

**E horizon** – underlies the O or A horizon and is characterized by intense leaching that removes Fe3+ or organic coatings from the mineral particles (***eluvial***).

## Chemical Weathering and Soils

***The soil profile***

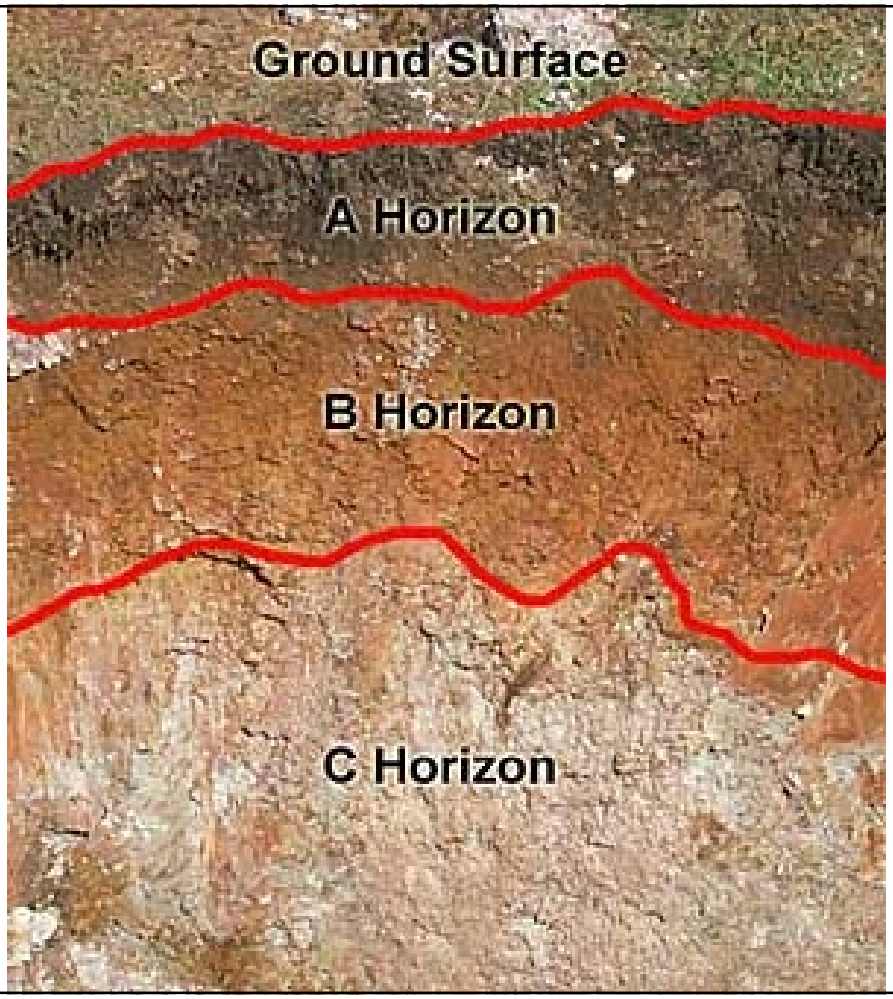
**B horizons** –generally show ***illuvial*** concentration of silicate clay, iron, aluminum, humus, carbonates, gypsum, or silica alone or in combination;

## Chemical Weathering and Soils

***The soil profile***

**C horizon** has no properties typical of the overlying horizons.

The **R horizon** is simply consolidated bedrock beneath the soil.


Ground Surface
A Horizon
B Horizon
C Horizon

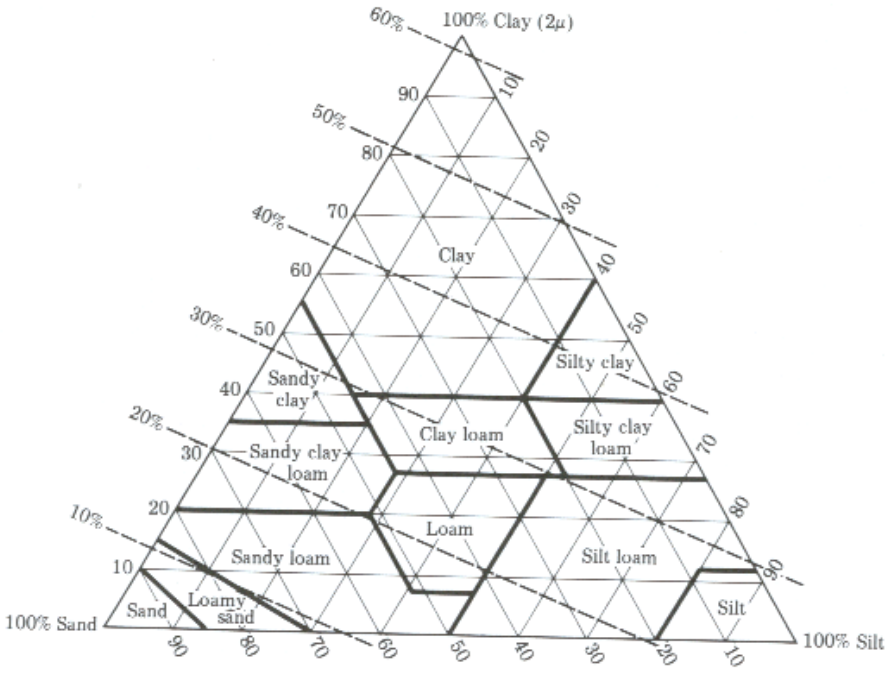

1
2
3


0
20
40
60
80
1
20
40

## Chemical Weathering and Soils

***Soil Properties***

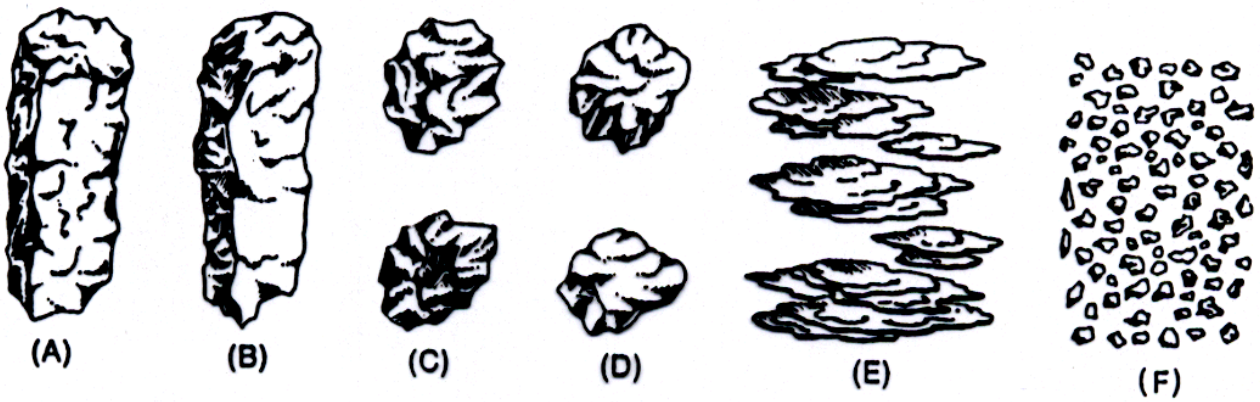
***Texture*** - proportions of different particle sizes in a soil horizon.



## Chemical Weathering and Soils

### *Soil Properties*

***Structure*** is a unique characteristic in that it designates the shape developed when individual particles cluster together into aggregates called ***peds***.

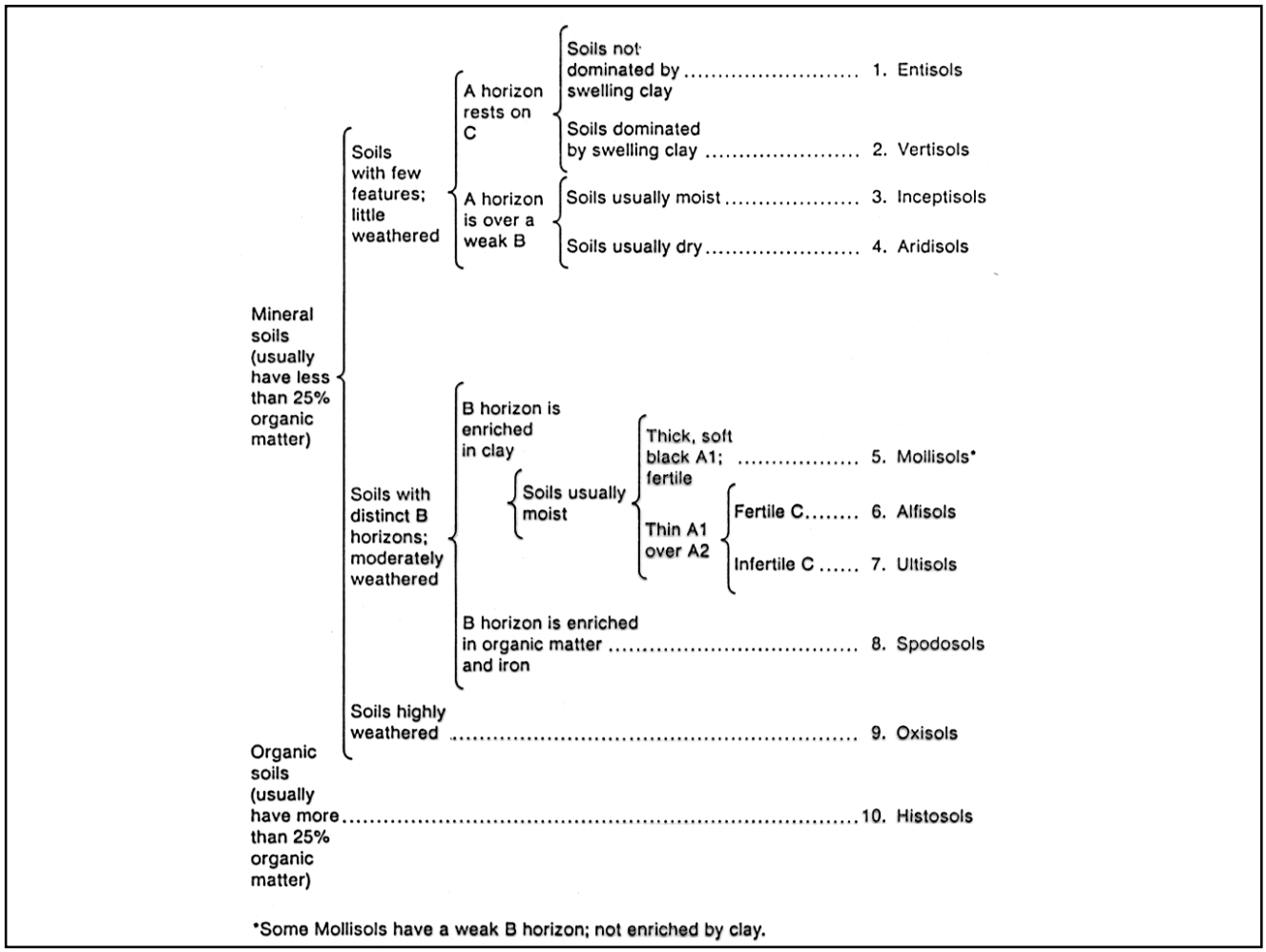


## Chemical Weathering and Soils

***Soil classification***

major orders are:

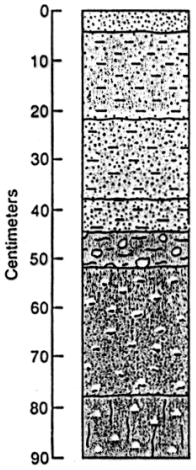
| | | |
|---|---|---|
| Entisols | - | recent |
| Vertisols | - | inverts |
| Inceptisols | - | inception |
| Aridisols | - | arid |
| Mollisols | - | mollify (to lessen in intensity, to soften |
| Spodosol | - | podzol, odd |
| Alfisol | - | pedalfer |
| Ultisol | - | ultimate |
| Oxisol | - | oxide |
| Histosol | - | histology (tissue) |


Mineral soils (usually have less than 25% organic matter)
Soils with few features; little weathered
A horizon rests on C
Soils not dominated by swelling clay ..... 1. Entisols
Soils dominated by swelling clay ..... 2. Vertisols
A horizon is over a weak B
Soils usually moist ..... 3. Inceptisols
Soils usually dry ..... 4. Aridisols
Soils with distinct B horizons; moderately weathered
B horizon is enriched in clay
Soils usually moist
Thick, soft black A1; fertile ..... 5. Mollisols*
Thin A1 over A2
Fertile C ..... 6. Alfisols
Infertile C ..... 7. Ultisols
B horizon is enriched in organic matter and iron ..... 8. Spodosols
Soils highly weathered ..... 9. Oxisols
Organic soils (usually have more than 25% organic matter) ..... 10. Histosols
*Some Mollisols have a weak B horizon; not enriched by clay.

## Chemical Weathering and Soils

| Symbol[a] | Meaning |
|---|---|
| b | buried soil horizon |
| g | strong gleying |
| h | illuvial humus |
| ir | illuvial iron |
| k[b] | accumulation of alkaline earth carbonates, commonly $CaCO_3$ |
| m | strong cementation |
| p | plowing |
| t | illuvial clay |
| x | fragipan character |

From Soil Survey Staff, 1975, 1981.
[a]Symbols used with other profile designations (e.g., B2t, B1h, Cca).
[b]Formerly designated as ca, a term many publications still use.

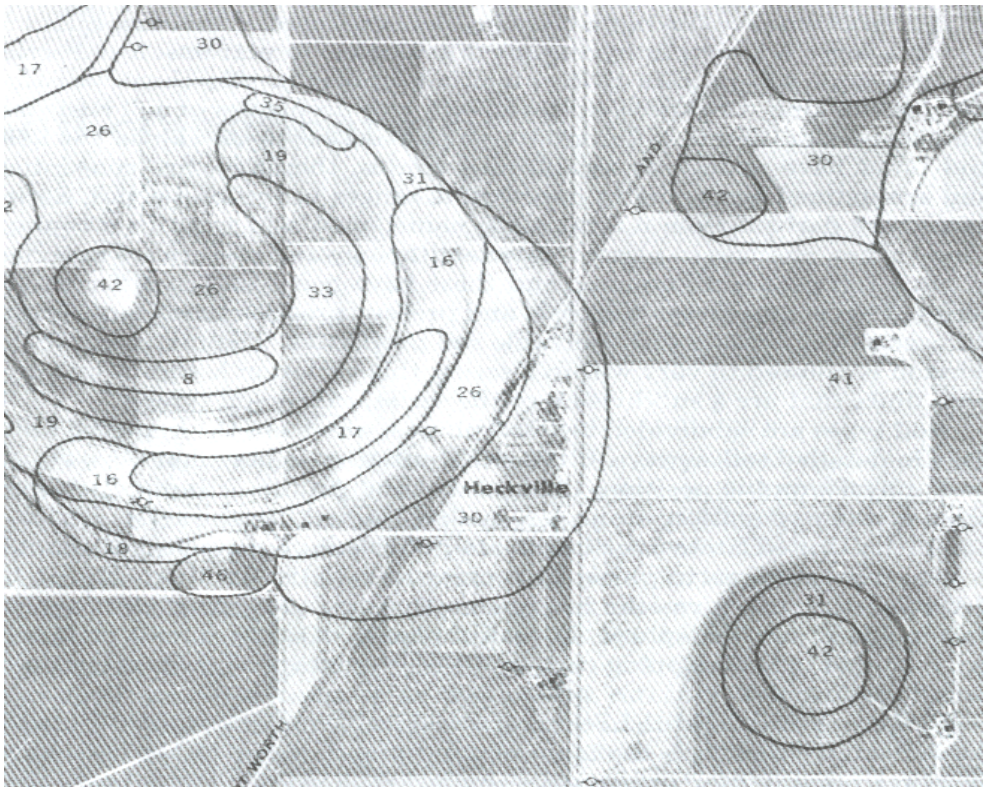



| *Section* | *Soil Horizon*[a] | *Description*[b] |
|---|---|---|
| | A2 | Fine loam, crumb soft, loose. |
| | B1t | Fine sandy loam, massive slightly hard. Color 7YR 4/2. |
| | B21t | Fine, sandy loam, massive hard. |
| | B22tk | Fine sandy loam, massive hard, calcareous. |
| | 2B1k | Sandy gravel, horizontally laminated. $CaCo_3$, Color 10YR 7/1. |
| | 2C1k | Sandy gravel. $CaCo_3$ coatings on pebbles. |
| | 3C1k | $CaCo_3$ in cracks of granite. |

[a] Lowercase k may now be used in place of ca.
[b] Color from Munsell color charts (see Soil Survey Staff, 1975, pp. 463–69 for discussion).

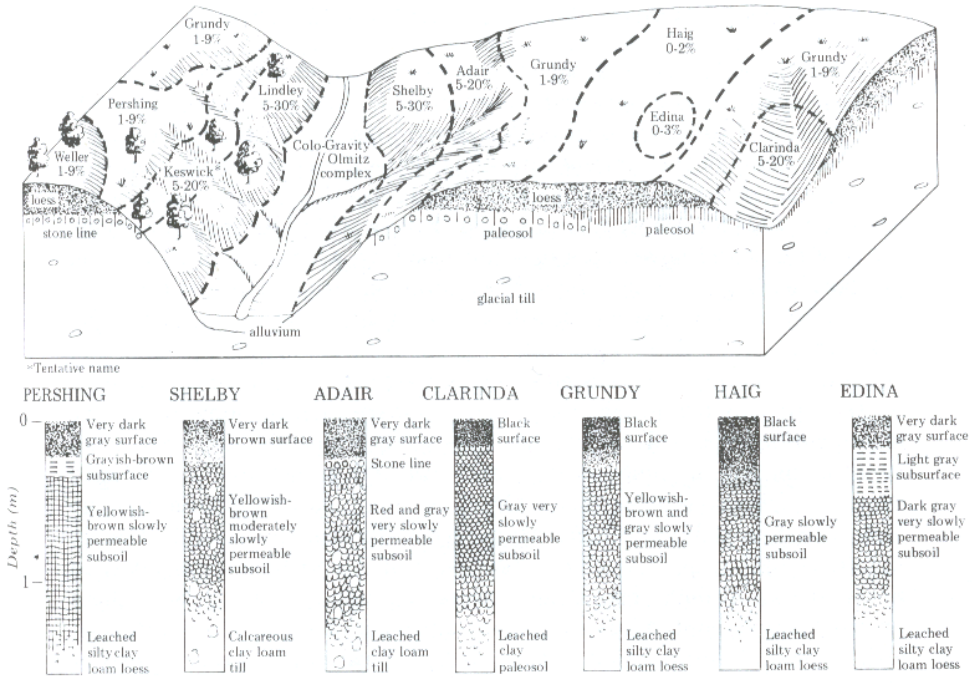
## Chemical Weathering and Soils

***How are soils mapped?***



## Chemical Weathering and Soils

### *How are soils mapped?*



## Chemical Weathering and Soils

***How are soils mapped?***

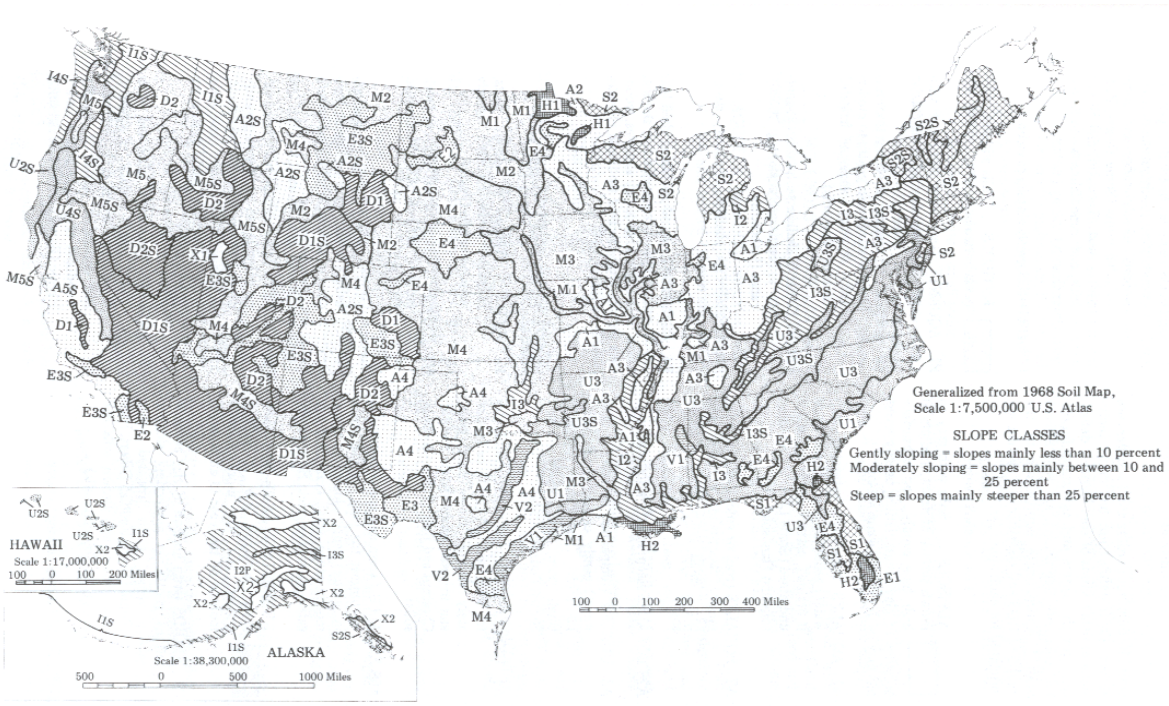



**Fig. 2-4** Patterns of soil orders and suborders of the United States. (Courtesy of the U.S. Dept. Agriculture, Soil Conservation Service.)

## Chemical Weathering and Soils

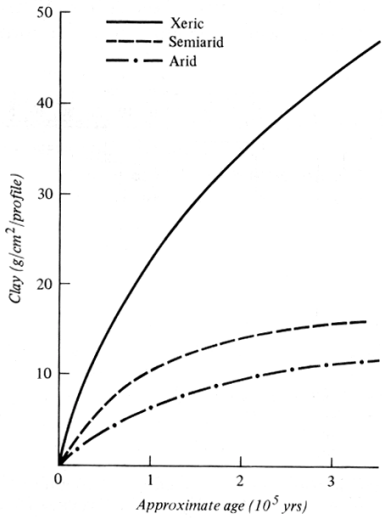
***Pedogenic controls and regimes***

Soil = ∫ (climate, biota, time, parent material, topography)

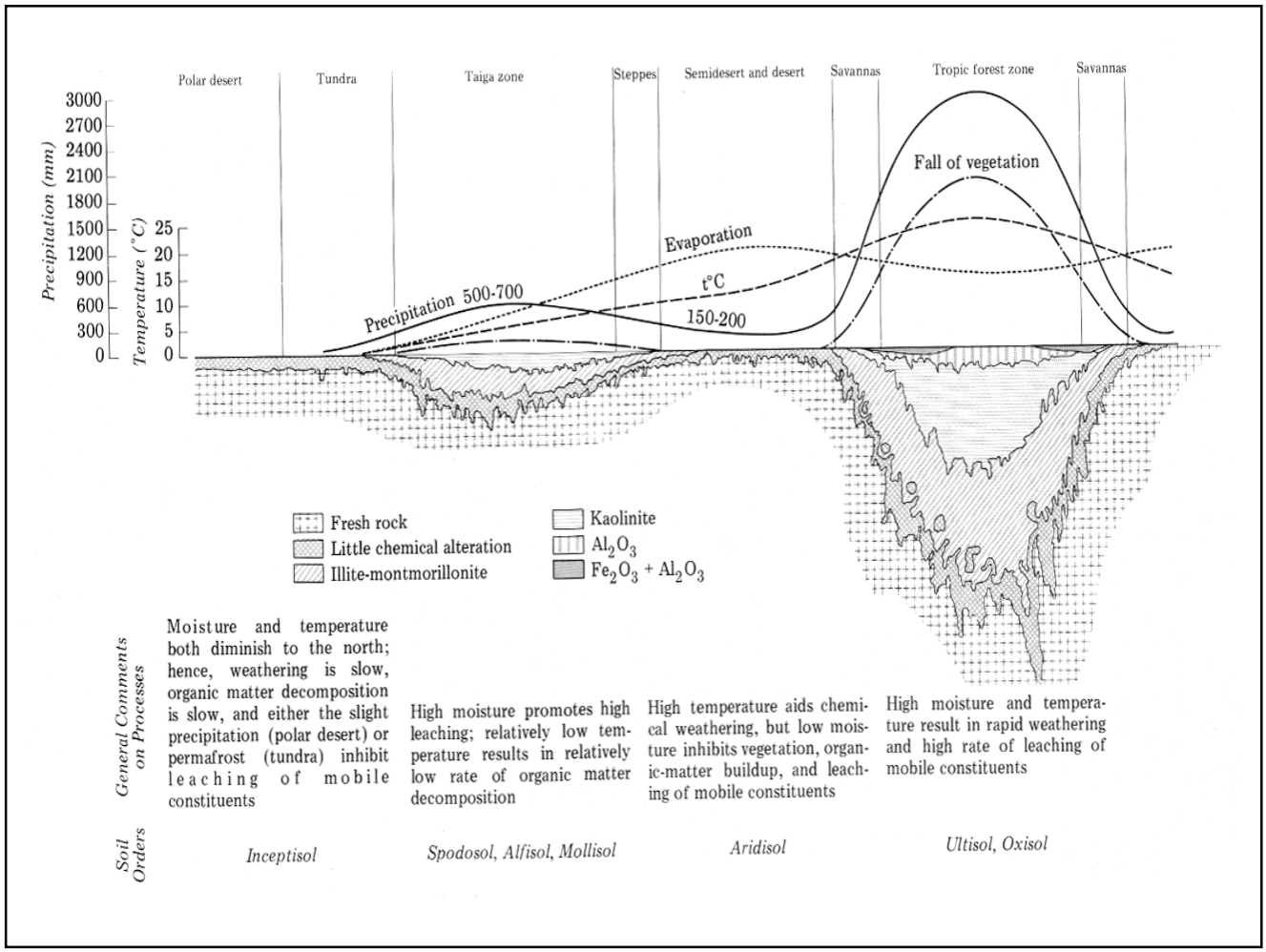
## Chemical Weathering and Soils

### *Pedogenic controls and regimes*

**Climate**



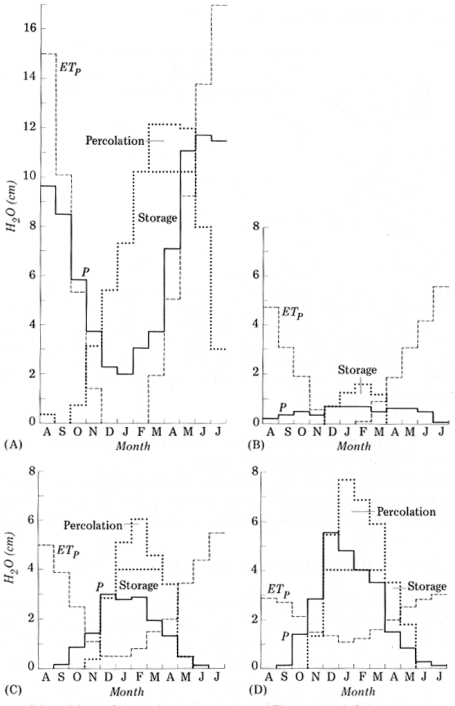

The amount of pedogenic clay as a function of time in three climatic regimes, Southern California. The mean annual precipitations (cm) and temperatures (°C) for the three regimes are, respectively, arid—<12, <22; semiarid—12–25; 15–22; and xeric—25–75, 12–22. (Taken from McFadden,[72] Fig. 27.)


Polar desert
Tundra
Taiga zone
Steppes
Semidesert and desert
Savannas
Tropic forest zone
Savannas
Precipitation (mm)
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
Temperature (°C)
25
20
15
10
5
0
Fall of vegetation
Evaporation
t°C
Precipitation 500-700
150-200
Fresh rock
Little chemical alteration
Illite-montmorillonite
Kaolinite
$Al_2O_3$
$Fe_2O_3 + Al_2O_3$
General Comments on Processes
Moisture and temperature both diminish to the north; hence, weathering is slow, organic matter decomposition is slow, and either the slight precipitation (polar desert) or permafrost (tundra) inhibit leaching of mobile constituents
High moisture promotes high leaching; relatively low temperature results in relatively low rate of organic matter decomposition
High temperature aids chemical weathering, but low moisture inhibits vegetation, organic-matter buildup, and leaching of mobile constituents
High moisture and temperature result in rapid weathering and high rate of leaching of mobile constituents
Soil Orders
Inceptisol
Spodosol, Alfisol, Mollisol
Aridisol
Ultisol, Oxisol

## Chemical Weathering and Soils

### *Pedogenic controls and regimes*

**Climate**




Monthly values of precipitation ($P$), potential evapotranspiration ($(ET_p)$, soil-moisture storage in the A and B horizons (10.2-cm available water-holding capacity), and soil-moisture percolation below the Bw or Bt horizon for various climatic stations. Mean temperature as follows:

| Station | Mean temperature (°C) Jan. | July |
|---|---|---|
| (A) Manhattan, Kan. | −1.6 | 26.6 |
| (B) Fallon, Nev. | −1.2 | 22.9 |
| (C) Sacramento, Calif. | 7.5 | 23.2 |
| (D) Half Moon Bay, Calif. | 9.9 | 17.0 |

## Chemical Weathering and Soils

### *Pedogenic controls and regimes*

**Parent material**

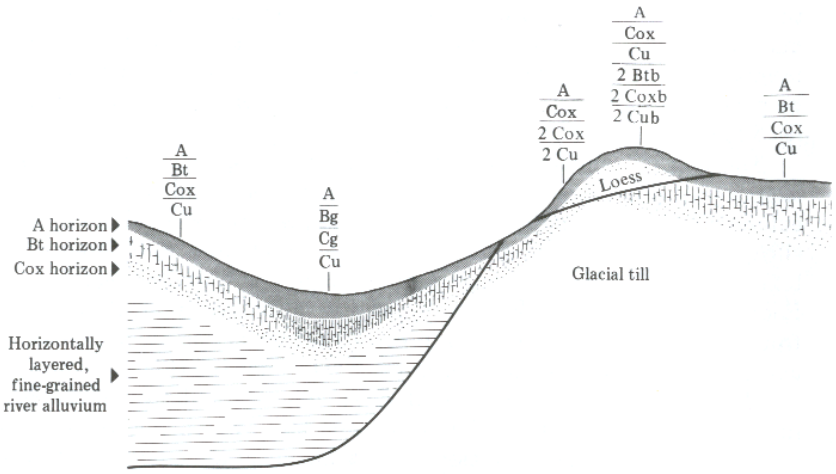


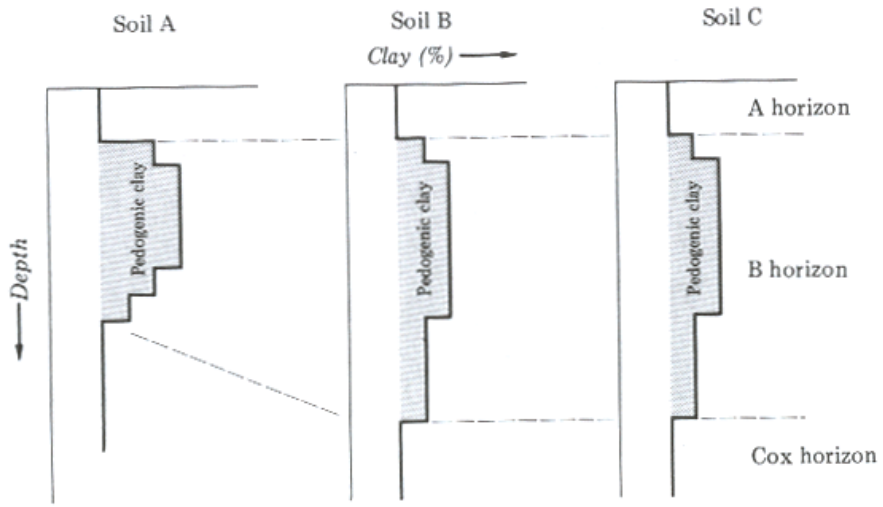

**Fig. 1-3** Lateral variation in soil profiles due to lateral variation in environmental conditions and lithology and age of parent materials. Soil horizons parallel the land surface. Those horizons that are developed from river alluvium truncate depositional layering; hence, soil properties are, for the most part, independent of properties of the depositional layers. The soil formed on glacial till was partly truncated by erosion before burial by loess; it grades laterally to the right from a buried to an exhumed soil, because the loess cover has been removed by erosion in that direction.

## Chemical Weathering and Soils

### *Pedogenic controls and regimes*

### Parent material

Comparison of 3 soil profiles based on both percent clay and weight of the clay formed. All formed at the same time.

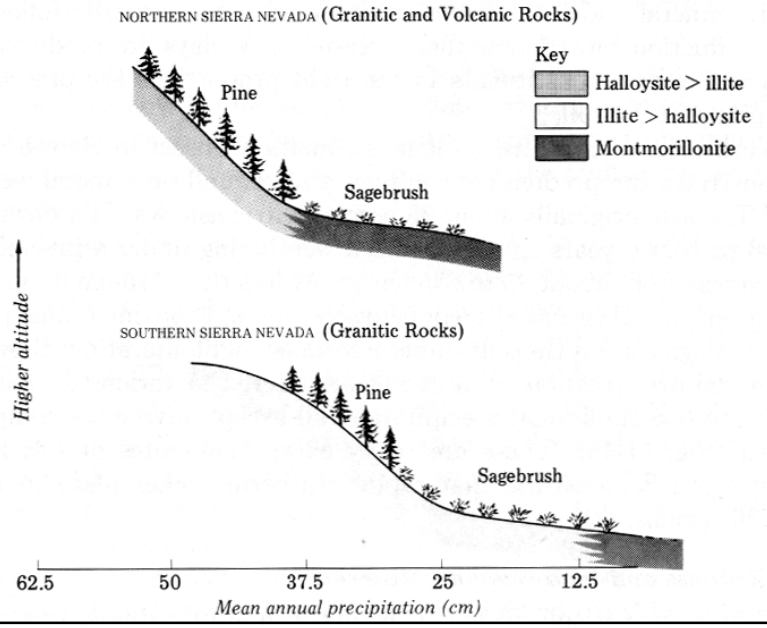



| | Soil A | Soil B | Soil C |
|---|---|---|---|
| Clay (g)/100 g < 2 mm parent material | 17 | 17 | 8.5 |
| Parent material: | Sandy alluvium | Sandy alluvium | Gravelly alluvium (50% of particles, by volume, are gravel) |

## Chemical Weathering and Soils

***Pedogenic controls and regimes***

**Parent material**



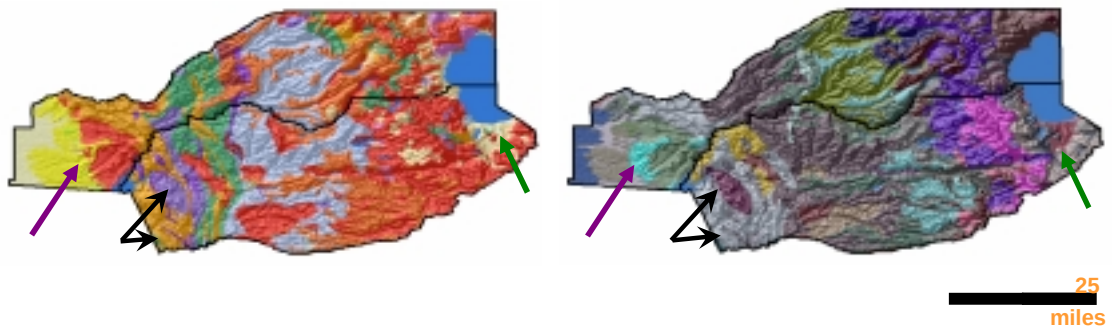
## Chemical Weathering and Soils

*Pedogenic controls and regimes*

**Parent material**

**Correlation of Geology and Soil Distribution for both El Dorado and Placer County**

**Geology** **Soil**

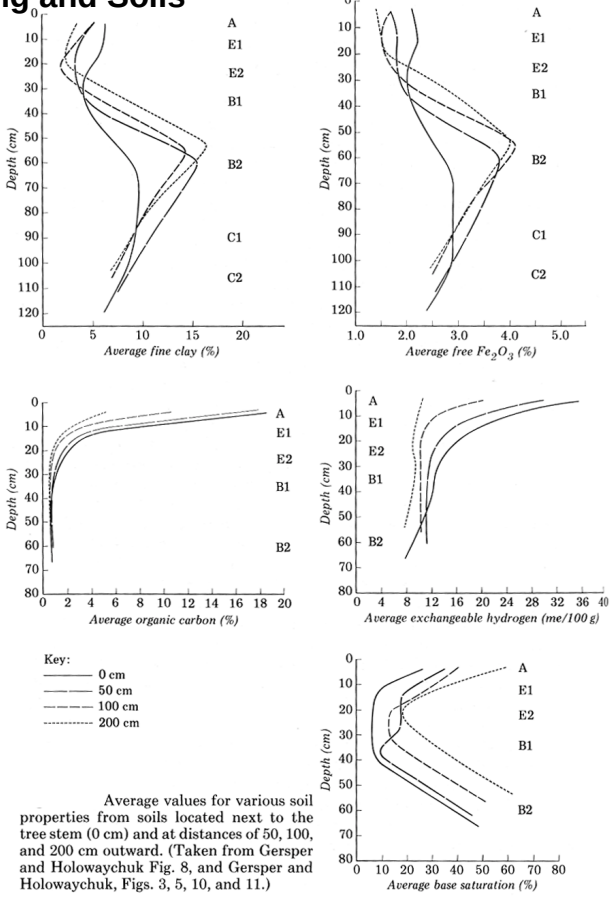



(Similarities shown in same colored arrow)

## Chemical Weathering and Soils

***Pedogenic controls and regimes***

**Biotic factor**




Average values for various soil properties from soils located next to the tree stem (0 cm) and at distances of 50, 100, and 200 cm outward. (Taken from Gersper and Holowaychuk Fig. 8, and Gersper and Holowaychuk, Figs. 3, 5, 10, and 11.)

## Chemical Weathering and Soils

### *Pedogenic controls and regimes*

**Topography**

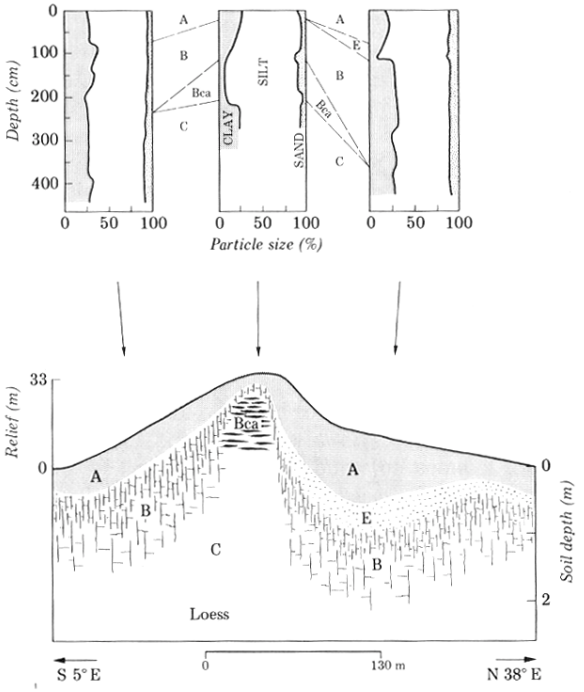



**Fig. 9-3** Variation in soil properties with slope orientation in loess hills, eastern Washington. (Taken from Lotspeich and Smith,[34] Figs. 2 and 3, © 1953, The Williams & Wilkins Co., Baltimore.)

## Chemical Weathering and Soils

### *Pedogenic controls and regimes*

**Topography**

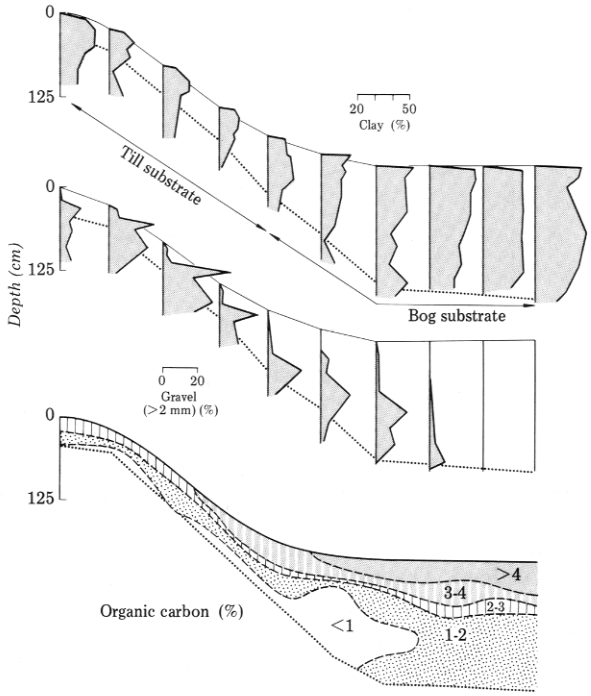
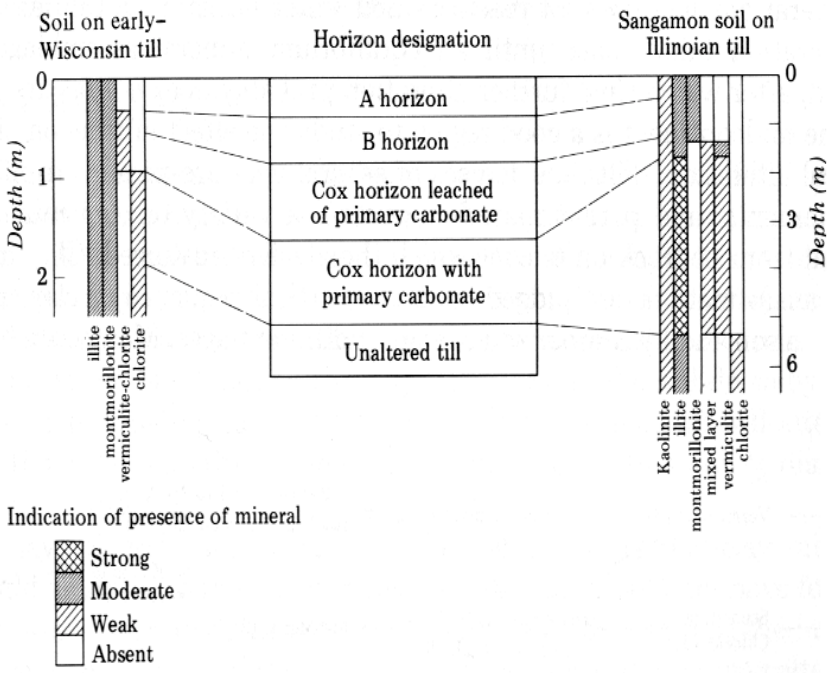



**Fig. 9-7** Relationship of particle size and organic carbon with topographic position in a closed depression and on surrounding hillslopes, Iowa. (Taken from Walker,[57] Figs. 19, 30, and 31.) The dotted line separates hillslope sediments from till on the hillslopes, and younger from older deposits in the low-lying area.

## Chemical Weathering and Soils

***Pedogenic controls and regimes***

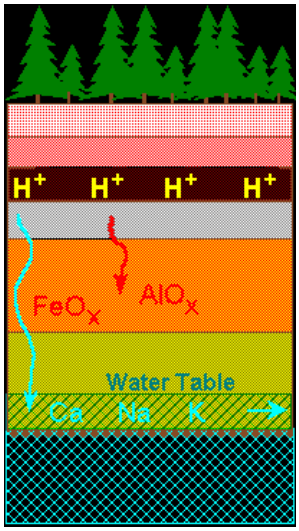
**Time**



## Chemical Weathering and Soils

### *Pedogenic controls and regimes*

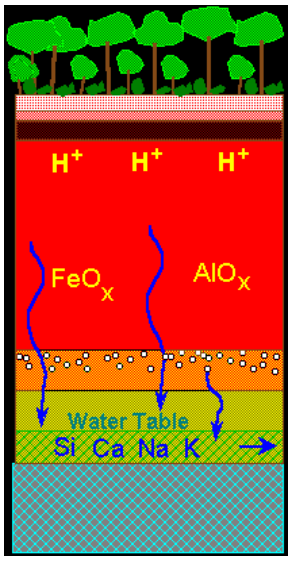
**Podzolization -** downward translocation of iron, aluminum, and organic matter to form a eluvial E horizon overlying a tan illuvial B horizon.

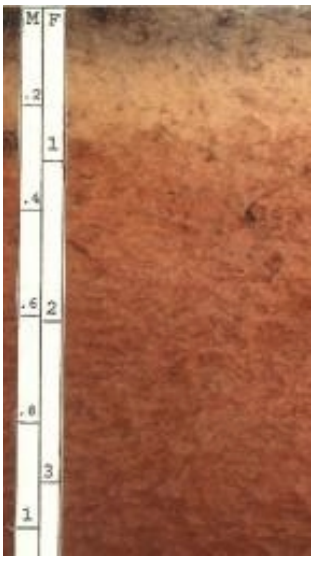



## Chemical Weathering and Soils

### *Pedogenic controls and regimes*

**Laterization** - extreme chemical alteration of the original parent material.



## Chemical Weathering and Soils

***Pedogenic controls and regimes***

**Calcification -** a general buildup of calcium carbonate in the soil profile.

## Chemical Weathering and Soils

### *Pedogenic controls and regimes*

**Salinization** - soluble salts precipitate from water and accumulate in the soil. Saline soils are common in desert and steppe climates.

## Chemical Weathering and Soils

### Geomorphic significance of soils

They are used primarily

- in the subdivision of a local succession of deposits,

## Chemical Weathering and Soils

### Geomorphic significance of soils

They are used primarily

- to provide data on the lengths of time that separate periods of deposition,
- to facilitate short- and long-term correlation, and, of recent discovery,
- to date Quaternary events (faulting, climate change, etc.)
- archeological studies
- Reconstruct climates

## Chemical Weathering and Soils

### Geomorphic significance of soils

Soils that form on a landscape of the past are ***paleosols***.

They can be of three types:

1. ***buried soils*** are developed on a former landscape and subsequently covered by younger alluvium or rock;

2. ***relict soils*** were not subsequently buried but still exist at the surface; and

3. ***exhumed soils*** were at one time buried but have been re-exhumed when their cover was stripped by erosion.