PEDOGENIC PROCESSES IN HYDRIC SOILS AND REDOXIMORPHIC FEATURES

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OVERVIEW

1. Chemistry of Waterlogged Soils
2. Basic Hydrology
3. Wet Soil Features
4. Problems

I. CHEMISTRY OF WATERLOGGED SOILS

A. Oxidation-Reduction (Redox) Reactions

1. The most important chemical reactions in waterlogged soils.

2. These reactions control: Soil colors, organic matter contents, and the amount of O_2, NO_3, Fe, and SO_4 in soil water.

B. Oxidation-Reduction Principles

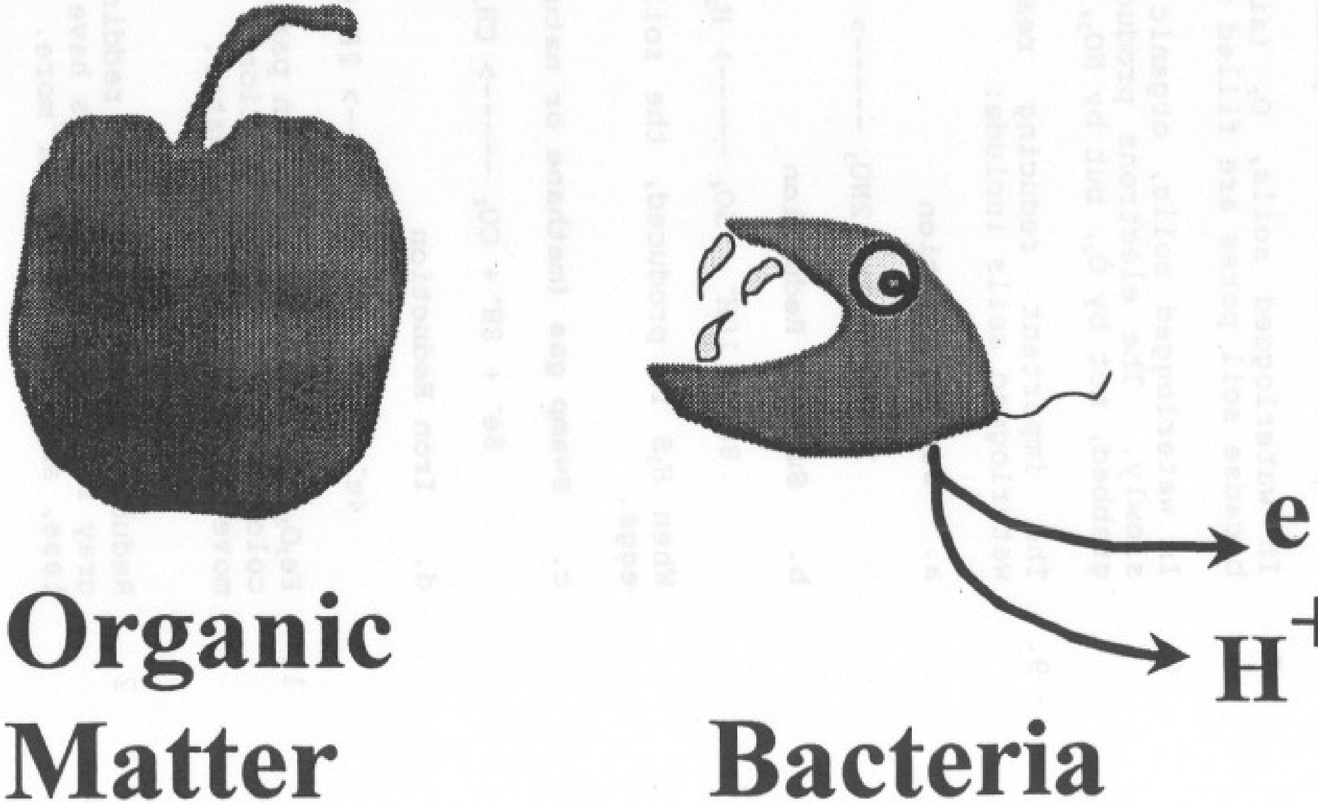
1. Electrons (e^-) are taken out of one substance and given to another.

2. Most electrons come from organic matter as it rots (decomposes).

3. If organic matter is not present, then oxidation-reduction reactions don't occur.

4. Oxidation: the production of electrons. Occurs when bacteria eat organic matter. The bacteria produce substances that donate electrons and H^+ (protons) for reduction (See Fig.).

Oxidation (Producing e^-)



5. Reduction: the consumption of electrons.

$$4e^- + O_2 + 4H^+ \text{ -----> } 2H_2O$$

6. When air is present in soil, all e^- produced by organic matter decomposition are grabbed by O_2 to make water.

7. In waterlogged soils, O_2 (air) does not enter soil because soil pores are filled with water.

8. In waterlogged soils, organic matter still decomposes slowly. The electrons produced by decomposition are grabbed, not by O_2, but by NO_3, Fe_2O_3, SO_4, and CO_2.

9. The important reducing reactions that occur in waterlogged soils include:

   a. **Denitrification**

   $$12e^- + 12H^+ + 2NO_3 \text{ -----> } N_2 + 6H_2O$$

   b. **Sulfate Reduction**

   $$8e^- + 10H^+ + SO_4 \text{ -----> } H_2S + 4H_2O$$

   When H_2S is produced, the soil has a smell of rotten eggs.

   c. **Swamp gas (methane or natural gas) Production**

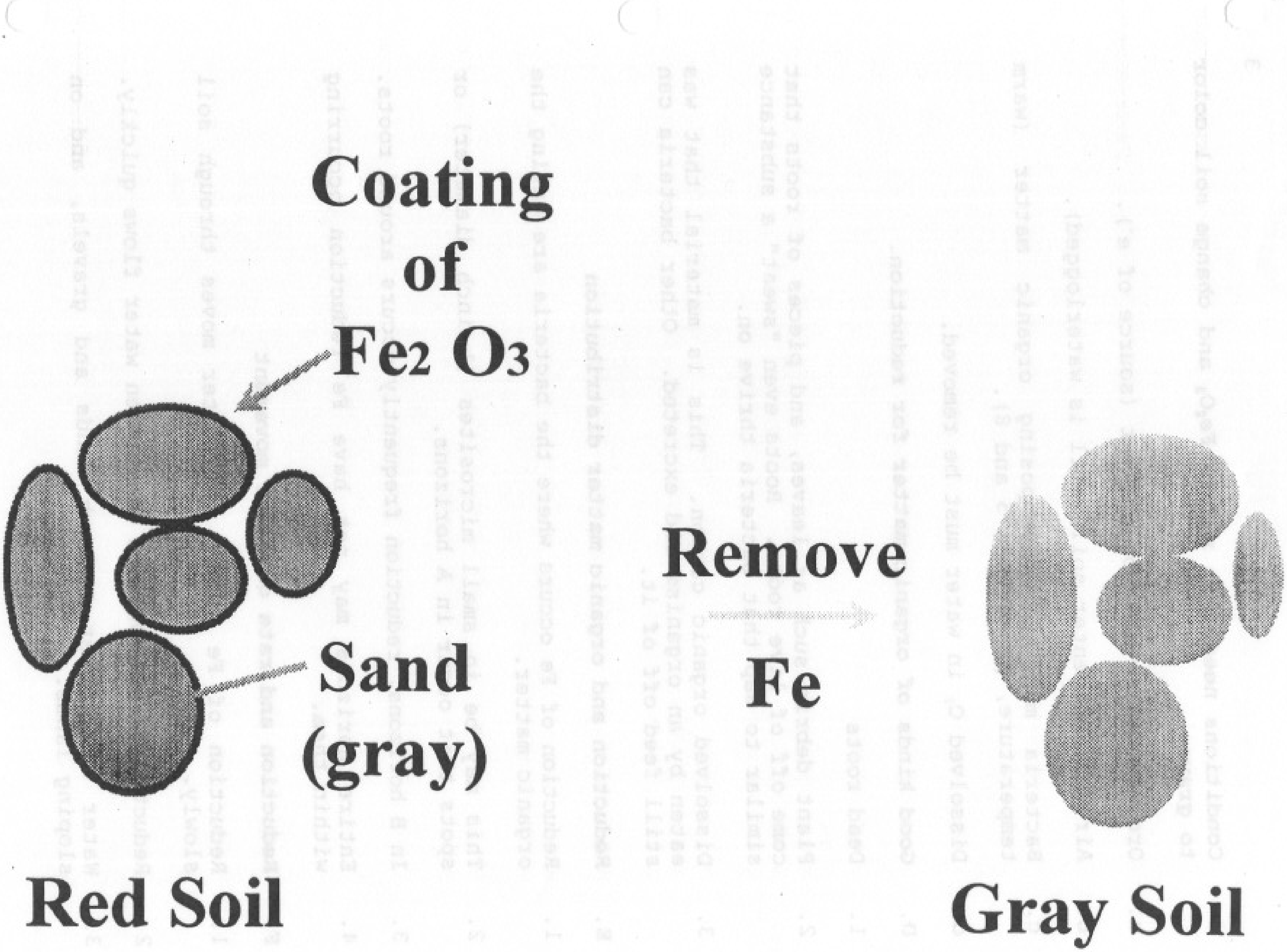
   $$8e^- + 8H^+ + CO_2 \text{ -----> } CH_4 + 2H_2O$$

   d. **Iron Reduction**

   $$4e^- + 6H^+ + Fe_2O_3 \text{ -----> } 2Fe(II) + 3H_2O$$

1. Fe_2O_3 is a solid coating on particle surfaces. Fe(II) is colorless and is in solution. It is dissolved Fe that moves through the soil water.

2. Reduction of Fe_2O_3 causes reddish colored soils to turn gray in color. Gray colors have Munsell chromas of 2 or less, and values of 4 or more.


Coating
of
Fe2 O3
Sand
(gray)
Red Soil
Remove
Fe
Gray Soil

C. Conditions needed to reduce Fe_2O_3 and change soil color to gray:

a. Organic matter must be present (source of e^-).

b. Air must not enter soil (soil is waterlogged).

c. Bacteria must be decomposing organic matter (warm temperature, pH between 5 and 8).

d. Dissolved O_2 in water must be removed.

D. Good kinds of organic matter for reduction.

1. Dead roots

2. Plant debris such as leaves, and pieces of roots that come off of live roots. Roots even "sweat" a substance similar to sap that bacteria thrive on.

3. Dissolved organic carbon. This is material that was eaten by an organism and excreted. Other bacteria can still feed off of it.

E. Reduction and organic matter distribution

1. Reduction of Fe occurs where the bacteria are eating the organic matter.

2. This may be in small microsites (1 inch diameter) or spots that occur in A horizons.

3. In B horizons, reduction frequently occurs around roots.

4. Entire horizons may not have Fe reduction occurring within them.

F. Reduction and rate of water movement

1. Reduction of Fe occurs when water moves through soil slowly.

2. Reduction of Fe does not occur when water flows quickly.

3. Water moves fast through sands and gravels, and on sloping lands.

4. Fast moving water carries O_2, which prevents Fe from being reduced.

5. When water tables rise due to rainfall alone, the water is aerated.

6. Reduction occurs after rainfall stops.

7. Soil may be waterlogged but not reduced, and not "mottled" if:

   a. organic matter content is low (e.g., < 2%).

   b. temperatures are cold (bacteria not active), such as outside of the normal growing season.

   c. water moves quickly (too much O_2)

G. **Case Study: Are all soils with "low chroma colors" saturated for similar lengths of time?**

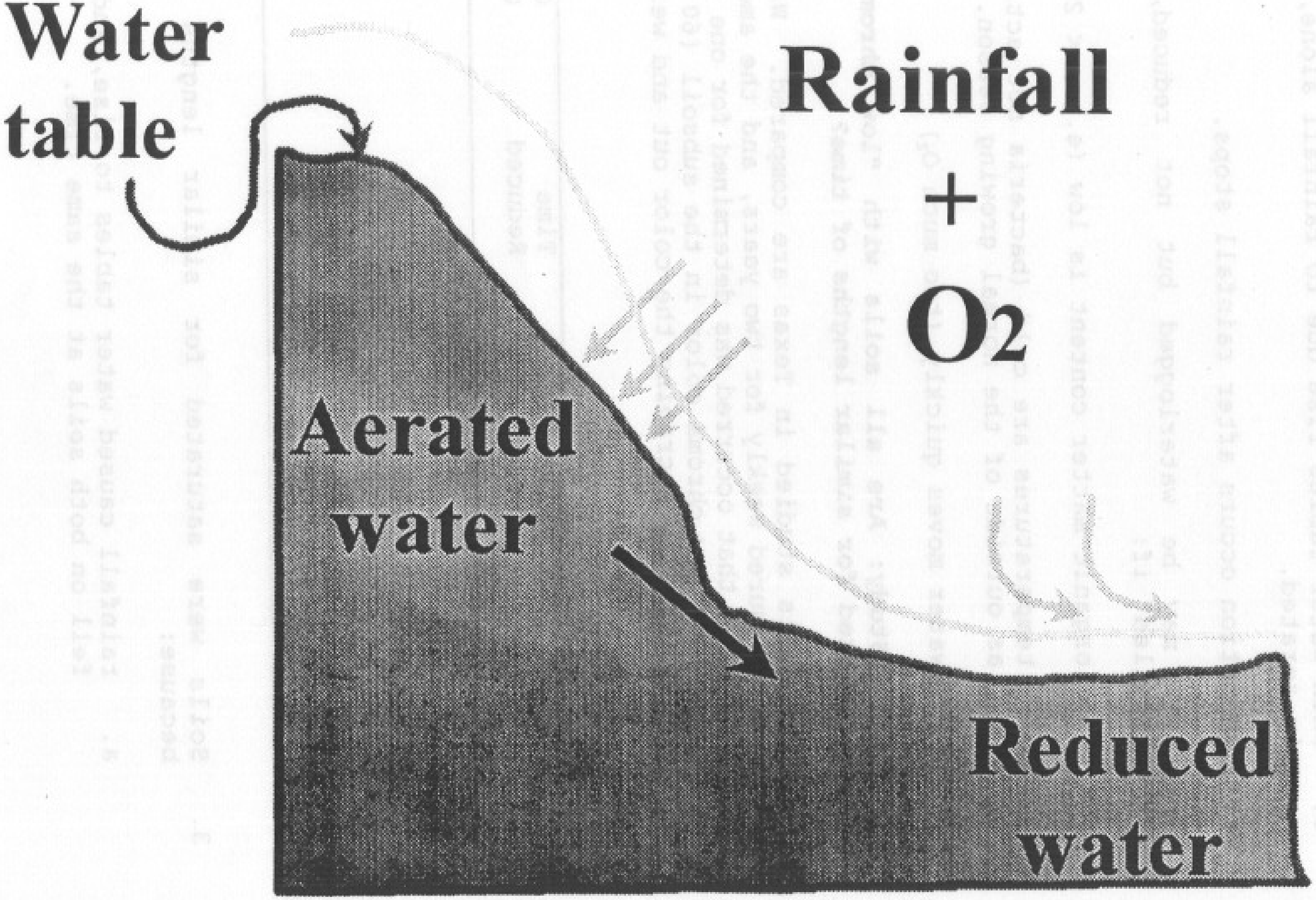
1. Two soils studied in Texas are compared. Watertables were measured weekly for two years, and the amount of Fe reduction that occurred was determined for one year. The amount of low chroma color in the subsoil (60 cm depth) was measured by scraping the color out and weighing it.

2. Results:

Soil Position	Time Saturated	Time Reduced	Gray Color
	% of Year		%
On Slope	35	5	20
Foot of Slope	35	30	80

3. Soils were saturated for similar lengths of times because:

   a. rainfall caused water tables to rise, and the rain fell on both soils at the same time.


Water table
Rainfall + O_2
Aerated water
Reduced water

b. evapotranspiration caused the water tables to fall, and the same kinds of trees were on both sites.

c. the water in the soil at the foot of the slope was reduced because the water was stagnant (not moving). Water on the sloping soil was moving constantly downslope.

H. **Color**

1. Gray colors usually mean "no iron" on particle surfaces.

2. Do "gray colors" always mean the soil has been reduced?

No. Some soil parent materials never had Fe_2O_3, and have always been gray.

3. Wet soils usually have both gray colors and reddish colors. The gray shows where Fe has been removed, while the red shows where the Fe has accumulated.

4. Gray color produced by reduction frequently has Fe concentrations in the same horizon or in lower horizons.

5. Soil color chromas of 2 or less:

a. No Fe is on particle surfaces,

b. Soils may be reduced for "significant" periods.

6. Soil color chroma of 3:

a. Soils may be reduced for "short" periods.

b. Soils may be saturated for "significant" periods, particularly if soil organic matter contents are < 1%, and soils are on slopes.

II. **BASIC HYDROLOGY**

A. **Water Tables**

1. Definitions: The surface of the water that fills a well or open auger hole, or

The upper level of "free water" that can flow out of soil into a well or hole.

2. The water table may not be the top of the saturated zone if a capillary fringe is present.

B. **Saturation:** There are two ways to define this, one definition is based on water content, the other is based on water pressure.

1. Saturation: Water Content definition. Saturation occurs when all pores are filled with water except for pores containing entrapped air.

   a. Problems with definition include: Must measure water content to know when soils is saturated, and this is not easy to due in the field.

   b. This definition includes the capillary fringe.

   c. The definition is difficult for workers to apply during field evaluations.

2. Saturation: Water Pressure definition. Saturation occurs where "free water" is present in the soil. The water has a pressure that is greater than atmospheric pressure.

   a. Comments: Free water fills wells and auger holes.

   b. The definition can be applied in the field.

   c. It does not include the capillary fringe.

Does Reduction occur near septic drainlines?

a. Is the soil waterlogged? Yes

b. Is organic matter present? Yes

c. Are bacteria present? Yes

Then reduction occurs.

Major points for Parts I and II:

a. Oxidation-reduction reactions causes gray colors to form in wet soils.

b. These reactions need organic matter, bacteria, and no air to be present in order to work.

c. The amount of gray color in the soil is usually related to how long the soils have been reduce, not how long they have been saturated.

d. To know how long a soil is saturated, you need to measure water tables with a well.

III. REDOXIMORPHIC FEATURES FOR IDENTIFYING AQUIC CONDITIONS

A. Introduction

1. In Soil Taxonomy, poorly drained soils had a "Aquic Moisture Regime". The moisture regime was poorly defined. It was defined on the basis of saturation and reduction, but was identified on the basis of soil morphology. This approach meant that it was never clear if all soils identified as having an aquic moisture regime were actually saturated and reduced.

2. In international committee was assembled to make improvements to the regime.

3. The committee recommended the moisture regime be modified, and the new regime was to be called "Aquic Conditions".

4. Aquic conditions is currently being used for soil classification purposes.

5. Objectives: The purpose of this lecture was to:

   a. Describe the requirements for aquic conditions,

   b. Discuss the morphology of redoximorphic features,

   c. Discuss how redoximorphic features can be interpreted, and

   d. Review the advantages of redoximorphic features.

B. **Aquic Conditions**

1. Definition: Aquic conditions requires that each of the following be documented separately for every soil series:

   a. Saturation depth,

   b. Occurrence of Fe reduction, and

   c. Redoximorphic features must be present.

2. Basic idea: The intent is to document that each soil series is saturated and reduced at one or two "local" sites, and then to extrapolate this information to similar soils using the redoximorphic features.

   It is now realized that we must calibrate a soils redoximorphic features to specific periods of saturation and reduction. This information cannot be obtained from the features themselves.

3. Saturation: A horizon is saturated when the soil water pressure is zero or positive.

   a. Water will run into an unlined auger hole or a piezometer when the horizon is saturated.

   b. Saturation may occur at any time of the year, not simply during the growing season as is required for jurisdictional wetlands.

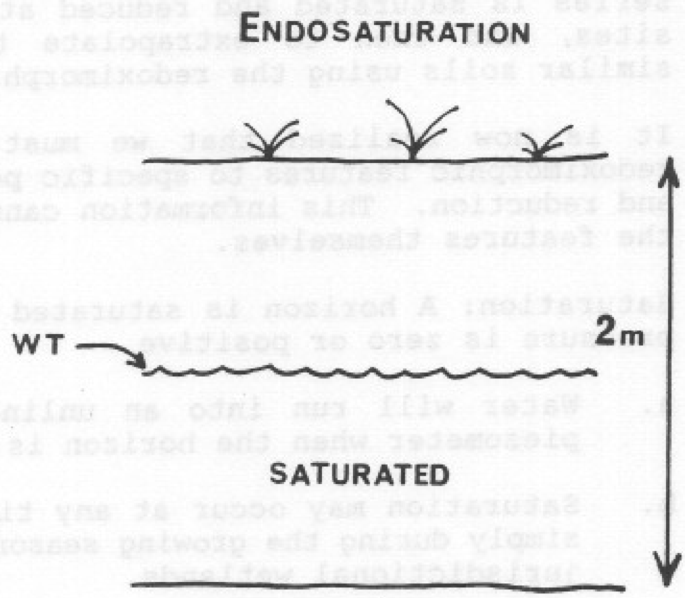
   c. Saturation is not required if the soils are artificially drained.

   d. Three kinds of saturation have been defined:

      i) Endosaturation-soil is saturated in all horizons that lie between the upper boundary of saturation and a depth of 2 m.

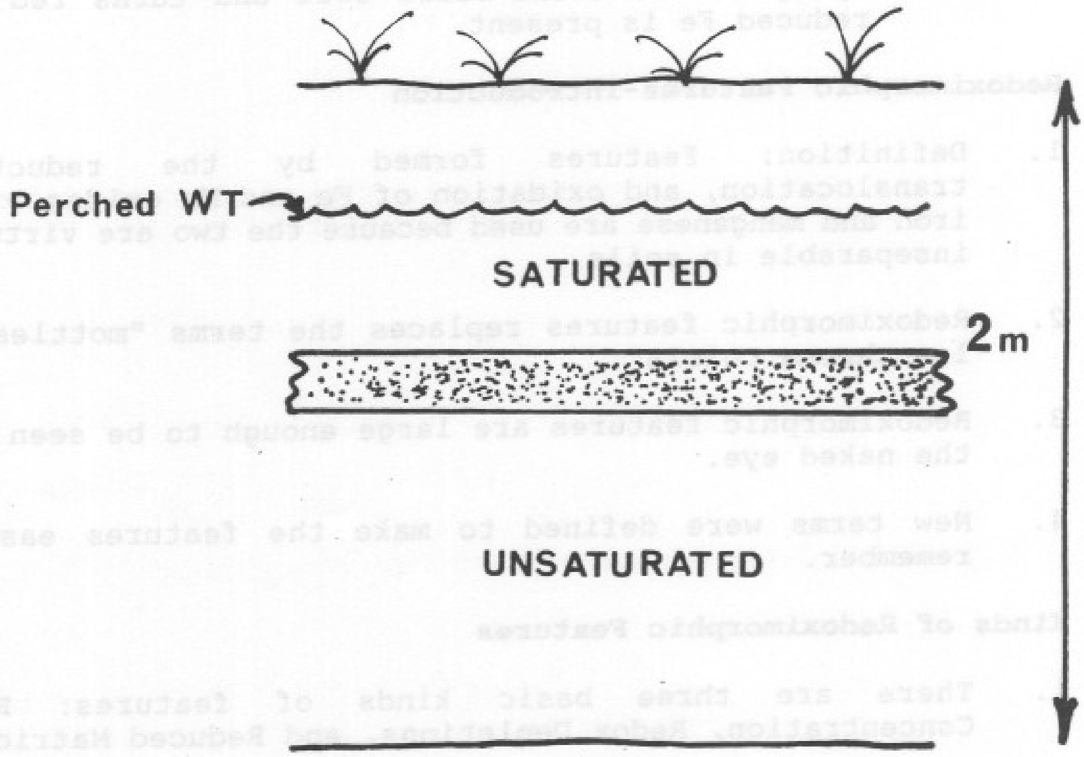
      ii) Episaturation-soil is saturated in a horizon that overlies an unsaturated horizon, where the unsaturated horizon lies within a depth of 2 m from the surface.

      iii) Anthric saturation-similar to episaturation but is used for sites having controlled flooding.



ENDOSATURATION
WT
2m
SATURATED

EPISATURATION



4. Reduction: Iron must be present in a reduced form (Fe(II)) at some time.

   a. No minimum time period is required for reduction.

   b. Any method that shows iron reduction is occurring can be used. This includes platinum microelectrodes to measure redox potential. It also includes the use of a-a'dipyridyl dye which is sprayed onto field-moist soil and turns red when reduced Fe is present.

C. **Redoximorphic Features-Introduction**

1. Definition: Features formed by the reduction, translocation, and oxidation of Fe and Mn oxides. Both iron and manganese are used because the two are virtually inseparable in soils.

2. Redoximorphic features replaces the terms "mottles and low chroma colors".

3. Redoximorphic features are large enough to be seen with the naked eye.

4. New terms were defined to make the features easy to remember.

D. **Kinds of Redoximorphic Features**

1. There are three basic kinds of features: Redox Concentration, Redox Depletions, and Reduced Matrices.

2. **Redox Concentrations:** Zones of apparent concentration of Fe/Mn oxides. There are three types:

   a. **Nodules and concretions** (hard bodies),

   b. **Masses** (soft bodies),

   c. **Pore linings** (coatings of Fe or Mn along cracks and root channels).

3. **Nodules and concretions:** firm to extremely firm irregularly shaped bodies with diffuse boundaries. These two terms are used interchangeably. Diffuse boundaries are thought to identify features that are currently forming. Most nodules and concretions with sharp boundaries have stopped forming.

4. **Masses:** Soft bodies, frequently within the matrix, whose shape is variable. This term replaces "mottles".

5. **Pore linings:** Zones of accumulation that may be either coatings on a pore surface or impregnations of the matrix adjacent to the pore.

6. **Redox Depletions**: Zones of low (<2) where Fe-Mn oxides alone have been removed, or where both Fe-Mn oxides and clay have been removed. There are two types:

   a. **Fe depletions**

   b. **Clay depletions**

7. **Iron Depletions:** low chroma bodies with clay contents similar to that of the adjacent matrix. These occur both along pores and in the matrix.

8. **Clay Depletions:** low chroma bodies containing less Fe, Mn, and clay than an adjacent soil matrix. Clay depletions form in place. They do not form by deposition of silt onto particle surfaces.

9. **Reduced matrix:** A soil matrix that has a low chroma in situ because of the presence of Fe(II), but whose color changes in hue or chroma when exposed to air as the Fe(II) is oxidized to Fe(III) or Fe2O3. The color change should occur within 30 minutes.

10. **Exceptions**

    a. Nodules and concretions should be considered relict features if they are the only kind of redoximorphic features present.

    b. Organic stains (color value <4) are not considered to be redoximorphic features.

E. **Interpretations of Redoximorphic Features**

1. Originally, the goal was to use sets of features to identify and separate endosaturation from episaturation.

2. Field testing showed that this was not possible.

3. Soils with perched and permanent water tables can have the same kinds of redoximorphic features.

4. Features should be interpreted to be indicators of where Fe reduction and oxidation occur in horizons. Redox depletions show where reduction has occurred, while redox concentrations show where oxidation occurs.

5. The arrangement of redox depletions and redox concentrations in a horizon might be used to interpret how water and air move through a horizon.

6. To do this effectively, you must specify which features lie along macropores and which lie in the matrix.

7. Interpretations of redoximorphic features should be based around a concept as to how specific features form.

F. **Formation of Fe Depletions and Clay Depletions**

1. Both features form in similar ways.
2. The simplest cases occur in horizons having stable macropores.

3. See figures for descriptions of formation.

G. **Interpreting water movement**

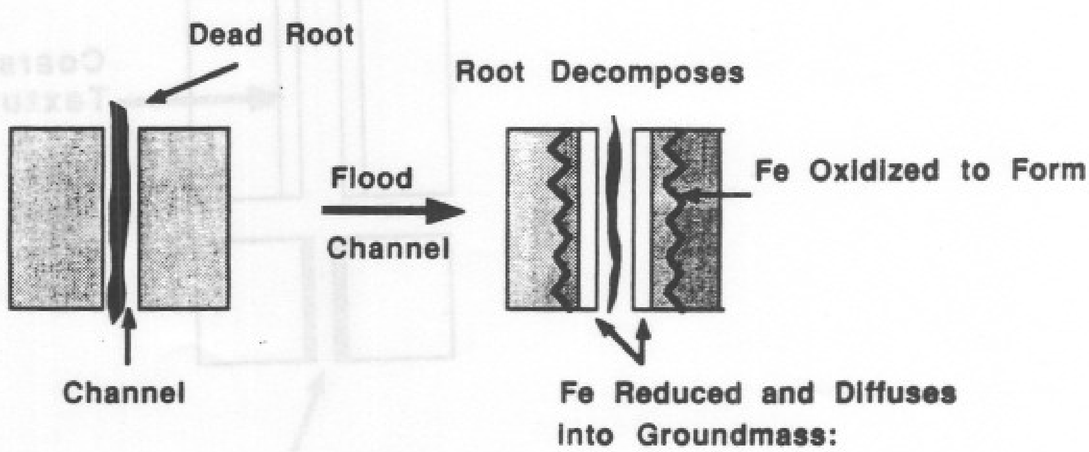
1. Case 1: Redox depletions were observed to occur around macropores, and redox concentrations were seen to occur within the matrix.

2. This pattern of redoximorphic features suggests:

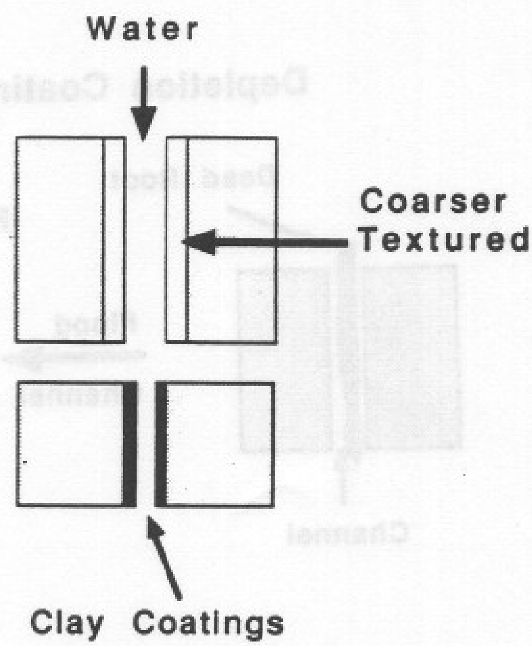
   a. The macropores are stable and control the movement of water.

   b. Saturation and reduction occur in the macropores which are root channels or cracks between soil peds.

Depletion Coating Formation



Depletion Coating Formation



c. Oxidation occurs in the matrix; it is not clear whether the matrix gets saturated with water.

d. Water flows from the macropores toward the matrix.

e. The horizon may have a low saturated hydraulic conductivity.

3. When redox depletions and concentrations occur within the same horizon, then at some point water must have moved:

From redox depletions toward redox concentrations.

H. Potential advantages of Redoximorphic Features

1. Recognizing redoximorphic features will correct some of the problems we've had with low chroma colors.

2. These problems include:

a. Using chromas of 3 or more as indicators of saturation reduction.

b. Identifying relict or fossil colors.

c. Estimating rates of formation of colors.

3. How can relict redoximorphic features be identified? Look for the following characteristics:

a. Feature boundary characteristics: relict features (e.g., nodules) have sharp boundaries, while features still forming have more diffuse boundaries.

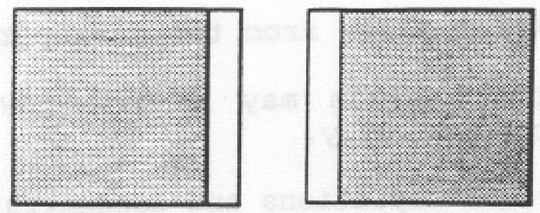
b. Relation to macropores: see figures.

c. Feature color: bright red colors may be relict while yellow and brown colors are more likely to be forming.

4. How long does it take to form redoximorphic features?

a. Reduced matrices can form within 7 days when water is ponded on the surface, temperatures are warm, and fresh organic matter is present.

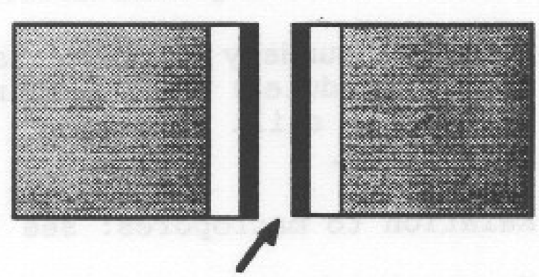
Contemporary Feature



Contemporary

- Adjacent to macrovoid
- Not overlain by clay or Fe oxide

Relict Feature



Brown clay film

not adjacent to void

b. Redox concentrations (pore linings) can form around rice roots in 30 days or less.

c. Redox depletions can form in 7 days in A horizons where water is ponded on the surface and organic matter contents are 5%.

CONCLUSIONS FOR PART III.

1. Redoximorphic features have been adopted for immediate use as part of aquic conditions.

2. The features need to be calibrated to specific periods of saturation for each soil.

3. Redoximorphic features show where oxidation and reduction of Fe occur in horizons.

4. The features offer several potential advantages over low chroma colors including more flexibility on color requirements for aquic conditions, and the ability to distinguish relict features.

IV. PROBLEMS

A. How can you identify redoximorphic features the occur in horizons that are not saturated?

1. This problem occurs with:

   a. **Capillary fringes:** zones above the water table where most pores are filled with water.

   b. **Stratified layers:** soil layers such as silts over sands where material with small pores overlies material with large pores.

2. The capillary fringe:

   a. Is thick in clays with massive soil structure.

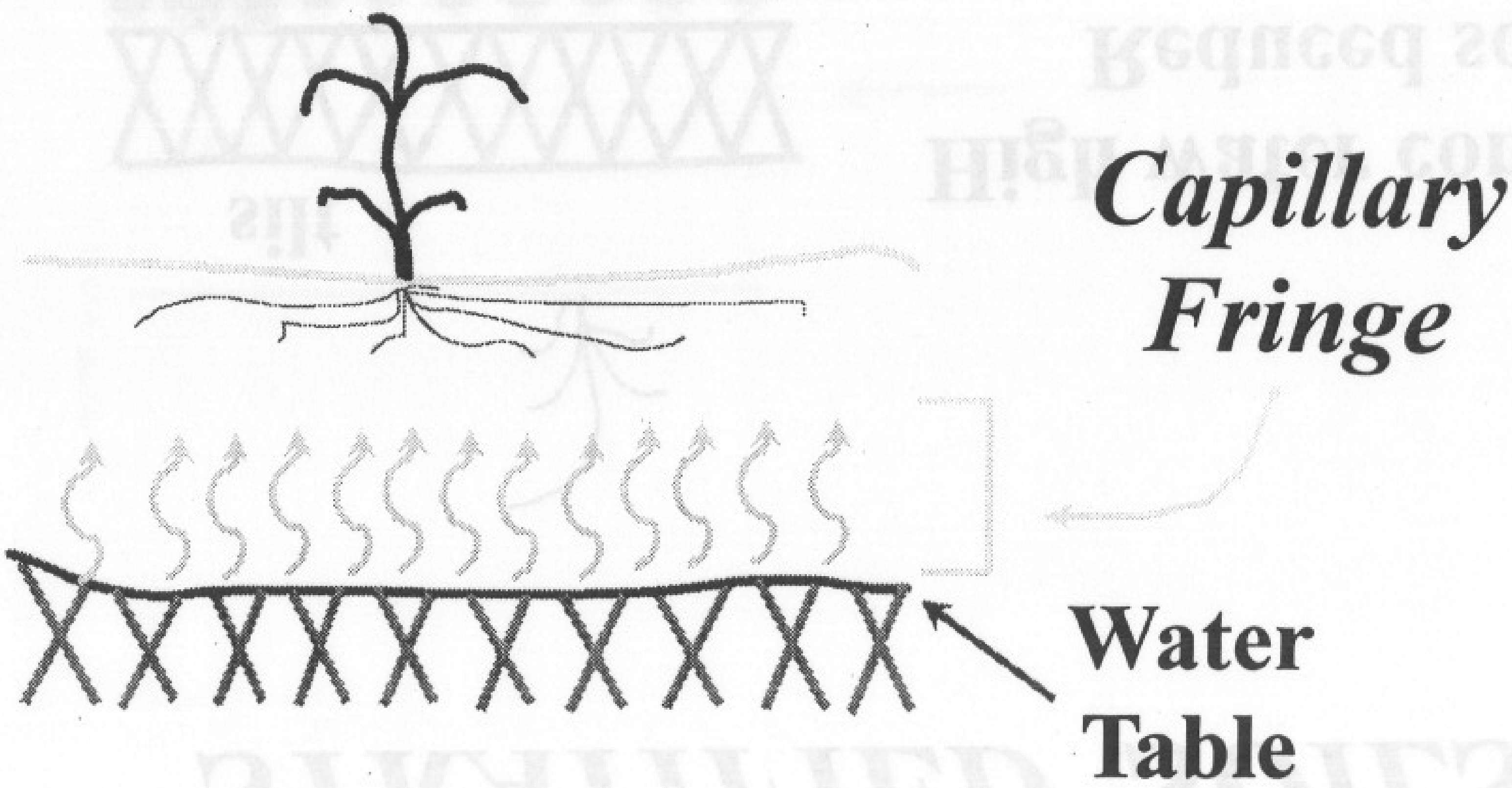
   b. Has a depth from the surface which changes as the water table fluctuates.

   c. Is important where the water table is static for long periods below the root zone.

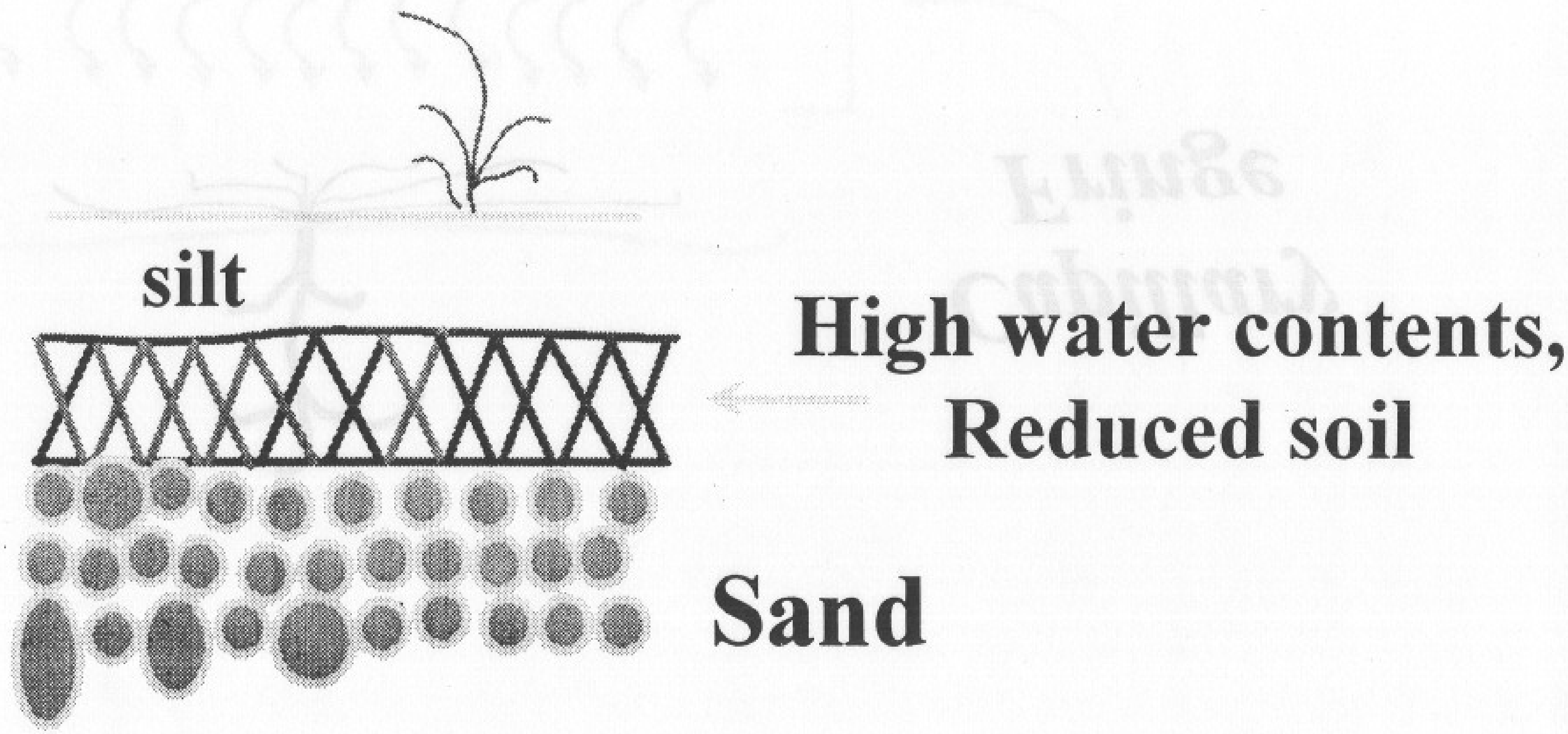
   d. Estimated thicknesses of the capillary fringe:

Soil	Range in Depth	Avg. Depth
Sands	0-3 inches	2 inches
Silts	0.5 - 5 feet	<12 inches
Clays	5 - 100 feet	<60 inches

   e. Redoximorphic features of soils within the capillary fringe and in stratified layers is similar, and consists of redox depletions within the matrix, with pores linings along macropores such as root channels and ped surfaces.


Capillary Fringe
Water Table

STRATIFIED SOILS



3. Restrictive layers:

   a. These are layers of low saturated hydraulic conductivity which cause perched water tables to form.

   b. Their saturated hydraulic conductivity is about 1/10 that of an overlying horizon.

   c. Such restrictive layers are prevalent in the Lower Coastal Plain where they consist of clays, silts, or organic layers.

   d. They are less common in Middle and Upper Coastal Plain soils.

4. Soils with low amounts of Iron: these are soils in which redoximorphic features cannot form.

   a. Both well-drained and poorly-drained soils in this category will appear gray.

   b. Generally such soils are sands or loamy sands.

   c. The parent materials of these soils did not contain iron.

   d. To identify reduction in these soils we must use features made of organic matter. These features include

   i) layers of muck at the soil surface,

   ii) "splotchy" color patterns,

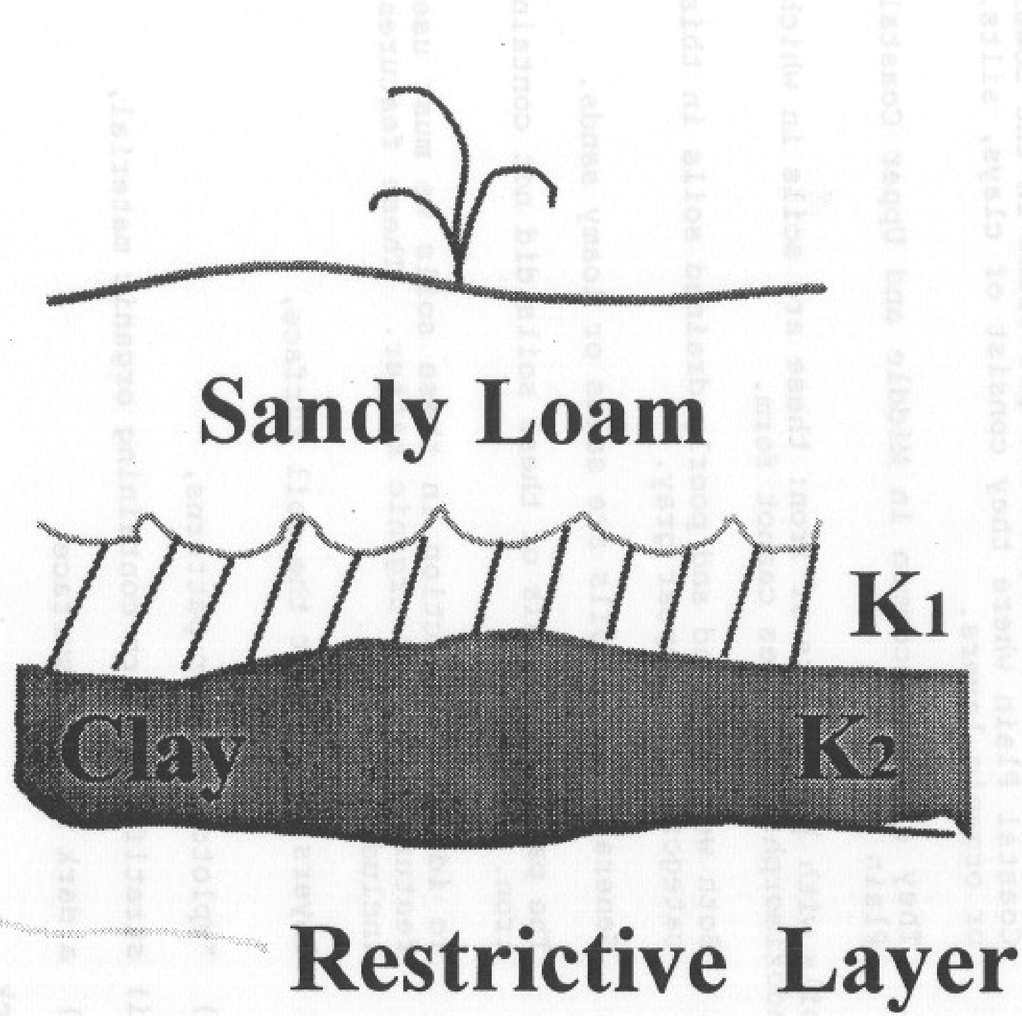
   iii) stratified layers containing organic material,

   iv) a dark mineral surface

5. Muck

   a. organic soil material

   b. plant parts can't be recognized



$K_2 = 1/10K_1$

6. "Splotchy" Color Pattern

   a. Mineral grains have been stripped of both iron and organic matter.

   b. The materials that have moved have "clumped" into masses of two or more colors.

   c. The stripped areas occupy at least 10% of the horizon, and are at least 1 to 3 cm in diameter.

7. Dark Mineral Surfaces

   a. A layer or horizon that is more than 4 inches thick.

   b. It has a Munsell value of 3 or less, and chroma of 1 or less (its black).

   c. The soil matrix in a layer below the surface layer has a chroma of 2 or less.

8. These organic features are not well-defined, nor is there formation understood. However, they are probably good indicators to use if they are properly identified.