

Wastewater System and Potable Water Supply Rules Soil Evaluation



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Discussion

What is the purpose of soil evaluation?

- **Observation >>> Interpretation >>> Design**
- Can wastewater infiltrate the soil at rate to facilitate design flow?
- Is the soil good habitat for aerobic microbes that treat effluent?
- Is an on-site soil-based wastewater system viable?

What should we expect from a test pit log?

- Is the minimum permit requirement the same as good practice?
- Is 5 minutes enough time? As a young engineering geologist I was expected to take around 30 minutes to log each test pit.

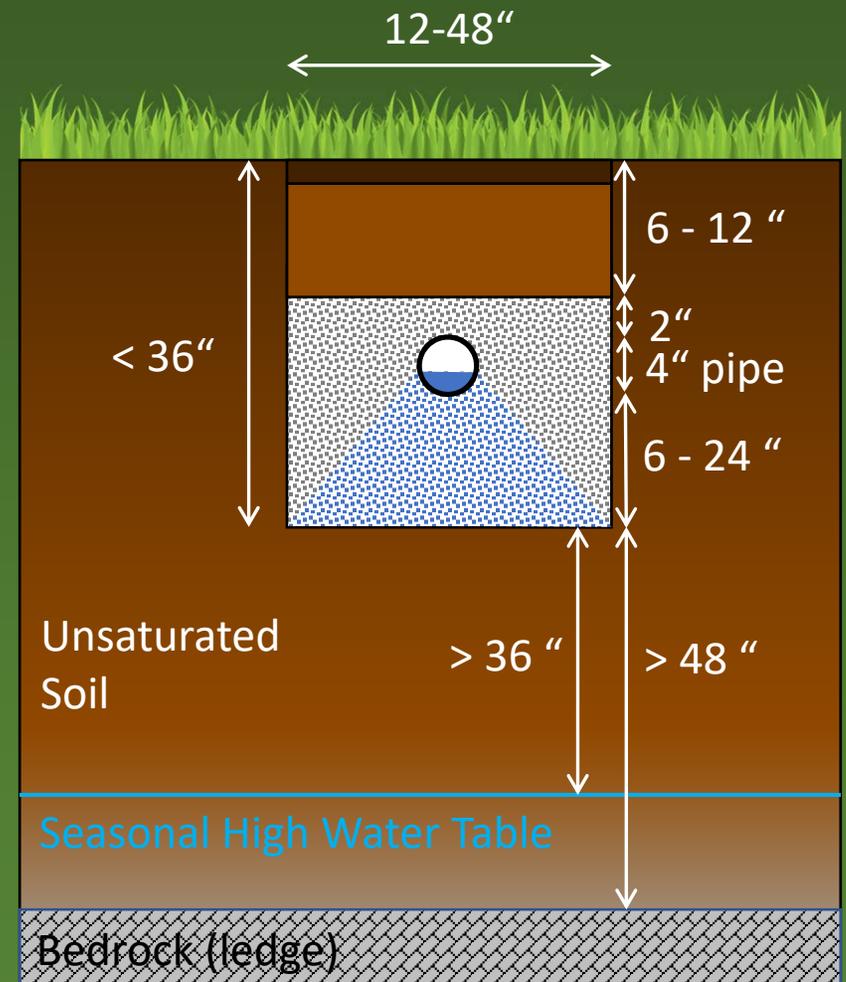
Remember the purpose of the site investigation for a soil-based wastewater system

1. Texture, structure, consistence: Application Rates

Can you get wastewater in the ground?

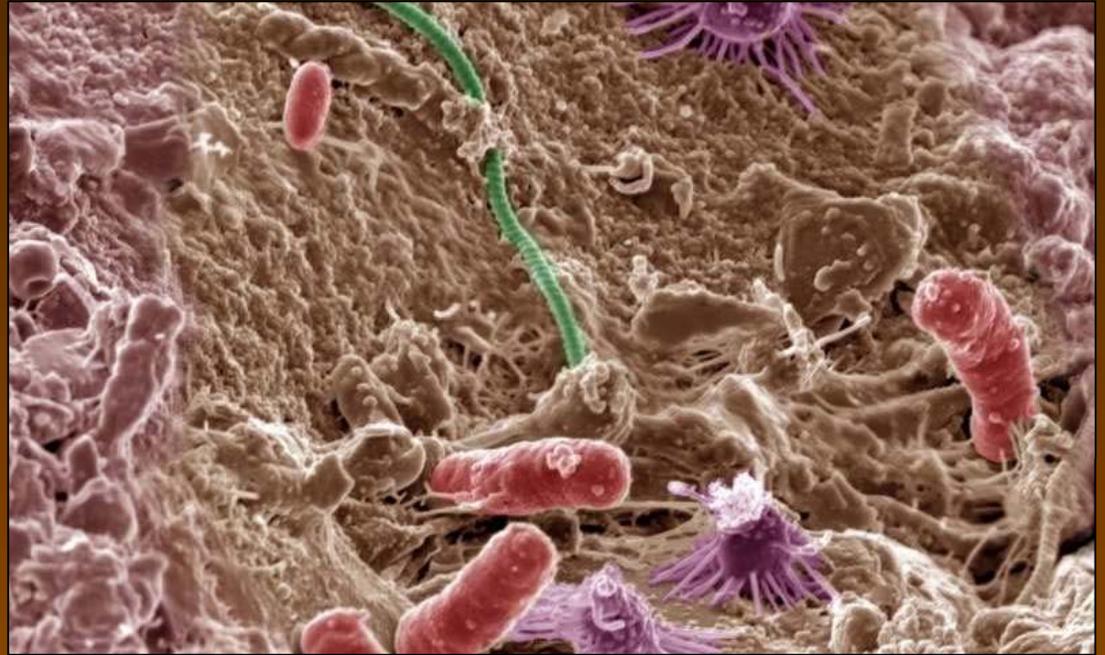
2. Color / Redox Conditions: Seasonal High Water Table

Is there aerobic habitat for the microbes that treat the wastewater once it is in the ground?



Teaming with microbes!

Mainly the aerobic,
bacteria.



Designers, engineers...
and microbe farmers?

§1-9 Specific Technical Standards for Wastewater Systems

§ 1-910 Soil Evaluation

- < 600 gpd - 2 excavations per in-ground leachfield & replacement area
- < 600 gpd - 3 excavations per mound or bottomless sand filter area
- Confirm soils under leachfield and 25 ft downslope of a mound
- Soil excavations shall be conducted using a backhoe unless authorized by the Secretary
- Secretary may allow fewer soil excavations if soils are uniform
- Secretary may require additional soil excavations to confirm complying soil conditions

§1-9 Specific Technical Standards for Wastewater Systems

§ 1-911 Application Rates

- Maximum application rate for sizing leachfield in **mound** shall be 1.0 gpd
- Maximum application rate for **in-ground** or **at-grade** leachfield shall be determined using one of the following methods:
 - Using Table 9-3 for most limiting **soil texture and structure** identified within 0 to 3 feet below leachfield infiltrative surface
 - Using the results of the **percolation tests** in the most limiting soil texture and structure identified within 0 to 3 feet below leachfield infiltrative surface
- If percolation test gives a higher application rate than soil description (Table 9-3) then the application rate determined by the soil description shall be used – **use the lowest application rate**

Both tools in your tool box, but you must give full soil descriptions

§1-9 Specific Technical Standards for Wastewater Systems

§ 1-910 Soil Evaluation

- Soil described for each horizon according to **USDA-NRCS** Field Book
- Description shall include
 1. Color based on Munsell notation (and name), e.g. 10YR 4/3 (brown)
 2. Redoximorphic features (reductions and concentration, 'mottles')
 3. Texture as identified by full name and USDA-NRCS abbreviation
 4. Structure
 5. Consistence
- Evidence of SHWT: redoximorphic features, seepage, standing water
- Percolation testing **may** be conducted for establishing application rates

§ 1-911 Application Rates

**Table 9-3
Application Rates Established Using Soil Excavation**

Soil Characteristics		Application Rates (gallons per square foot per day)			
Texture	Structure Type ¹	In-Ground Trench	In-ground Bed	At-Grade Leachfield	Leachfield in a Bottomless Sand Filter
Very Coarse Sand or Coarser	SG	See § 1-919(b)	See § 1-919(b)	See § 1-919(b)	1.00
Coarse Sand, Sand	SG	1.50	1.20	1.00	1.00
Loamy Coarse Sand, Loamy Sand	SG	1.50	1.20	1.00	1.00
Fine Sand, Very Fine Sand, Loamy Fine Sand, Loamy Very Fine Sand	SG	1.00	0.80	0.80	0.80
	MA/PL	0.50	0.40	0.40	0.40
	PR/ABK/SBK/GR	0.70	0.60	0.60	0.60
Coarse Sandy Loam, Sandy Loam	MA/PL	0.50	0.40	0.40	0.40
	PR/ABK/SBK/GR	0.70	0.60	0.60	0.60
Fine Sandy Loam, Very Fine Sandy Loam	MA/PL	0.50	0.40	0.40	0.40
	PR/ABK/SBK/GR	0.60	0.50	0.50	0.50
Loam	MA/PL	0.50	0.40	0.40	0.40
	PR/ABK/SBK/GR	0.60	0.50	0.50	0.50
Silt Loam, Silt	MA/PL	0.30	0.20	0.20	N/A
	PR/ABK/SBK/GR	0.40	0.30	0.30	N/A
Sandy Clay Loam, Clay Loam, Silty Clay Loam	MA/PL	0.25	0.20	0.20	N/A
	PR/SBK/GR	0.30	0.20	0.20	N/A
Sandy Clay, Clay, Silty Clay	N/A (See § 1-926)				

Adapted from J. Tyler, 2000.

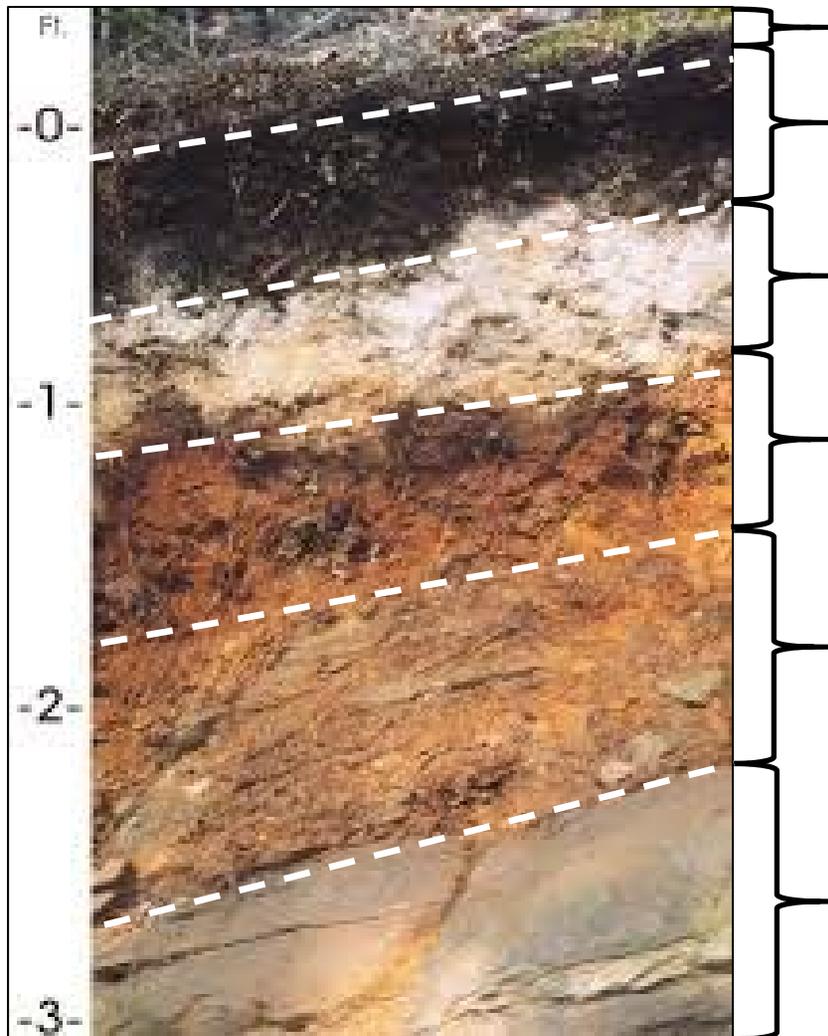
¹ The abbreviations used for structure are: SG = single grain; GR = granular; MA = massive; PL = platy; PR = prismatic; ABK = angular blocky; SBK = subangular blocky.

Percolation Rates back-calculated from Application Rates in Table 9-3 WW Rules

Soil Characteristics		Application Rates (gallons per square foot per day)			Percolation Rates (minutes per inch)		
Texture	Structure Type ¹	In-Ground Trenches	In-ground Beds and At-Grade Leachfields	Leachfields in Bottomless Sand Filters	In-Ground Trenches	In-ground Beds and At-Grade Leachfields	Leachfields in Bottomless Sand Filters
Very Coarse Sand or Coarser	SG	See § 1-919(b)	See § 1-919(b)	1	See § 1-919(b)	See § 1-919(b)	6
Coarse Sand, Sand	SG	1.5	1.2	1	4	4	6
Fine Sand, Very Fine Sand, Loamy Fine Sand, Loamy Very Fine Sand	SG	1	0.8	0.8	9	9	9
	MA/PL	0.5	0.4	0.4	36	36	36
	PR/ABK/ SBK/GR	0.7	0.6	0.6	18	16	16
Coarse Sandy Loam, Sandy Loam	MA/PL	0.5	0.4	0.4	36	36	36
	PR/ABK/ SBK/GR	0.7	0.6	0.6	18	16	16
Fine Sandy Loam, Very Fine Sandy Loam	MA/PL	0.5	0.4	0.4	36	36	36
	PR/ABK/ SBK/GR	0.6	0.5	0.5	25	23	23
Loam	MA/PL	0.5	0.4	0.4	36	36	36
	PR/ABK/ SBK/GR	0.6	0.5	0.5	25	23	23
Silt Loam, Silt	MA/PL	0.3	0.2	N/A	100	144	N/A
	PR/ABK/ SBK/GR	0.4	0.3	N/A	56	64	N/A
Sandy Clay Loam, Clay Loam, Silty Clay Loam	MA/PL	0.25	0.2	N/A	144	144	N/A
	PR/SBK/ GR	0.3	0.2	N/A	100	144	N/A
Sandy Clay, Clay, Silty Clay		N/A (See § 1-926)			N/A (See § 1-926)		

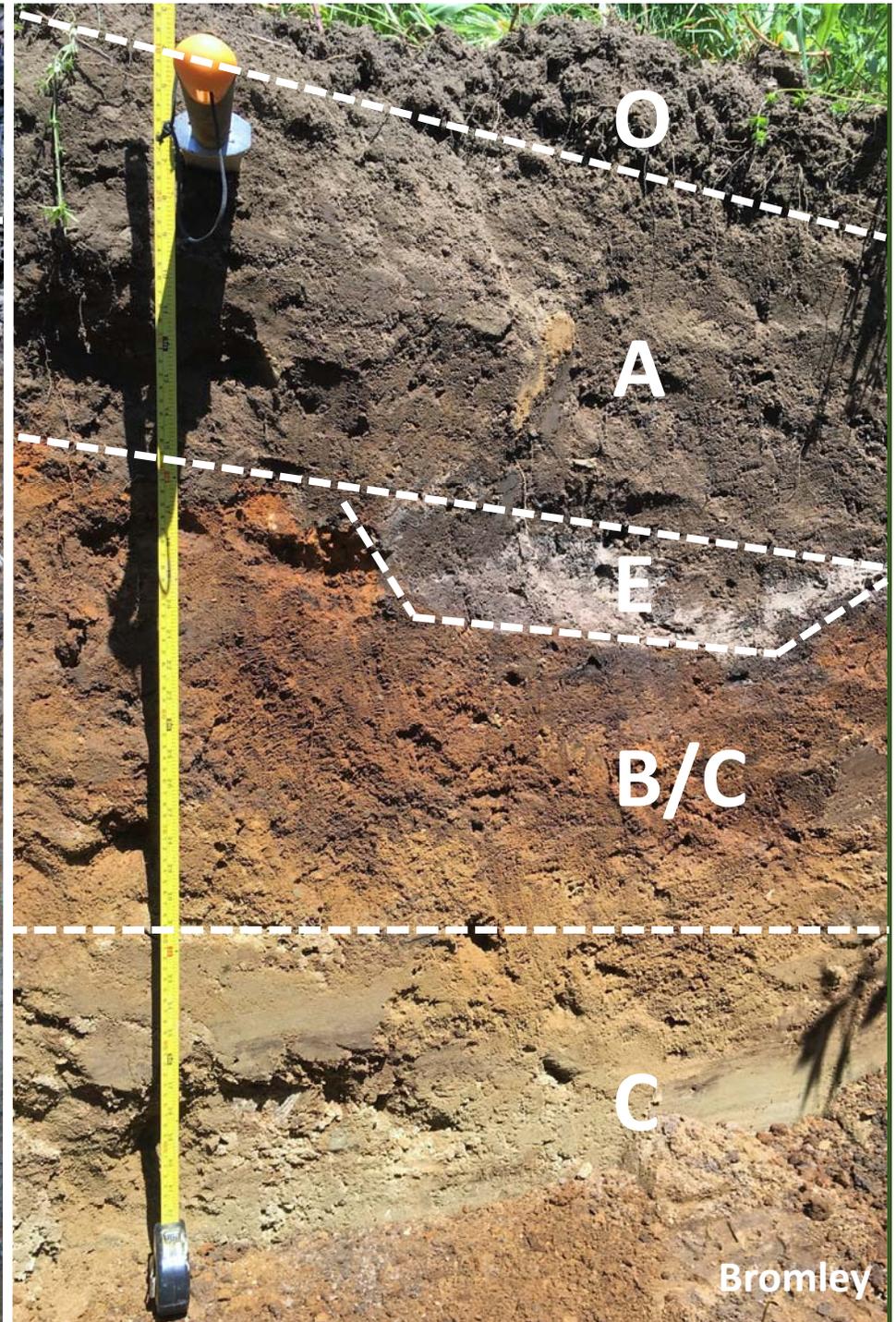
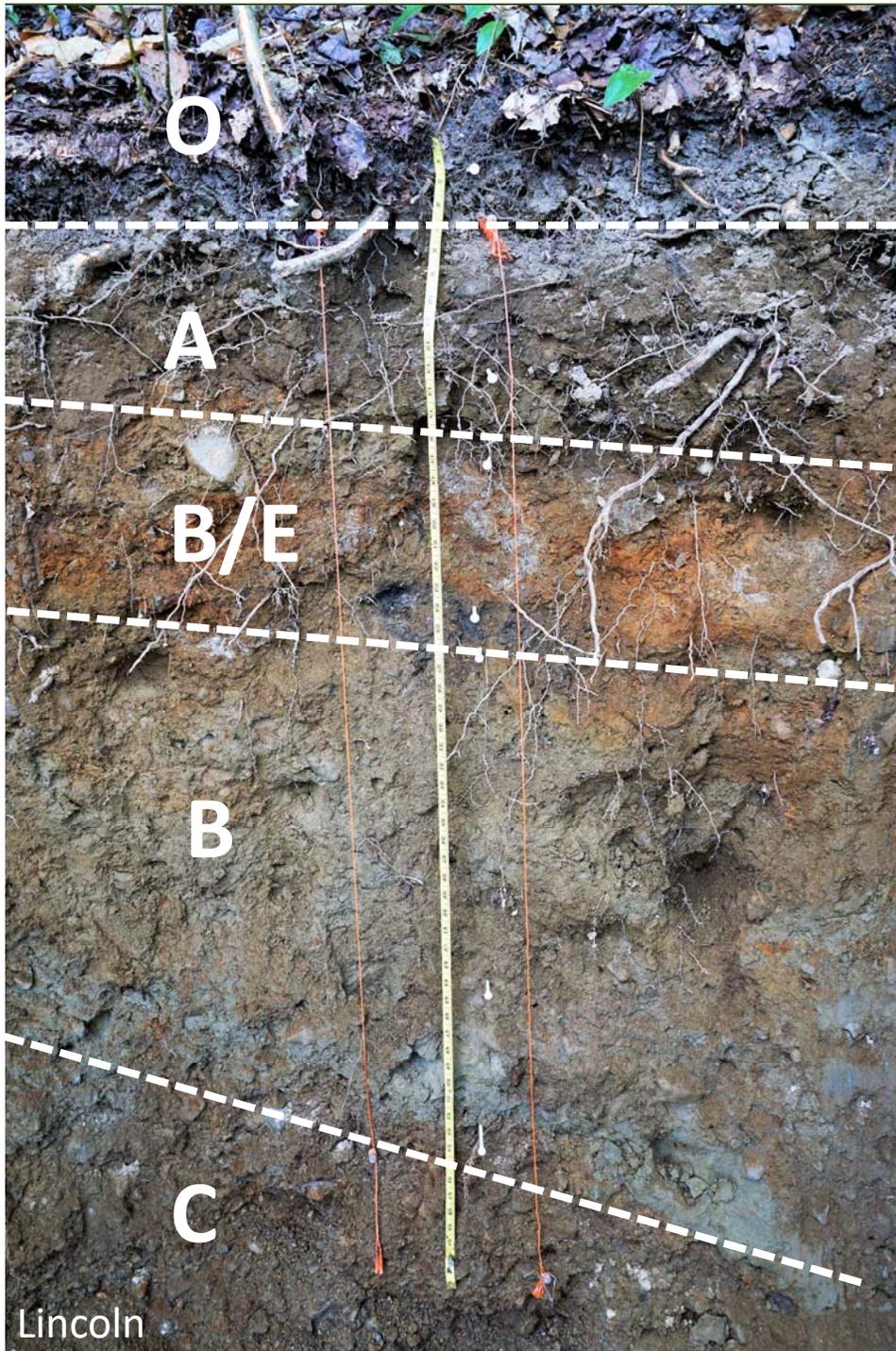
Diagnostic Soil Horizons

e.g. Vermont State Soil - Tunbridge Series

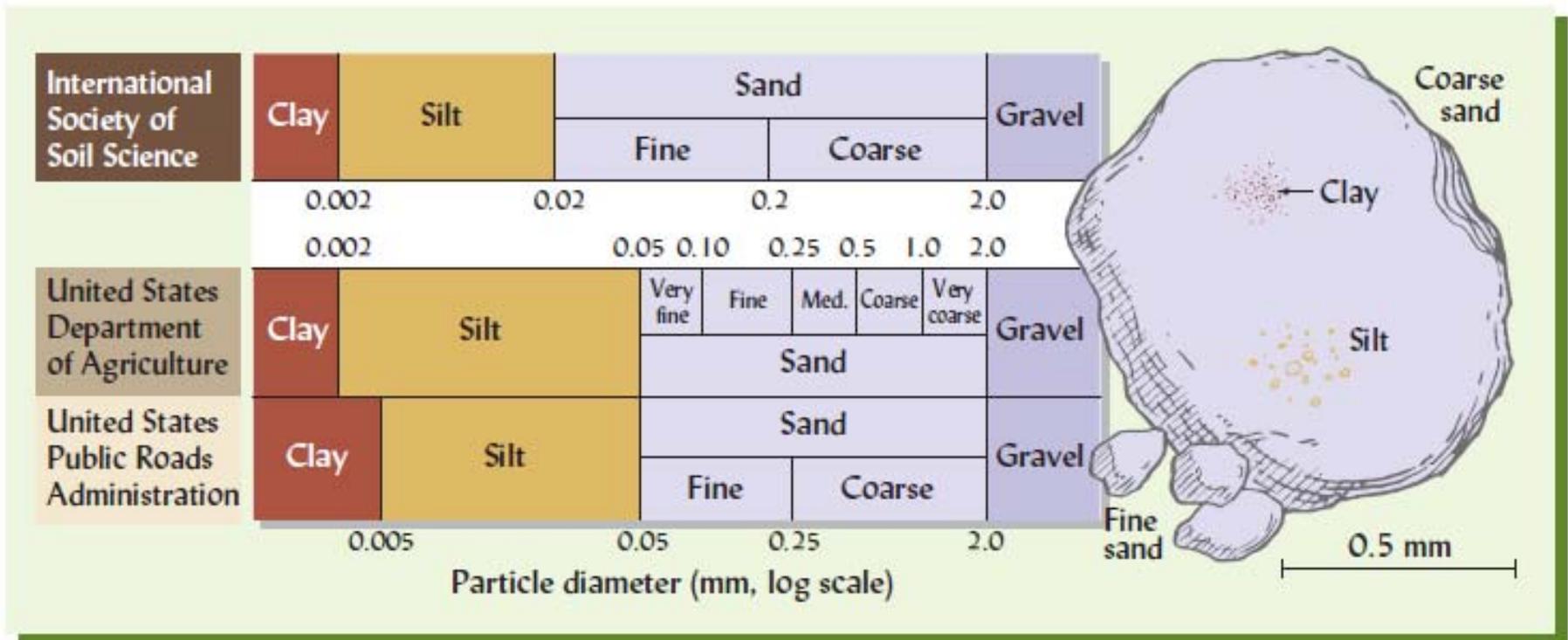


- O** Humus: organic leaf litter
- A*** Topsoil: humus, minerals, organisms
- E** Leached by humic acid: mineral soil (forest soils, not present in most soils)
- B*** Subsoil: Mineral soil, weathered with accumulated iron, clay etc.
- C** Parent material: weathered rock, glacial till, alluvium, lacustrine etc. (Tunbridge is till)
- R** Bedrock – metamorphic

* not always present in Tunbridge Series



Soil Texture (particle size distribution)



Particle Size Analysis

Sieve sand & gravel



Sand

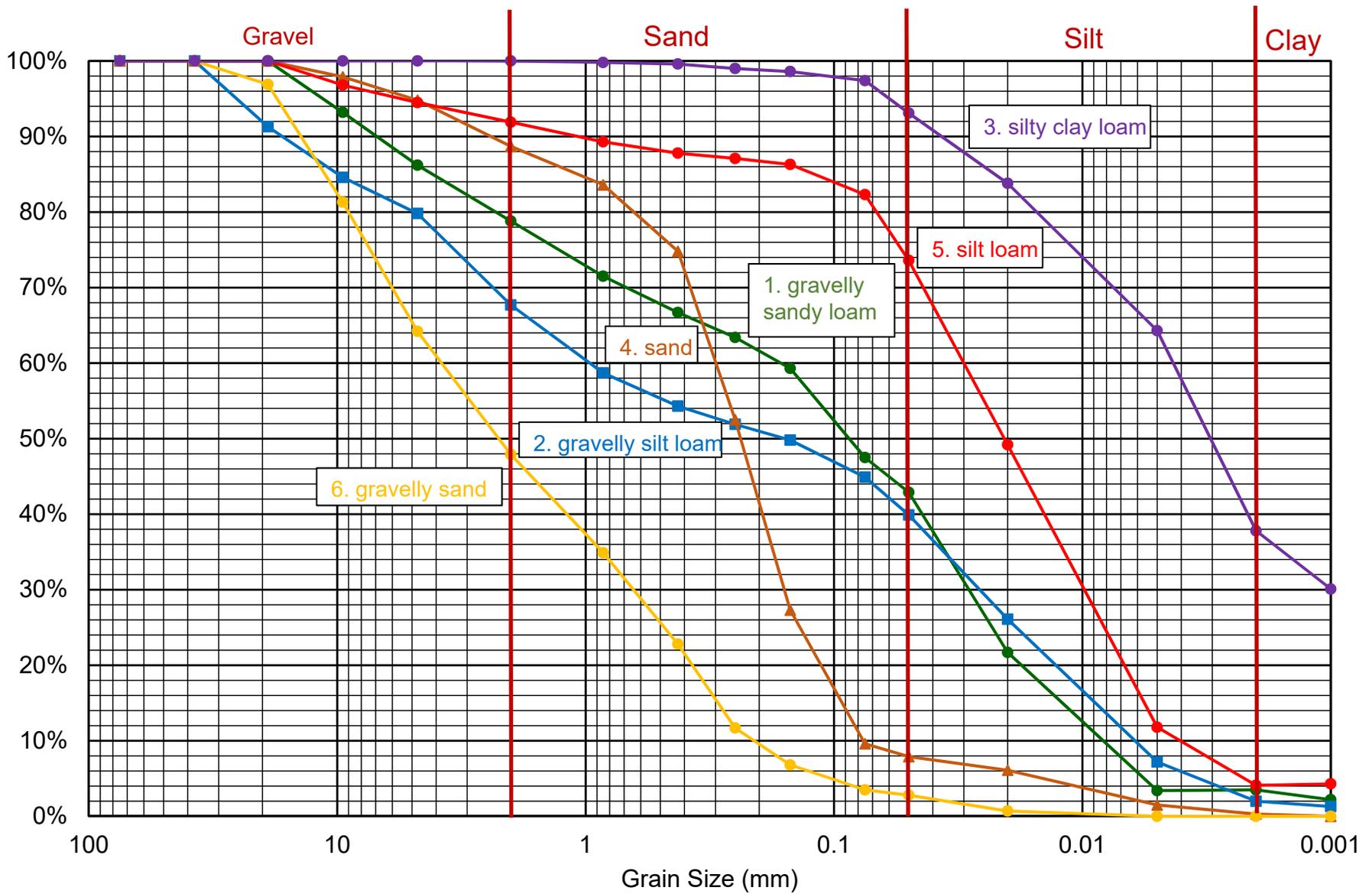
Silt

Sieve size (mm)	BSS	Tyler (approx)	US (approx)
4.75	-	4	4
3.35	5	6	6
2.81	6	7	7
2.38	7	8	8
2.00	8	9	10
1.68	10	10	12
1.40	12	12	14
1.20	14	14	16
1.00	16	16	18
0.853	18	20	20
0.710	22	24	25
0.599	25	28	30
0.500	30	32	35
0.422	36	35	40
0.354	44	42	45
0.297	52	48	50
0.251	60	60	60
0.211	72	65	70
0.178	85	80	80
0.152	100	100	100
0.125	120	115	120
0.104	150	150	140
0.089	170	170	170
0.075	200	200	200
0.066	240	250	230
0.053	300	270	270
0.044	350	325	325
0.037	440	400	400

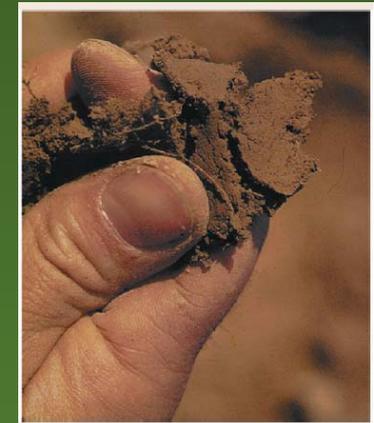
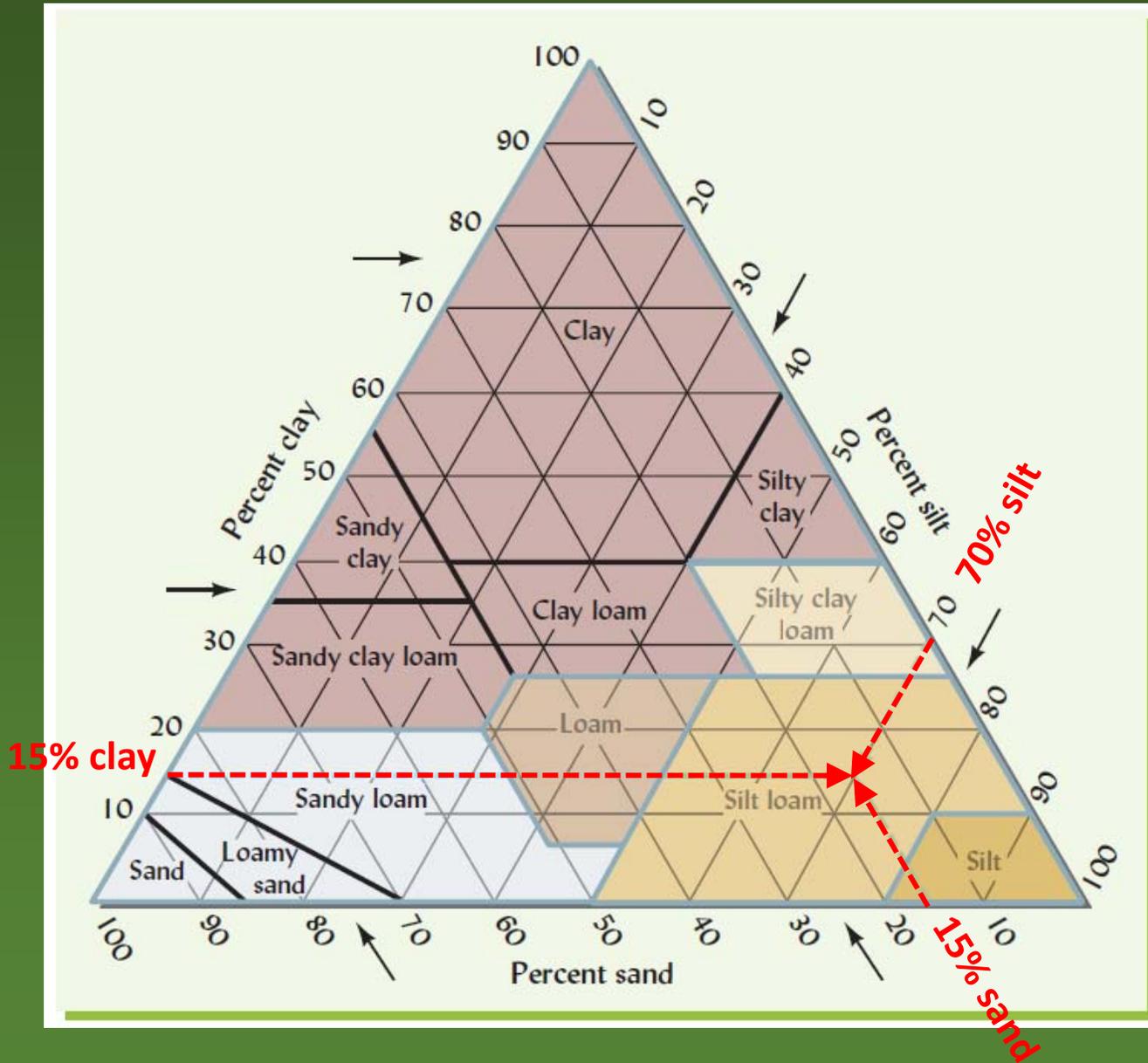
Use hydrometer and Stokes Law to determine silt and clay fraction



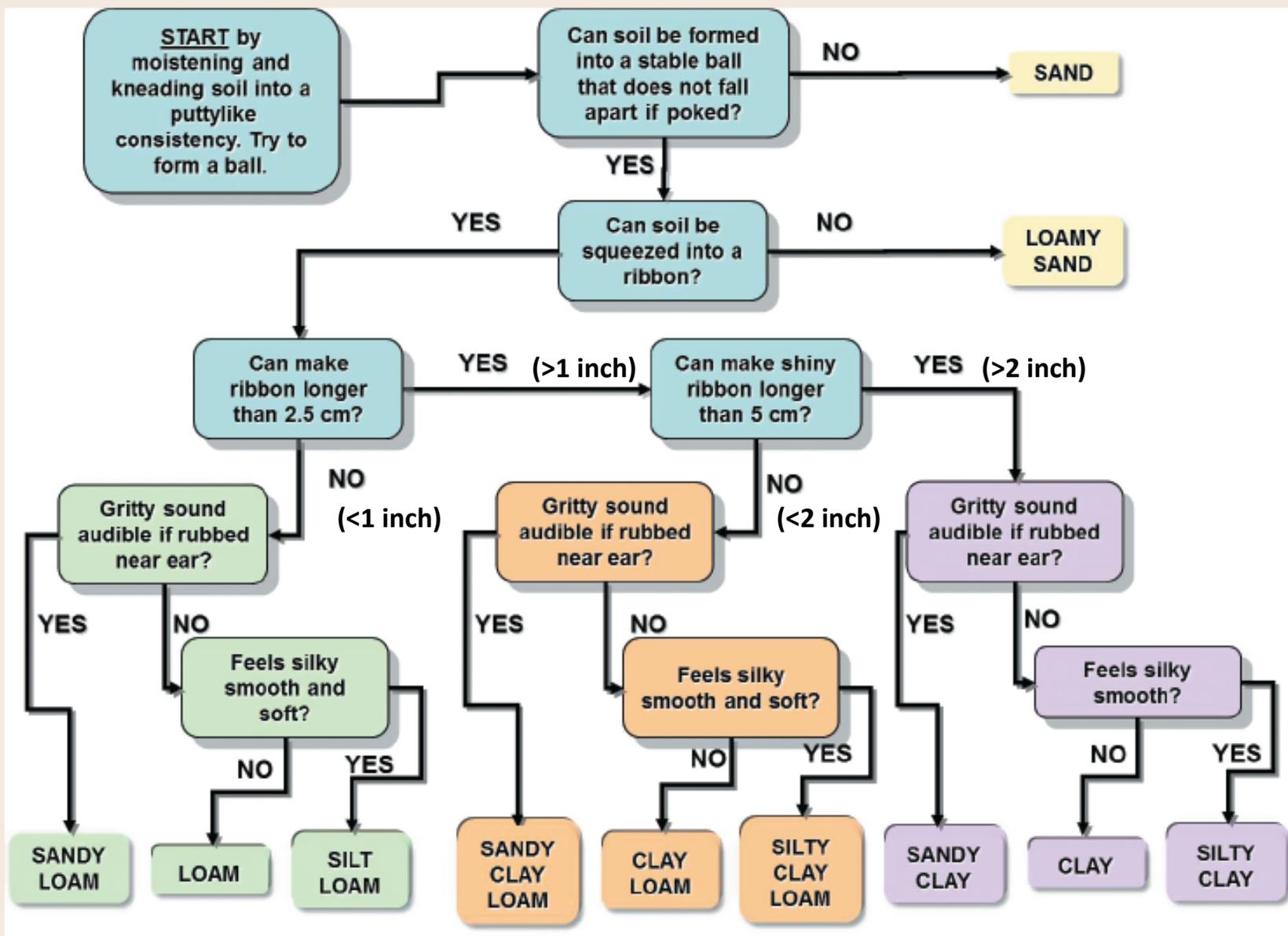
Particle Size Distribution



USDA-NRCS Soil Texture Triangle



Soil Texture: Field Determination



Soil Textures ... Stay Calibrated!

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Pedology

A Comparison of Soil Texture-by-Feel Estimates: Implications for the Citizen Soil Scientist

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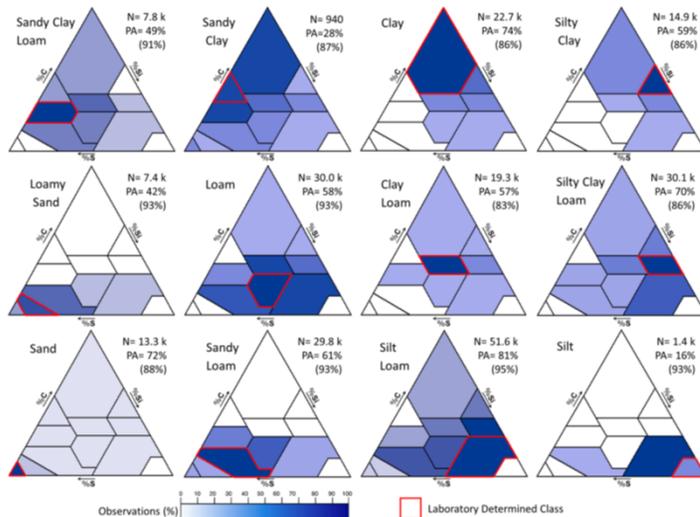
Estimating soil texture is a fundamental practice universally applied by soil scientists to classify and understand the behavior, health, and management of soil systems. While the accuracy of both the soil texture class and the estimates of the percentage of sand and clay is generally accepted when completed by trained soil scientists, similar estimates by "citizen scientists" or less experienced seasonal resource scientists are often questioned. We compared soil texture classes determined by texture-by-feel and laboratory analyses for two groups: professional soil scientists who contributed to the USDA-NRCS National Soil Characterization Database and seasonal field technicians working on rangeland inventory and assessment programs in the Western United States and Namibia. Texture accuracy was compared using a confusion matrix to evaluate classification accuracy based on the assumption that laboratory measurements were correct. Our results show that the professional soil scientists predicted the laboratory-determined texture class for 66% of the samples. Accuracy for seasonal field technicians was between 27 and 41%. When a "correct" prediction was defined to include texture classes adjacent to the laboratory-determined texture based on a standard USDA texture triangle, accuracy increased to 91% for professionals and 71 to 78% for seasonal field technicians. These findings highlight the need to improve options for increasing the accuracy of field-textured estimates for all soil texture observers, with relevance to career soil scientists, seasonal technicians, and citizen scientists. Opportunities for improving soil texture accuracy include training, calibration, and decision support tools that go beyond simple dichotomous keys.

Professional Soil Scientists

- 66% textures correct!
- 91% textures 'correct' when include adjacent classes
- Sand & clay classes good
- Silt & loam ... not so much

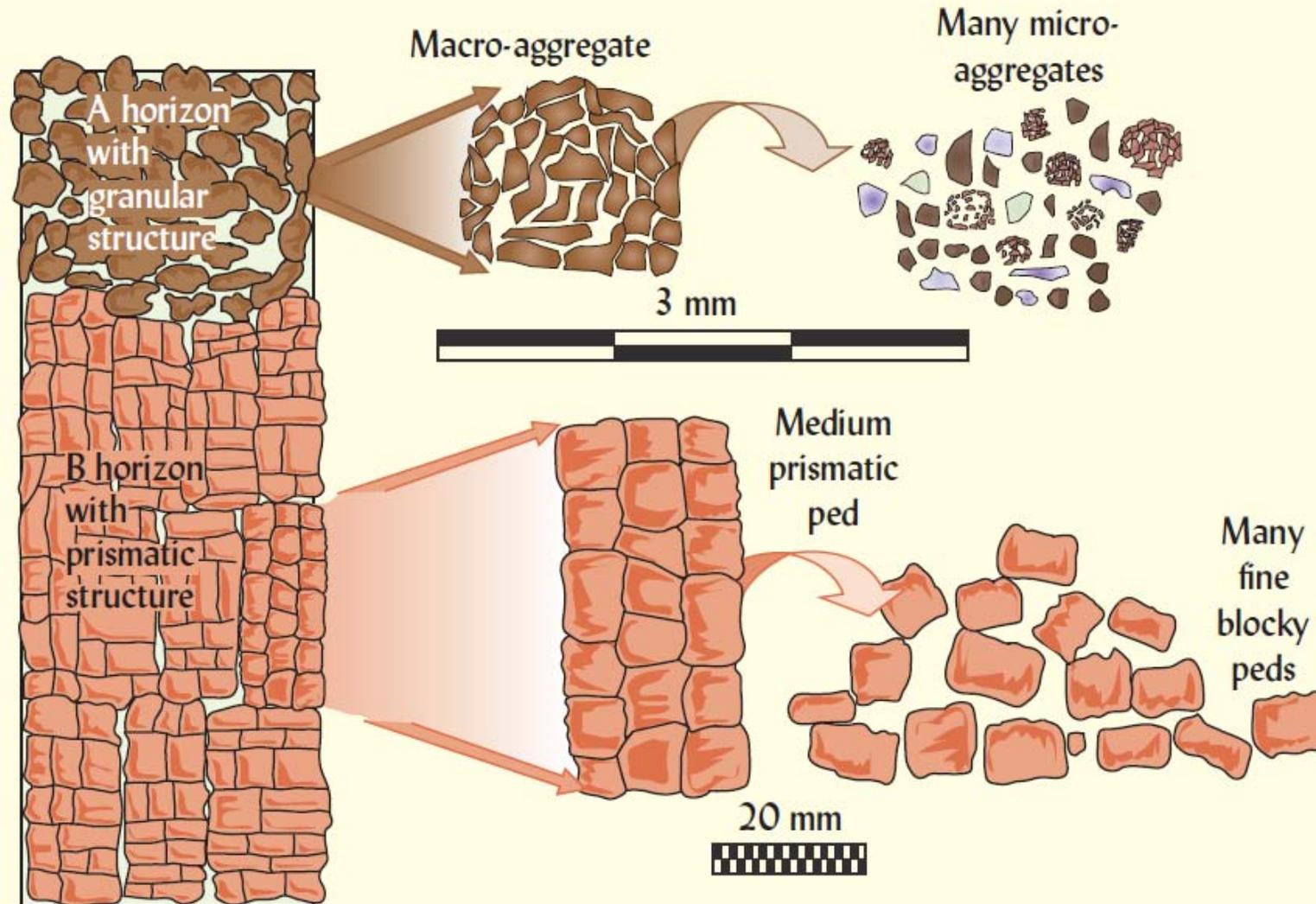
Seasonal Field Technicians?

- 41% textures correct
- 78% textures 'correct' when include adjacent classes
- Silty classes most difficult
- Professionals: 59% Novice: 17%



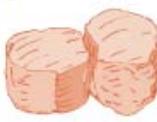
Soil Structure

Arrangement of aggregated particles called peds



Soil Structure: regular field calibration essential



<p>Spheroidal Characteristic of surface (A) horizons. Subject to wide and rapid changes.</p>	<p>Granular (porous)</p> 	
	<p>Crumb (very porous)</p> 	
<p>Plate-like Common in E horizons, may occur in any part of the profile. Often inherited from parent material of soil, or caused by compaction.</p>	<p>Platy</p> 	
<p>Block-like Common in B horizons, particularly in humid regions. May occur in A horizons.</p>	<p>Angular blocky</p> 	
	<p>Subangular blocky</p> 	
<p>Prism-like Usually found in B horizons. Most common in soils of arid and semi-arid regions.</p>	<p>Columnar (rounded tops)</p> 	
	<p>Prismatic (flat, angular tops)</p> 	

Soil Structure

- Single Grain
- Granular
- Crumb
- Angular blocky
- **Subangular blocky**
- Columnar
- Prismatic
- **Platy**
- Massive

Grade

0 = structureless

1 = weak

2 = moderate

3 = strong

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

Granular (porous)



(a)



Crumb (very porous)



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

Platy



(b)



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

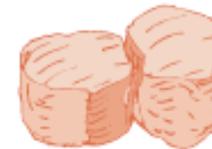
Angular blocky



(c)



Subangular blocky



(d)



Prism-like
Usually found in B horizons. Most common in soils of arid and semi-arid regions.

Columnar (rounded tops)



(e)



Prismatic (flat, angular tops)



(f)



“Consistence” = Ped resistance to deformation

Soil consistence ^a			
Dry soil	Moist to wet soil	Soil dried then submerged in water	Field rupture (crushing) test
Loose	Loose	Not applicable	Specimen not obtainable
Soft	Very friable	Noncemented	Crumbles under very slight force between thumb and forefinger
Slightly hard	Friable	Extremely weakly cemented	Crumbles under slight force between thumb and forefinger
Hard	Firm	Weakly cemented	Crushes with difficulty between thumb and forefinger
Very hard	Extremely firm	Moderately cemented	Cannot be crushed between thumb and forefinger, but can be crushed slowly underfoot

^aAbstracted from USDA-NRCS (2005).

McCarthy (1993) “Consistency”

Uses field penetration test similar to designers

Soil consistence ^a				Soil consistency ^b	
Dry soil	Moist to wet soil	Soil dried then submerged in water	Field rupture (crushing) test	Soil at in situ moisture	Field penetration test
Loose	Loose	Not applicable	Specimen not obtainable	Soft	Blunt end of pencil penetrates deeply with ease
Soft	Very friable	Noncemented	Crumbles under very slight force between thumb and forefinger	Medium firm	Blunt end of pencil can penetrate about 1.25 cm with moderate effort
Slightly hard	Friable	Extremely weakly cemented	Crumbles under slight force between thumb and forefinger	Firm	Blunt end of pencil can penetrate about 0.5 cm
Hard	Firm	Weakly cemented	Crushes with difficulty between thumb and forefinger	Very firm	Blunt end of pencil makes slight indentation; thumbnail easily penetrates
Very hard	Extremely firm	Moderately cemented	Cannot be crushed between thumb and forefinger, but can be crushed slowly underfoot	Hard	Blunt end of pencil makes no indentation; thumbnail barely penetrates

^aAbstracted from USDA-NRCS (2005).

^bModified from McCarthy (1993).

USDA “Excavation Difficulty” Field penetration test.

EXCAVATION DIFFICULTY—The relative force or energy required to dig soil out of place. Describe the **Excavation Difficulty Class** and the moisture condition (*moist* or *dry*, but not *wet*); use the “(Soil) Water State” table; e.g., *moderate, moist* or *M, M*. Estimates can be made for either the most limiting layer or for each horizon.

Class	Code	Criteria
Low	L	Excavation by tile spade requires arm pressure only; impact energy or foot pressure is not needed.
Moderate	M	Excavation by tile spade requires impact energy or foot pressure; arm pressure is insufficient.
High	H	Excavation by tile spade is difficult but easily done by pick using over-the-head swing.
Very High	VH	Excavation by pick with over-the-head swing is moderately to markedly difficult. Backhoe excavation by a 50- to 80-hp tractor can be made in a moderate time.
Extremely High	EH	Excavation via pick is nearly impossible. Backhoe excavation by a 50- to 80-hp tractor cannot be made in a reasonable time.

Summary

TEXTURE	STRUCTURE	CONSISTENCE
Very Coarse Sand (VCOS)	Single Grain (SG)	Loose (L)
Coarse Sand (COS) , Sand (S)	Granular (GR)	Very Friable (VFR)
Loamy Coarse Sand (LCOS), Loamy Sand (LS)	Massive (MA)	Friable (FR)
Fine Sand (FS), Very Fine Sand (VFS), Loamy Fine Sand (LFS), Loamy Very Fine Sand (LVFS)	Platy (PL)	Firm (FI)
Coarse Sandy Loam (COSL), Sandy Loam (SL)	Angular Blocky (ABK)	Very Firm (VFI)
Fine Sandy Loam (FSL), Very Fine Sandy Loam (VFSL)	Subangular Blocky (SBK)	
Loam (L)	0 = structureless	
Silt Loam (SIL), Silt (SI)	1 = weak	
Sandy Clay Loam (SCL), Silty Clay Loam (SICL), Clay Loam (CL)	2 = moderate	
Sandy Clay (SC), Silty Clay (SIC), Clay (C)	3 = strong	

“TAC Table 1” TAC Report 2001

Table 1. Hydraulic Loading Method for Detailed Soil Descriptions in Vermont

TAC Guidance on selecting “desk top” hydraulic conductivity for groundwater mounding calculations.

Soil logs must record:

1. texture
- 2a. structure
- 2b. grade of structure

If they do not then lowest K consistent with available description should be selected.

- 1
- 2
- 3
- 4
- 5
- 6
- 7

Soil Texture ¹	Soil Structure ²		K ³ (ft/day)	Hydraulic Loading Rate (gpd/square foot)								
				(Sorted by hydraulic gradient and % ground surface slope range as noted)								
				0-2%	2.1-4%	4.1-6%	6.1-8%	8.1-10%	10.1-15%	15.1-20%	20.1-30%	
Coarse Sand, Sand, Loamy Coarse Sand, Loamy Sand	--	0SG	100	7.5	22.4	37.4	52.4	67.3	93.5	130.9	187.0	
			50	3.7	11.2	18.7	26.2	33.7	46.8	65.5	93.5	
Fine Sand, Very Fine Sand, Loamy Fine Sand, Loamy Very Fine Sand Coarse Sandy Loam, Loamy Sand	--	0M	50	3.7	11.2	18.7	26.2	33.7	46.8	65.5	93.5	
			25	1.9	5.6	9.4	13.1	16.8	23.4	32.7	46.8	
			25	1.9	5.6	9.4	13.1	16.8	23.4	32.7	46.8	
			40	3.0	9.0	15.0	20.9	26.9	37.4	52.4	74.8	
			50	3.7	11.2	18.7	26.2	33.7	46.8	65.5	93.5	
			10	0.7	2.2	3.7	5.2	6.7	9.4	13.1	18.7	
Fine Sandy Loam, Very Fine Sandy Loam	PL	1,2,3	10	0.7	2.2	3.7	5.2	6.7	9.4	13.1	18.7	
			20	1.5	4.5	7.5	10.5	13.5	18.7	26.2	37.4	
			30	2.2	6.7	11.2	15.7	20.2	28.1	39.3	56.1	
			20	1.5	4.5	7.5	10.5	13.5	18.7	26.2	37.4	
Loam	PL	1,2,3	10	0.7	2.2	3.7	5.2	6.7	9.4	13.1	18.7	
			15	1.1	3.4	5.6	7.9	10.1	14.0	19.6	28.1	
			20	1.5	4.5	7.5	10.5	13.5	18.7	26.2	37.4	
			10	0.7	2.2	3.7	5.2	6.7	9.4	13.1	18.7	
Silt Loam	PL	1,2,3	5	0.4	1.1	1.9	2.6	3.4	4.7	6.5	9.4	
			10	0.7	2.2	3.7	5.2	6.7	9.4	13.1	18.7	
			20	1.5	4.5	7.5	10.5	13.5	18.7	26.2	37.4	
			5	0.4	1.1	1.9	2.6	3.4	4.7	6.5	9.4	
Sandy Clay Loam, Clay Loam, Silty Clay Loam	PL	1,2,3	5	0.4	1.1	1.9	2.6	3.4	4.7	6.5	9.4	
			8	0.6	1.8	3.0	4.2	5.4	7.5	10.5	15.0	
			10	0.7	2.2	3.7	5.2	6.7	9.4	13.1	18.7	
			3	0.2	0.7	1.1	1.6	2.0	2.8	3.9	5.6	
Sandy Clay, Clay, Silty Clay	PL	1,2,3	3	0.2	0.7	1.1	1.6	2.0	2.8	3.9	5.6	
			5	0.4	1.1	1.9	2.6	3.4	4.7	6.5	9.4	
			10	0.7	2.2	3.7	5.2	6.7	9.4	13.1	18.7	

Note: 1. Soil texture and structure columns are based on Tyler and Kuns (2000).

2. Structure Abbreviations: Shapes: PL = platy; BK = blocky; PR = prismatic; GR = granular

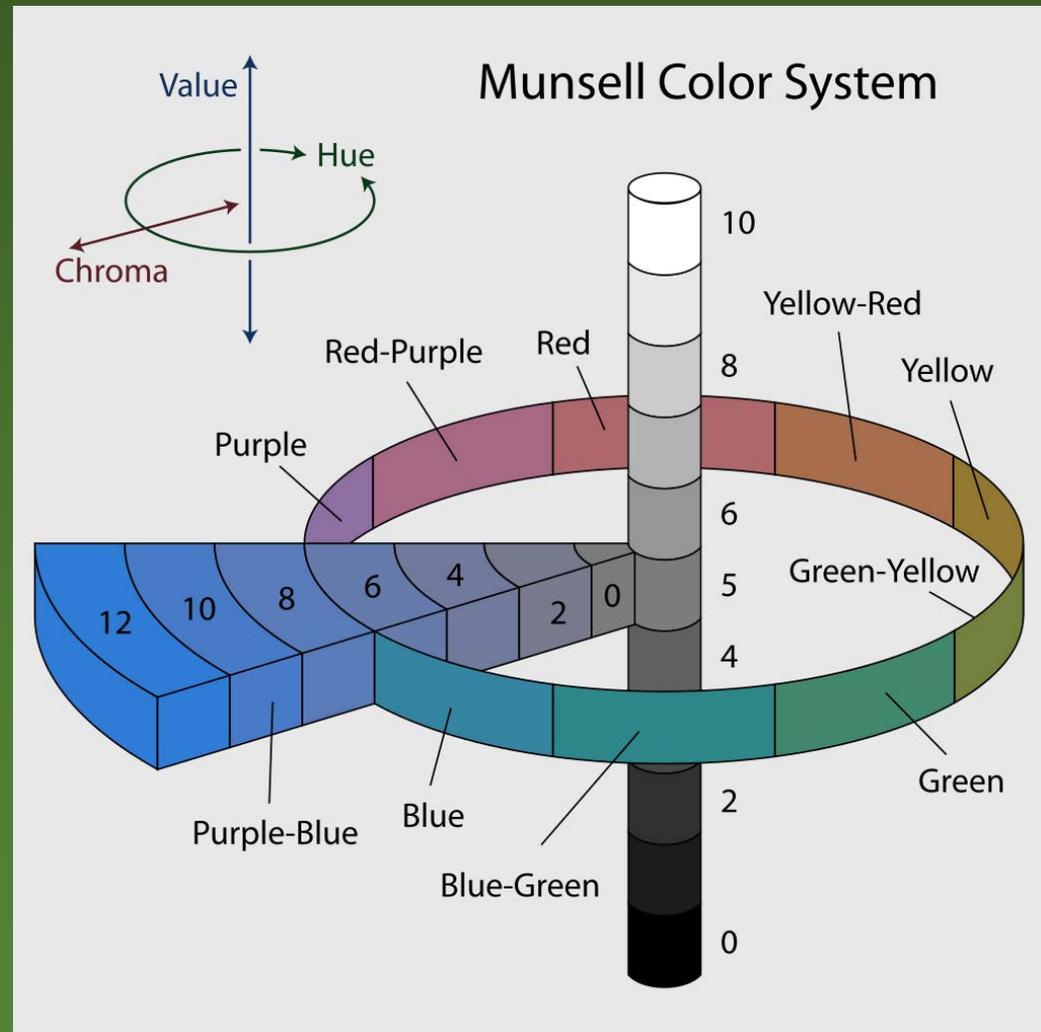
Grade: 0 = structureless; SG = single grain; M = massive; 1 = weak; 2 = moderate; 3 = strong

3. K = hydraulic conductivity (estimated)

Munsell Colors, Redox Features, SHWT, and Aerobic Conditions

Munsell Color System:

- hue
- value
- chroma



Munsell color: hue, value/chroma (name)

Example:

2.5YR 4/4 (reddish brown)

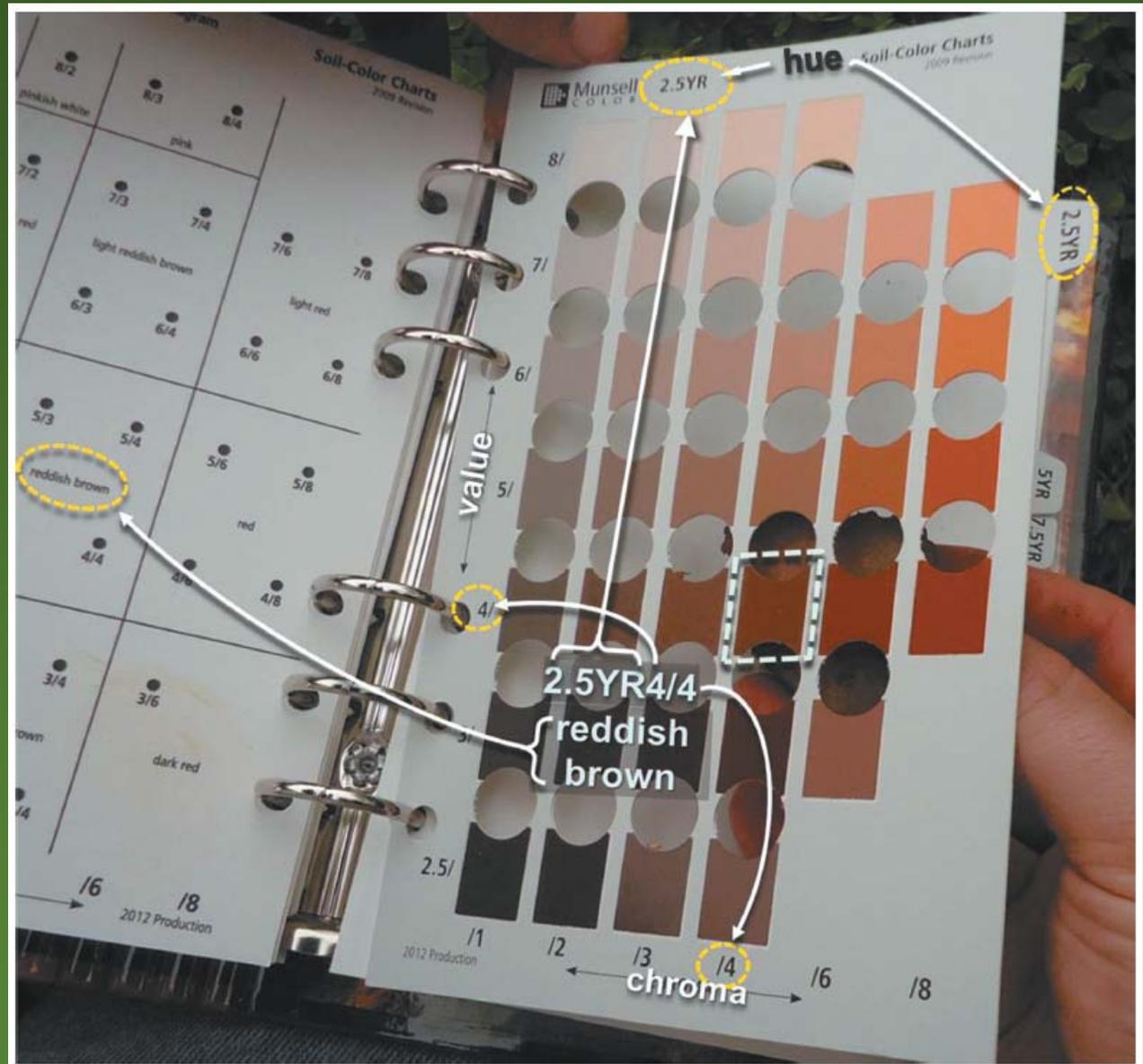
Hue (related to wavelength) e.g. 2.5YR

Value (lightness to darkness) e.g. 4/

Chroma (related to saturation / degree washed out) e.g. /4

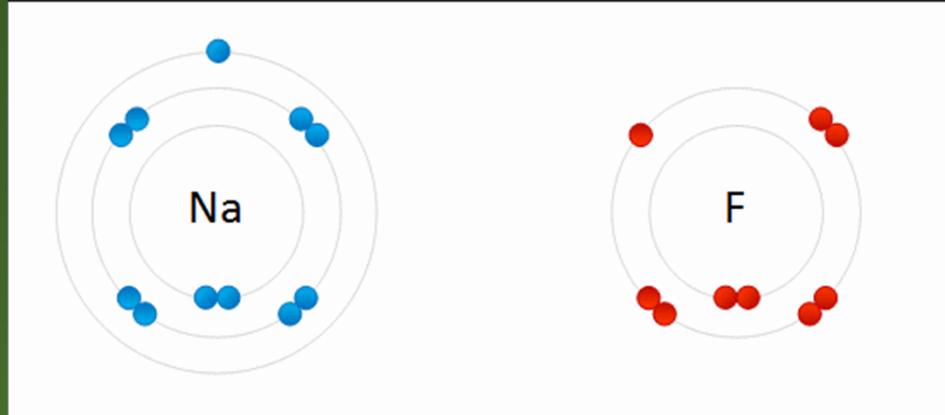
Name (applied to a group of color chips on adjacent page) e.g. reddish brown

Start on page 10YR!



What is Redox (reduction-oxidation)?

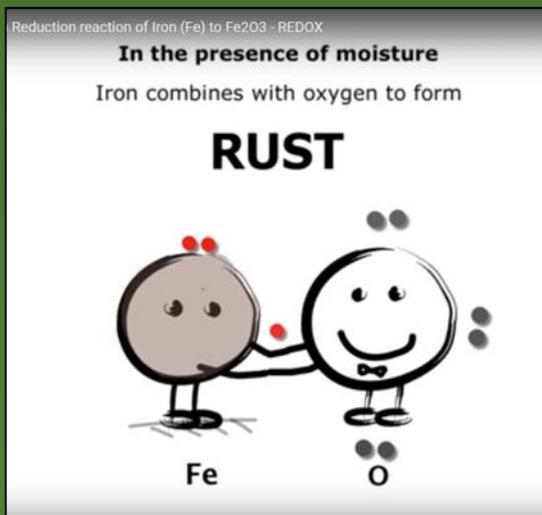
Sodium



Fluorine

Oxidation =
loss of
electrons

Reduction =
gain of
electrons



Oxygen is an oxidizer. It is reduced by gaining electrons as it oxidizes metals

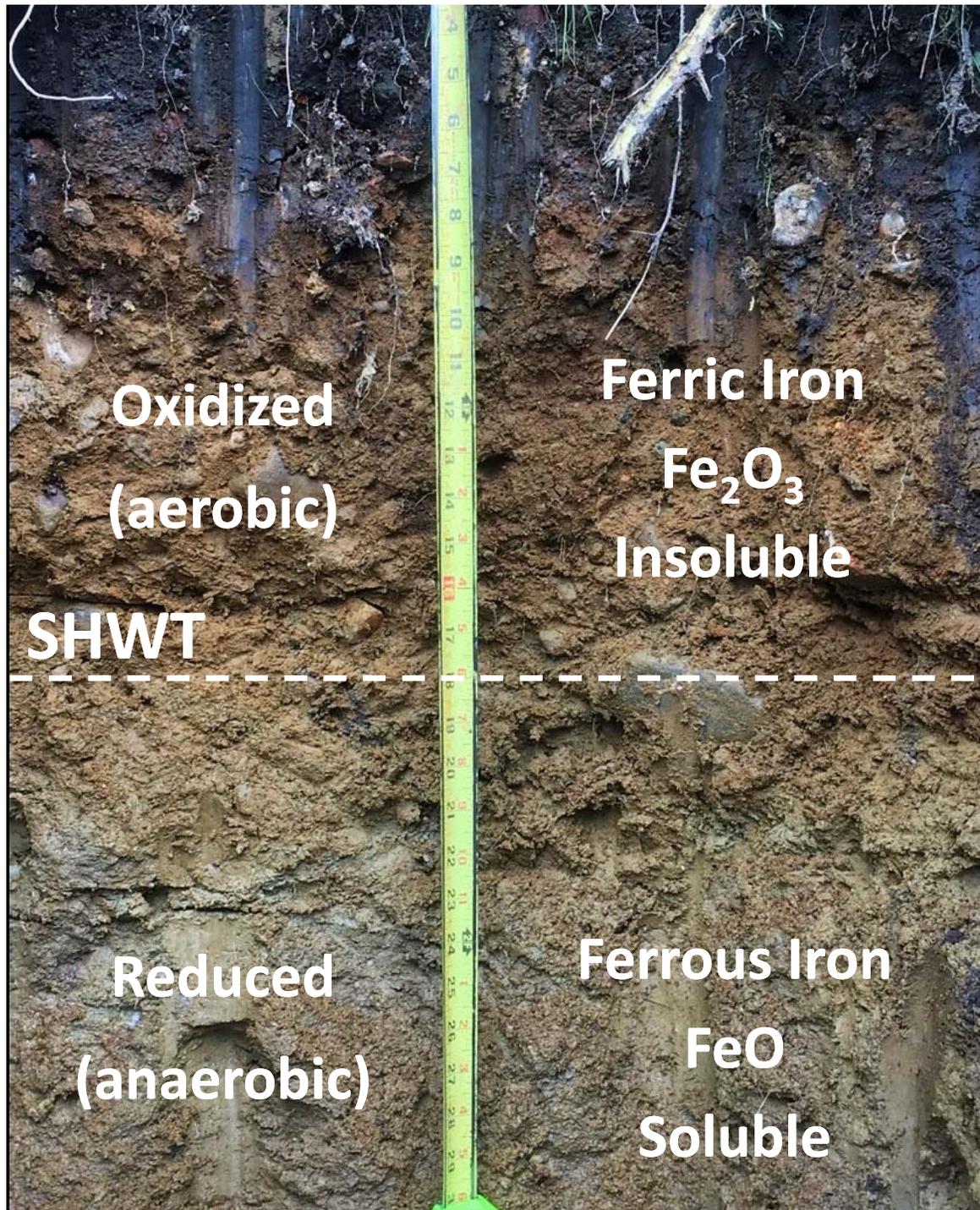
Iron³⁺ oxide = ferric oxide

Fe₂O₃ is insoluble (rust)

Iron²⁺ oxide = ferrous oxide

FeO dissolves in groundwater

<https://youtu.be/CMnkgKOTN-o>



Observations:

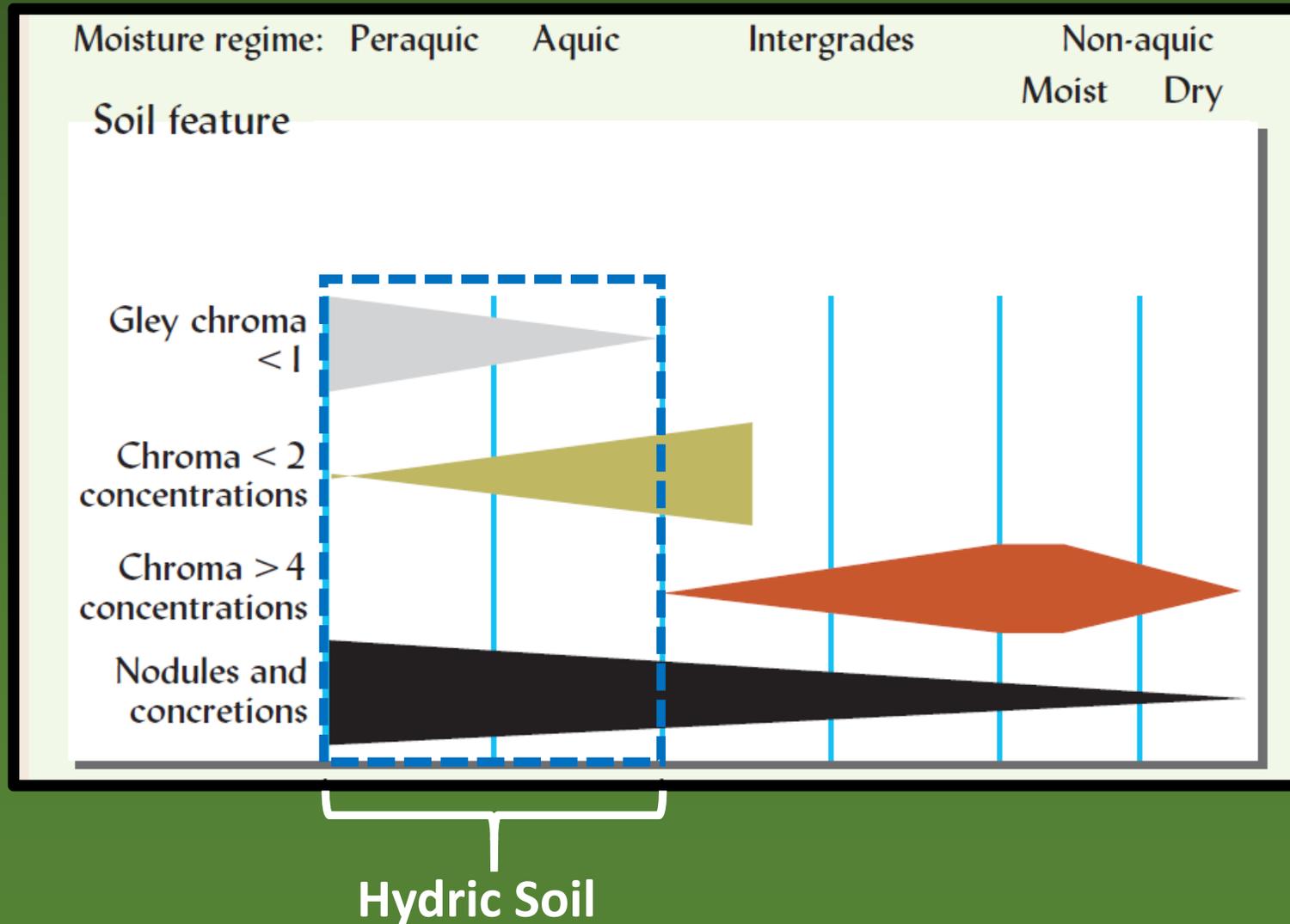
- What is the matrix color?
- Are there redox colors?
- Are there concentrations or depletions?

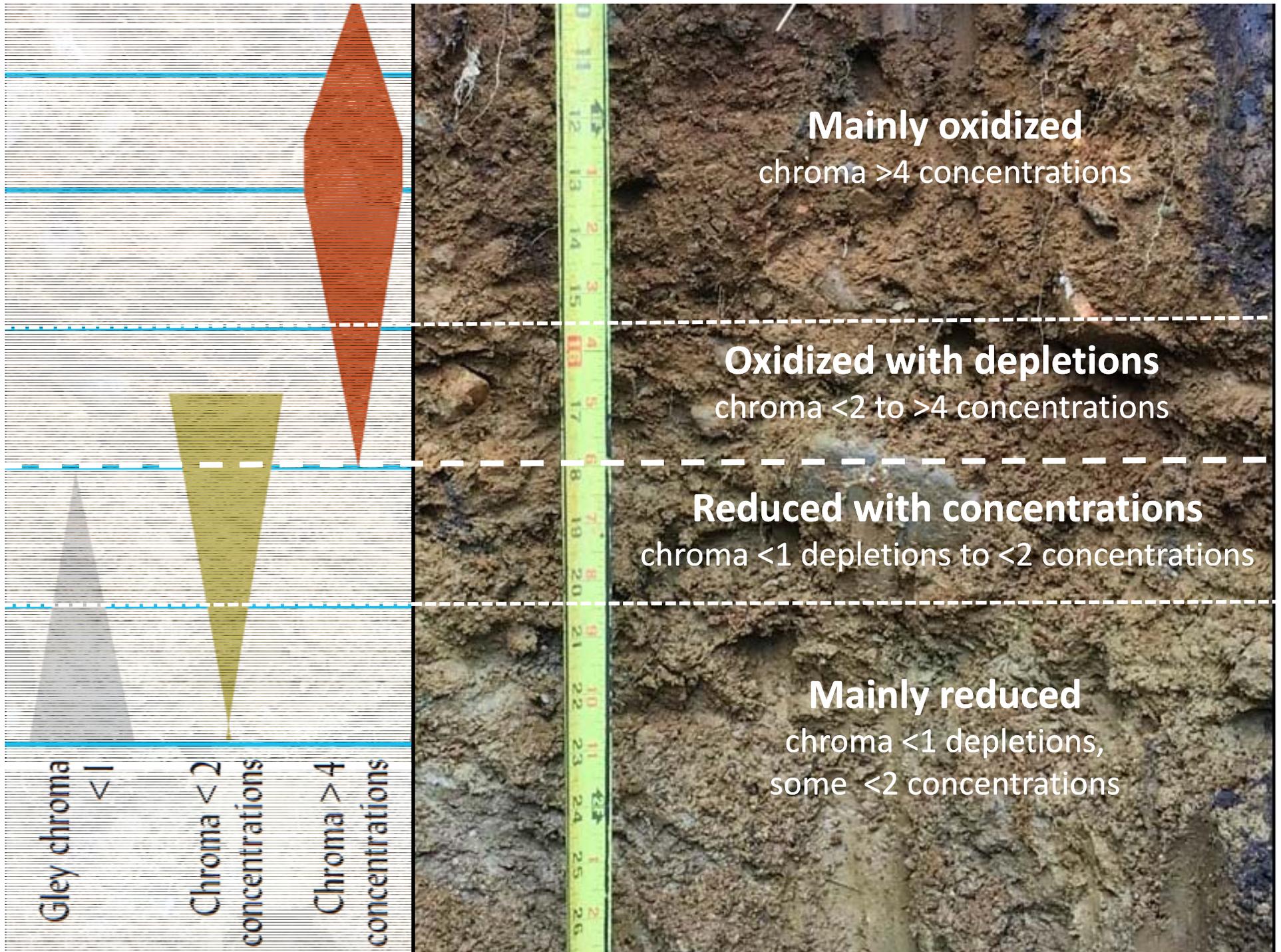
Interpretation:

- Where is the Seasonal High Water Table?

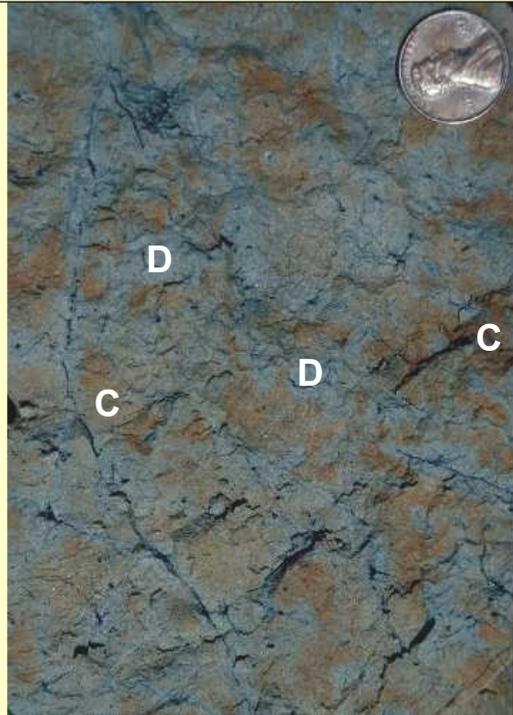
Soil Features & Duration of Water Saturation

← Increasing period of saturation

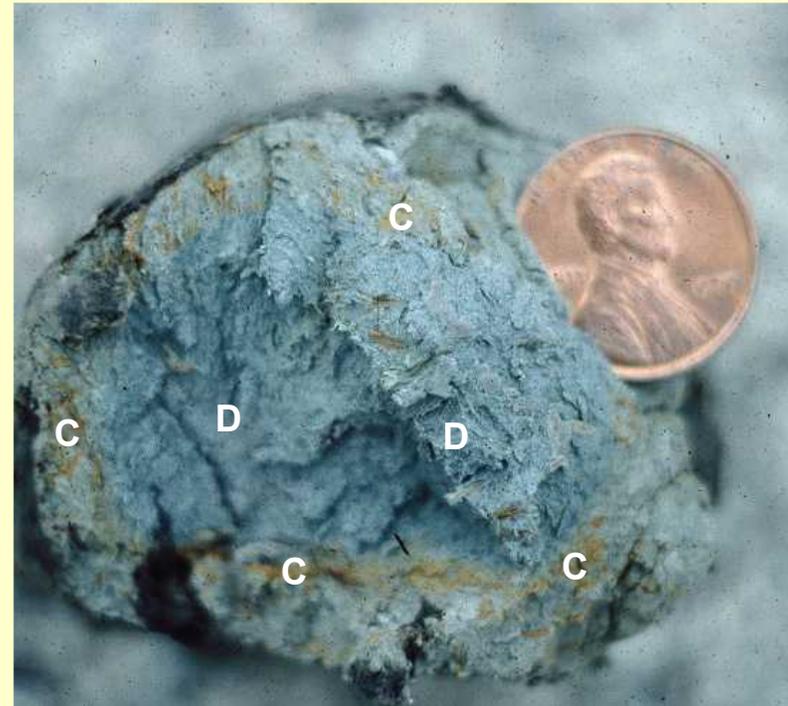




Redoximorphic Features



This photo shows redox concentrations (bright yellowish-brown colors 10YR5/6 munsell color), redox depletions (gray colors - 2.5Y 6/1 colors) with a pale yellowish-brown matrix color (2.5Y 5/3 munsel color).



This photo shows a redox depletion (5BG 6/0 munsell color) along a dead root channel (visible in the center) with redox concentrations (10YR 5/6) around the depleteion.

Redoximorphic Features



e.g. 1: Depletions in macropores & concentrations in matrix - water is infiltrating along macropores, matrix is unsaturated



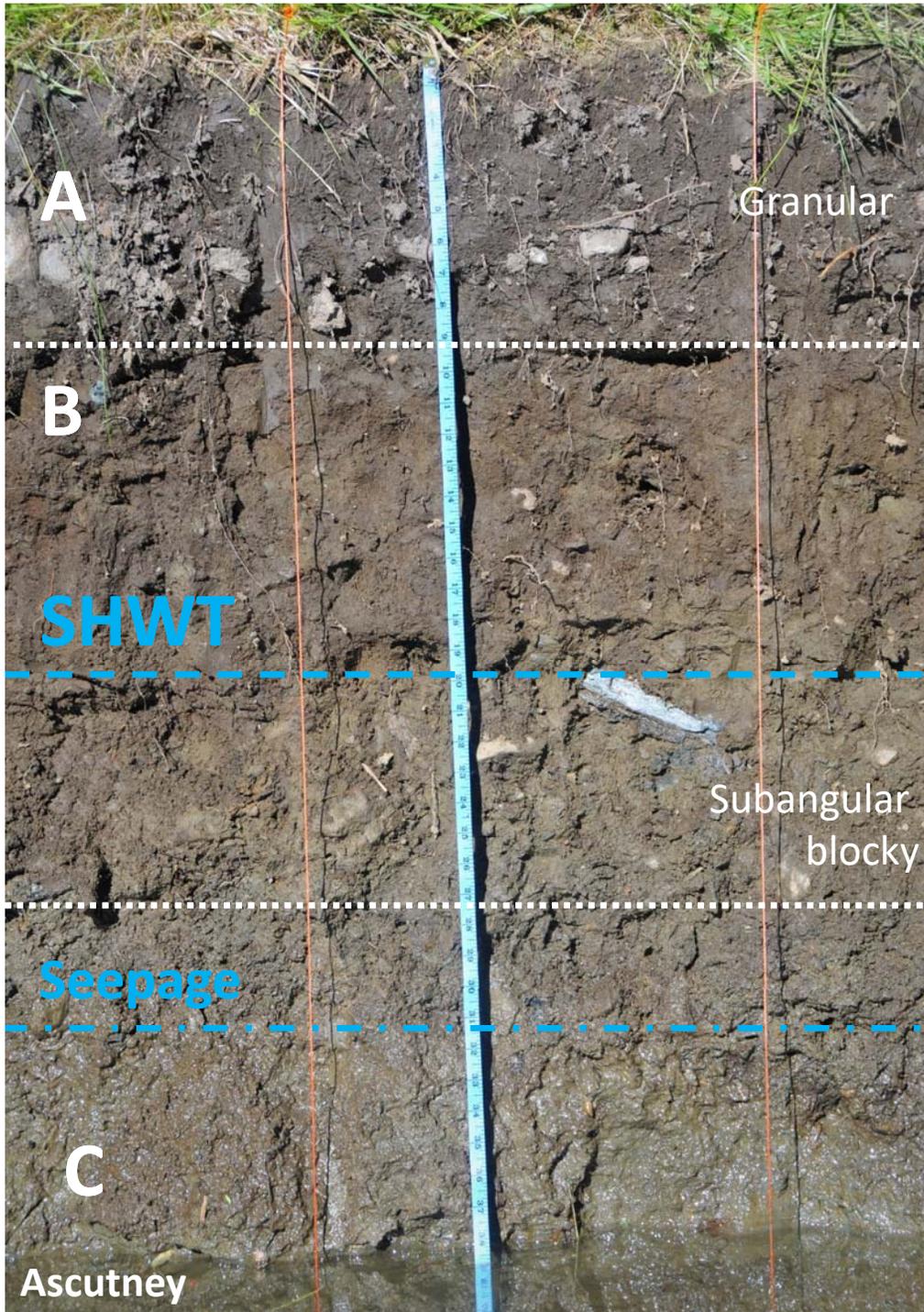
e.g. 2: Concentration in macropores & depletions in matrix - matrix is saturated for long periods, macropores are drained

Redoximorphic Features



e.g. 3: Depletions and concentrations have no consistent relationship to macropores – common indicator in sandy soils. This example show iron-manganese concentrations





What can you see?

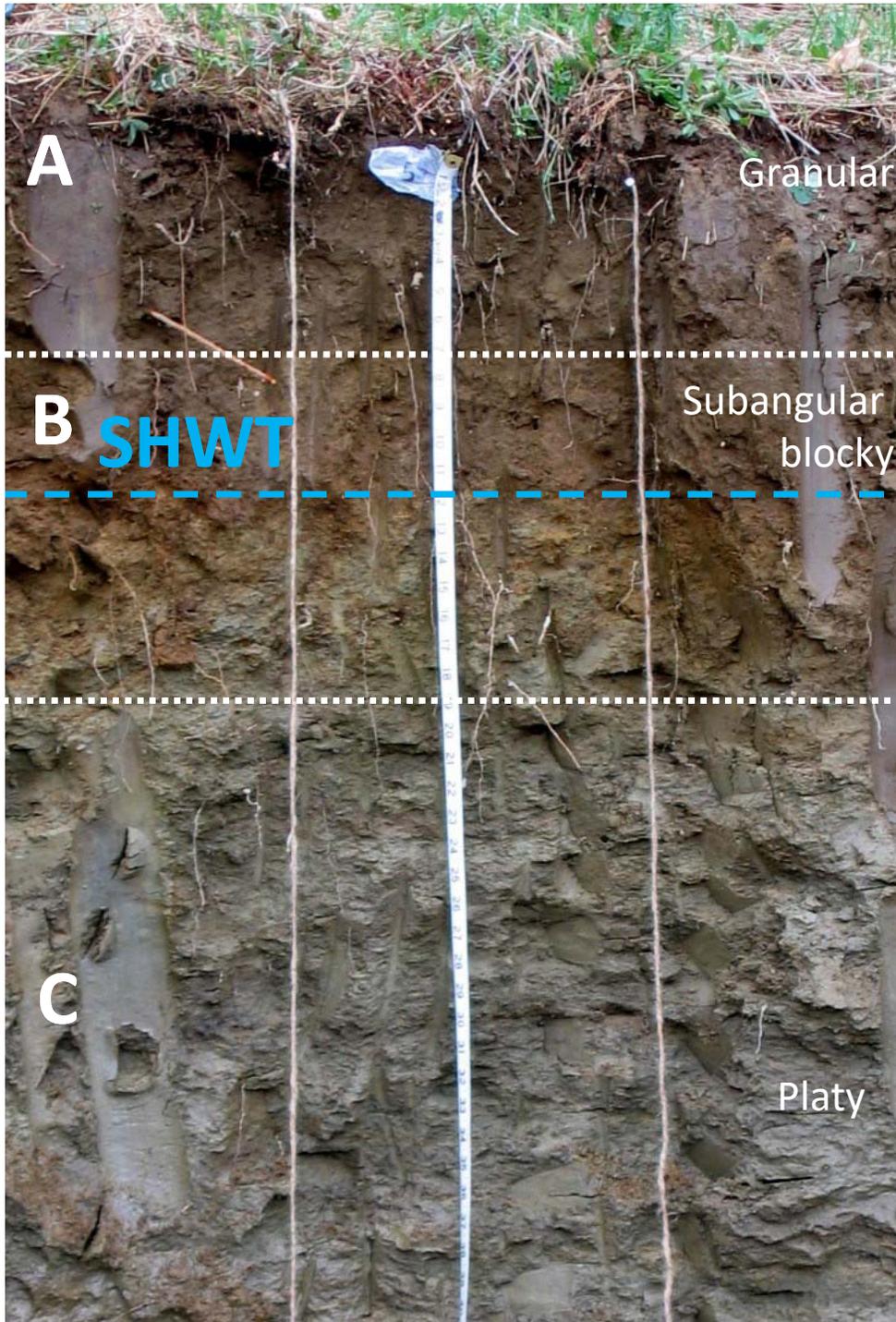
- Horizons
- Structure
- Seepage
- Redox colors
- Seasonal High Water Table



SHWT

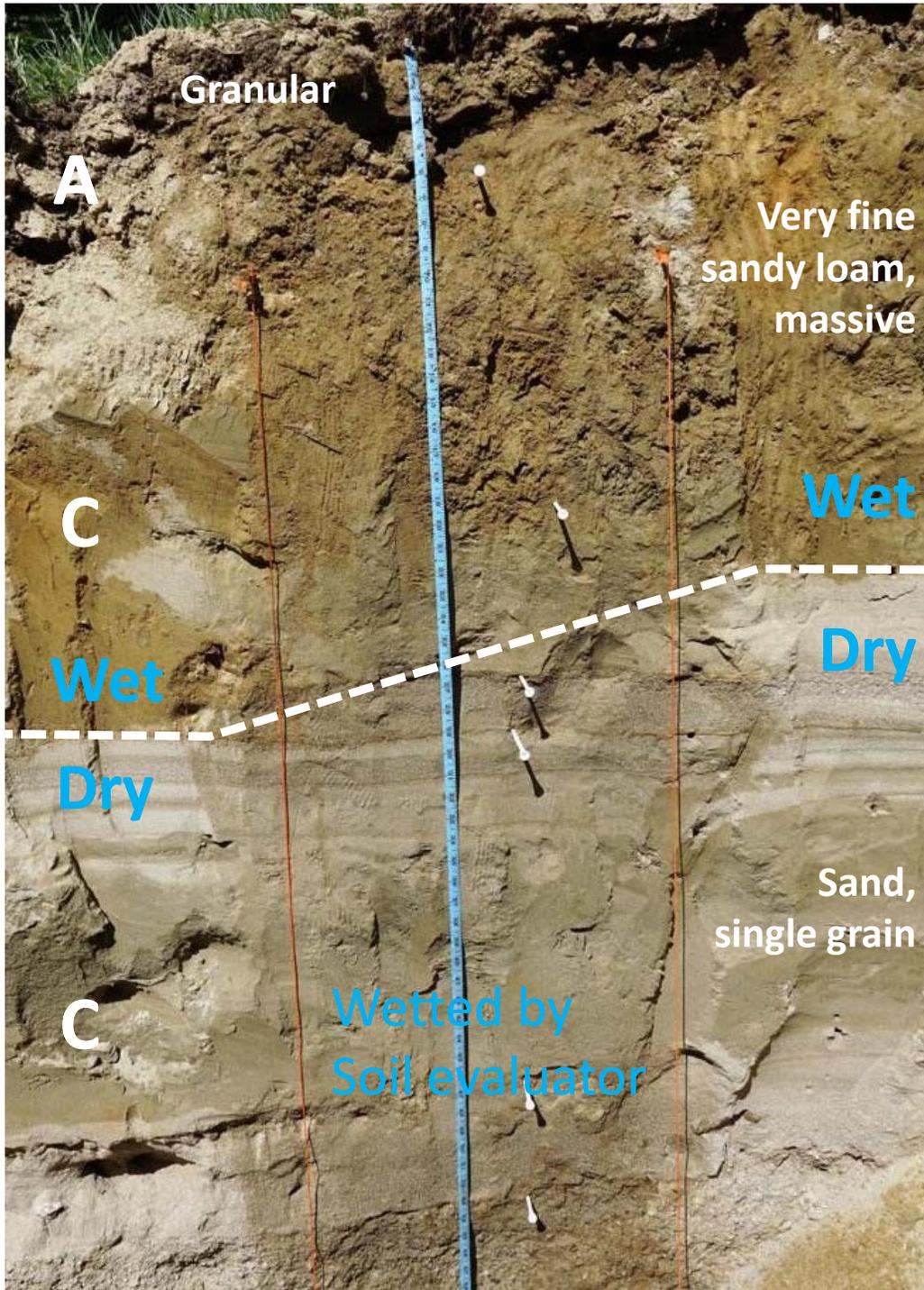
Seepage Flowing in

Flowing out



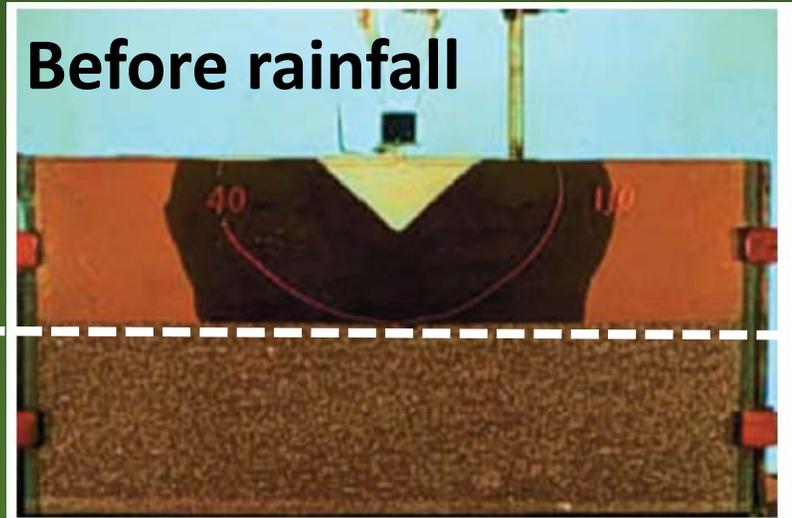
What can you see?

- Horizons
- Structure
- Seepage
- Redox colors
- Seasonal High Water Table

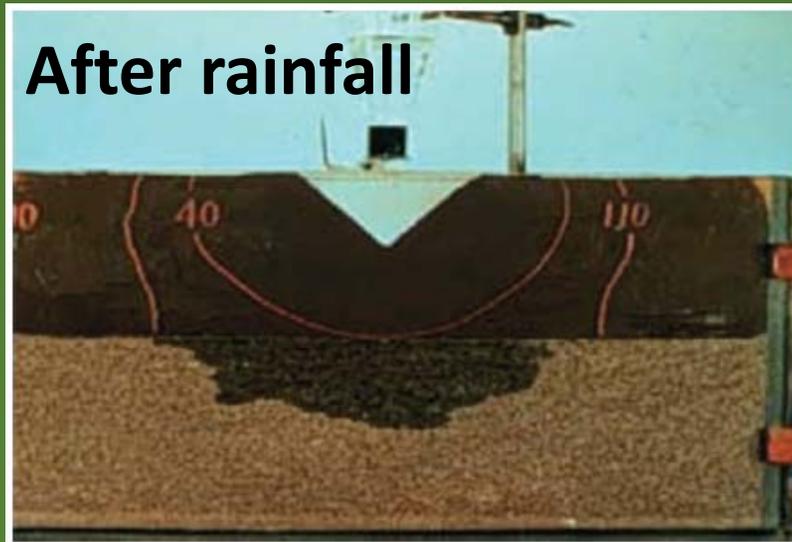


Example of infiltration through stratified soil kame terrace, Lincoln, VT

Before rainfall



After rainfall



Texture	Selected Munsell Colors							Average Value	Average Chroma	
organic sandy loam	10YR 3/2	10YR 3/2	10YR 2/2	10YR 2/1	10YR 3/2	10YR 2/2	10YR 3/3	2.6	2.0	
sand	10YR 4/6	10YR 5/6	10 YR 5/6	10YR 3/4	10YR 5/6	7.5YR 4/4	10YR 4/4	4.3	5.1	
gravelly sandy loam	10YR 5/6	2.5Y 5/3	10YR 4/4	10YR 4/4	10YR 4/4	7.5YR 4/6	10YR 5/4	4.6	4.4	
silt loam	2.5Y 6/4	2.5Y 6/4	10YR 4/2	10 YR 5/3	2.5Y 4/3	10YR 4/4	10YR 5/2	4.9	3.1	
silty clay loam	2.5Y 6/2	5Y 6/2	10YR 3/1	2.5Y 5/2	5Y 4/2	5Y 6/2	2.5Y 6/2	5.7	1.9	