Wetland Soils

Importance of wetland soils

- Chemical transformations
- Chemical (nutrient) storage

These affect plant growth and peat formation

Lecture outline:

- What are soils?
- How does inundation change upland soils into hydric soils?
- What are the important distinguishing characteristics of hydric soils?
- What are the implications of the unique characteristics of hydric soils for plants and chemical transformations?
What are soils?

__________ = study of the components and formation of soils

Soil mapping is done by the Natural Resources Conservation Service (NRCS), a branch of the USDA.

Soil Definitions:

• Early definition of soil: the material capable of supporting the growth of land plants.

• A natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or more of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy or the ability to support rooted plants in a natural environment. (Soil Survey Staff 1998)
What are NOT soils?

- Bedrock
- Rocky outcrops & plateaus
- Salt flats
- Sand beaches and sand bars
- Muddy shores
- Unconsolidated material lacking any vegetation cover
- Permanently flooded bottoms (this is SUBSTRATE)

Can you have a wetland if you don’t have soil?

Tiner 1999: “Tidal mud flats, sandy intertidal beaches, and rocky shores are examples of nonvegetated wetlands occurring on nonsoils.”
Soil Types

Two main types of soil: organic and mineral

% C = half the amount of % organic material, $\sim > 40\%$ organic material by weight

Organic matter must be $\geq 40$ cm for a soil to be a histosol (organic soil); otherwise, it is a mineral soil with an organic layer (horizon) on the top.

Organic Soils = Histosols

Formed when decomposition & mineralization of organic matter is greatly slowed due to either anaerobic conditions or cool-cold humid conditions.

3 of the 4 types of organic soils form due to hydric conditions:

- Fibrists = peat less than \( \frac{1}{4} \) decomposed, mostly identifiable plant fibers
- Hemists = mucky peat (peaty muck); intermediate decomposition and identifiability.
- Saprists = muck; mostly decomposed, mostly unidentifiable.

- Folists = non-hydric organic soils of boreal & tropical mountain areas
Mineral soil is comprised of particles < 2 mm in size.

Sand  
Silt  
Clay

<table>
<thead>
<tr>
<th>Limiting particle diameter (mm)</th>
<th>Size</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>2048 (-11)</td>
<td>V. Large</td>
<td>Boulders</td>
</tr>
<tr>
<td>1024 (-10)</td>
<td>Large</td>
<td></td>
</tr>
<tr>
<td>512 (-9)</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>256 (-8)</td>
<td>Small</td>
<td></td>
</tr>
<tr>
<td>128 (-7)</td>
<td>Large</td>
<td></td>
</tr>
<tr>
<td>64 (-6)</td>
<td>Small</td>
<td></td>
</tr>
<tr>
<td>32 (-5)</td>
<td>V. Coarse</td>
<td></td>
</tr>
<tr>
<td>16 (-4)</td>
<td>Coarse</td>
<td></td>
</tr>
<tr>
<td>8 (-3)</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>4 (-2)</td>
<td>Fine</td>
<td></td>
</tr>
<tr>
<td>2 (-1)</td>
<td>V. Fine</td>
<td></td>
</tr>
<tr>
<td>1 (0) (Microns µ)</td>
<td>V. Coarse</td>
<td></td>
</tr>
<tr>
<td>1/2 (+1)</td>
<td>Coarse</td>
<td></td>
</tr>
<tr>
<td>1/4 (+2)</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>1/8 (+3)</td>
<td>Fine</td>
<td></td>
</tr>
<tr>
<td>1/16 (+4)</td>
<td>V. Fine</td>
<td></td>
</tr>
<tr>
<td>1/32 (+5)</td>
<td>V. Coarse</td>
<td></td>
</tr>
<tr>
<td>1/64 (+6)</td>
<td>Coarse</td>
<td></td>
</tr>
<tr>
<td>1/128 (+7)</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>1/256 (+8)</td>
<td>Fine</td>
<td></td>
</tr>
<tr>
<td>1/512 (+9)</td>
<td>V. Fine</td>
<td></td>
</tr>
</tbody>
</table>

FIGURE 4.3 Standard sizes of sediments with limiting particle diameters and the $\phi$ scale of sediment size, in which $\phi$ is equal to $\log_s$, $s$ (the particle diameter). Source: G. M. Friedman and J. E. Sanders, *Principles of Sedimentology* (New York: John Wiley & Sons, 1978). Used with permission.
Soil Horizons

O = organic horizon:
   Oa = sapric
   Oe = hemic
   Oi = fibric
A = top mineral horizon
E = light colored horizon depleted in clay, other minerals
B = mineral subsoil horizon
C = parent material
R = unweathered rock

Horizons are often missing in natural soil profiles

Soil is studied only to a depth of about 2 m

Mineral soil, non-hydric

Histosol, hydric

Limnic Haplosaprist
E horizon
<table>
<thead>
<tr>
<th>Soil Property</th>
<th>Organic soil</th>
<th>Mineral soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic C content</td>
<td>&gt; 12-18%</td>
<td>&lt; 12-18%</td>
</tr>
<tr>
<td>Bulk density</td>
<td>&lt; 0.6 g/cm³</td>
<td>1-2 g/cm³</td>
</tr>
<tr>
<td>Porosity</td>
<td>&gt; 80%</td>
<td>45-55%</td>
</tr>
<tr>
<td>pH</td>
<td>&lt; 4.5</td>
<td>3.5 – 8.5</td>
</tr>
<tr>
<td></td>
<td>Fens &gt; 7.0</td>
<td></td>
</tr>
<tr>
<td>Nutrient availability</td>
<td>Low</td>
<td>Low – high</td>
</tr>
<tr>
<td>Cation exchange capacity</td>
<td>High</td>
<td>Low – high</td>
</tr>
<tr>
<td>Plant available water</td>
<td>High</td>
<td>Low – high</td>
</tr>
<tr>
<td>Hydraulic conductivity</td>
<td>Moderate – rapid</td>
<td>Very low – very rapid</td>
</tr>
</tbody>
</table>

Soil Formation

Factors: organisms, topography, climate, parent material, time.
Processes: additions, deletions, transformations, translocations

Hydrarch Succession

Tiner 1998
Hydric soils

**Definition:** A hydric soil is a soil that is formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part. (Federal Register, Feb. 24, 1995, Vol 60, No. 37, p. 10349). (Upper part = rooting zone of non-tree vegetation; typically 2 ft).

**Length of inundation:**

Extended inundation → anaerobic conditions → slowed decomposition → organic matter buildup = organic soils

Wet-dry cycles → mineral soils with unique characteristics caused by aerobic/anaerobic cycles.

**Anaerobic conditions develop due to (all are required for hydric soil):**

- Slow diffusion of oxygen into water-filled soil pores (stagnant water)
- Microbial respiration
- Presence of organic material (microbe substrate)
- Sufficient temperature for biological activity in soil (0 – 2 C)
Oxidation-reduction process

Typical respiration (a redox reaction):

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} \]

Half-reactions:

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} \rightarrow 6\text{CO}_2 + 24\text{e}^- + 24\text{H}^+ \] \text{(Oxidation = losing electrons, becoming more positive)}

\[ 6\text{O}_2 + 24\text{e}^- + 24\text{H}^+ \rightarrow 12\text{H}_2\text{O} \] \text{(Reduction = gaining electrons, becoming more negative)}

Alternate e\(^-\) acceptors:

- \(\text{NO}_3^-\)
- \(\text{MnO}_2\)
- \(\text{Fe(OH)}_3\)
- \(\text{SO}_4^{2-}\)
- \(\text{CO}_2\)
Oxidation-reduction process

Mitsch & Gosselink 2000.
## Oxidation-reduction process

<table>
<thead>
<tr>
<th>Terminal e- acceptor</th>
<th>Reduction Reaction</th>
<th>Soil colors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$</td>
<td>red, yellow, brown</td>
</tr>
<tr>
<td>Nitrate</td>
<td>$2NO_3^- + 10e^- + 12H^+ \rightarrow N_2 + 6H_2O$</td>
<td>no change</td>
</tr>
<tr>
<td>Manganese Oxides</td>
<td>$MnO_2 + 2e^- + 4H^+ \rightarrow Mn^{2+} + 2H_2O$</td>
<td>loss of mineral blacks</td>
</tr>
<tr>
<td>Iron Oxides</td>
<td>$Fe(OH)_3 + e^- + 3H^+ \rightarrow Fe^{2+} + 3H_2O$</td>
<td>gray, greenish, bluish</td>
</tr>
<tr>
<td>Sulfate</td>
<td>$SO_4^{2-} + 8e^- + 10H^+ \rightarrow H_2S + 4H_2O$</td>
<td>no change</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>$CO_2 + 8e^- + 8H^+ \rightarrow CH_4 + 2H_2O$</td>
<td>no change</td>
</tr>
</tbody>
</table>

Hydric soil colors

Gleization, Gleys
Pore linings
Oxidized rhizospheres
Redoxomorphic
Redox depletions
Reduced Fe diffuses into matrix, Soil drains
Oxygen moves into soil
Fe masses form when Fe$^{2+}$ is oxidized

Reduced Fe diffuses into matrix,
Color of depletion is gray
Munsell Color Charts
Oxidation-reduction cont.

Mitsch & Gosselink 2000.
Oxidation-reduction cont.

### Oxidation-reduction cont.

<table>
<thead>
<tr>
<th>Process</th>
<th>Electron acceptor</th>
<th>Energy ((-\Delta G°)) kJ/mole e(^{-}))*</th>
<th>Redox potential (Eh) in (mV)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic</td>
<td>(O_2)</td>
<td>125.1</td>
<td>&gt; 300</td>
</tr>
<tr>
<td>Nitrate reduction</td>
<td>(NO_3^-)</td>
<td>118.8</td>
<td>250</td>
</tr>
<tr>
<td>Manganese reduction</td>
<td>(MnO_2)</td>
<td>94.5</td>
<td>225</td>
</tr>
<tr>
<td>Iron reduction</td>
<td>(Fe(OH)_3)</td>
<td>24.3</td>
<td>100 – (-100)</td>
</tr>
<tr>
<td>Sulfate reduction</td>
<td>(SO_4^{2-})</td>
<td>25.4</td>
<td>-100 – (-200)</td>
</tr>
<tr>
<td>Methanogenesis</td>
<td>(CO_2)</td>
<td>23.2</td>
<td>&lt; -200</td>
</tr>
</tbody>
</table>

** Redox potentials are rough estimates, they vary depending on pH and temperature. Mitsch & Gosselink 2000.

Figure 2. pE–pH diagram for the iron system.
Hypothetical changes in redox potential over a wet-dry cycle