Geology 229
Engineering Geology
Lecture 24

Soil Profiles

(West, Ch. 8)
We have just finished the discussion of rock weathering. One direct consequence of weathering is the formation of the soil profile. Soil is certainly one of the primary resources of any country.
Outline of this Lecture

1. Soil Profile
2. Factors controlling soil profile development
3. Soil Classification
4. Construction problems with different soils
Definitions for SOIL

Engineering definitions:
  Civil Engineering:
    Soil is the earth material that can be disaggregated in water by gentle agitation.
  Construction:
    Soil is material that can be removed by conventional means without blasting. Similar to the definition of regolith in geological terms.

Agronomy definition:
  Soil consists of the thin layers of the earth’s crust formed by surface weathering that are able to support plant life.
Figure 8.6 Illustrations of the term soil.

(West, Figure 8.6)
Soil profiles

Soil profile is a vertical cross section from surface down to the parent materials. A well-developed soil profile shows distinct horizons. The three major horizons are A, B, and C horizons. Horizons are sometimes also called zones.
A Horizon:
The topsoil of leaching from which downward percolation of water has removed some clays and soluble ions. It is also commonly rich in organic matters (humus).

B Horizon:
The subsoil of accumulation. Clays are more prevalent and organic matter is less abundant.

C Horizon:
The transition from the soil profile to the unweathered parent material below.
In summary, Soil Profile is an end result of surface weathering brought about primarily by downward percolation of water.
Figure 8.7 Typical soil profiles: (a) glacial till and (b) granite bedrock.
A Horizon- This layer is the top 15cm of the soil profile and has the highest percentage of organic matter. The layer was likely formed from decomposing plant and mineral materials. It has a large amount of sand, likely deposited from the floods of Walnut Creek.

B1 Horizon- The second layer or B1 horizon is similar to the A horizon and is found from 15-30cm. It also contains a large percentage of sand particles and has likely been deposited in recent times.

B2 Horizon- This third horizon has gray mottles, or patches of gray colors throughout the soil matrix. It is sandy, with a slight increase in clay composition throughout its thickness of 30-60cm. The water table comes into this layer throughout the year.

B3 Horizon- The fourth horizon is found from 60cm and beyond. The strong gray colors indicate that it is exposed to water frequently throughout the year. It has an even stronger increase in clay content, but is still predominately sandy.
Profile description

* 0cm: A1 horizon. Dark grayish brown loamy fine sand. Sets hard when dry, plant roots common, good drainage, trace of gravel, signs of regeneration activity at 5cm, pH 4.4

* 13cm: A1 (gravelly). Same color and texture as above but the gravel content increases to moderate to heavy, plant roots as above, drainage as above.

* 26cm: A2 horizon. Grayish brown loamy sand. More than 70% gravel content, some pieces up to 100mm in diameter, massive structure, some plant roots, fair drainage - probably enhanced by the gravel, pH 4.8

* 43cm: B horizon. Gray and yellow brown sandy clay. Slight to moderate content of rounded gravel, clay is tough dense and cemented in the dry state, massive structure, only a few plant roots, poor drainage, horizon is water logged at the top, old tree root at about 60cm, pH 4.1

A real world example of soil profile in the state of Maryland
Factors controlling soil profile development

- Parent material
- Climate
- Time
- Topography
- Vegetation
Parent Material (I)

The two primary subdivisions for parent material:

1) Bedrock weathered in place (producing the residual soils); and
2) Transported regolith or unconsolidated material (producing the transported soils).

The natural of parent material affect soils in two ways:

(1) The type of parent materials affects the rate of weathering.
(2) The chemical make up of the parent material affects the soil's fertility, which affects vegetation.
Parent Material (II)

1) Bedrock weathered in place:
   • In most cases the parent rock provides a range of chemical components in soil profile.
   • However, quartz-rich rocks (e.g., sandstone, quartzite, etc.) lacking chemical diversity, not good for supporting vigorous plant growth

2) Clay minerals
   • Illite in marine shales, kaolinite and illite in freshwater sediments

3) Transported soils
   • Water, glaciation, depositing while sorting
Climate

Climate is perhaps the most important ambient factor in soil profile development.

(1) As we pointed out in weathering, temperature and precipitation have great influence on weathering.

(2) The amount of precipitation affects how much various materials are leached from the soil, thereby affecting soil fertility.

(3) Climate affects the type of plant and animal life present.
Soil types: The prevailing climate has controlling influences on soil types. The soil types in the U.S. can be roughly described as **pedalfers** in the eastern half (east of a line from northwest of Minnesota to south-central Texas) of the U.S., and **pedocals** in the drier western U.S.

**Pedalfer** = pedon(soil)+Al(aluminum)+Fe(iron) in Greek. Pedalfers are found in the eastern U.S. with high precipitation. In pedalfers the soluble carbonates are removed and Al-rich clays and Fe oxides are carried downward to the B horizon.

**Pedocal** = pedon(soil)+**CAL**cite. Pedalcals contain an accumulation of calcium carbonate in the B horizon. Pedalcals are found in the drier western U.S. with grassland and brush vegetation.
The Effect of Climate on Soil Profile Development

**Table 8.1** Weathering Details for Rocks Under Various Climatic Conditions

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Minerals Present</th>
<th>Weathering Conditions</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>Quartz, orthoclase</td>
<td>Humid</td>
<td>Quartz pieces, clay, oxides</td>
</tr>
<tr>
<td>Gabbro</td>
<td>Calcic plagioclase, olivine</td>
<td>Humid</td>
<td>Iron oxide and clay</td>
</tr>
<tr>
<td>Quartz sandstone</td>
<td>Quartz</td>
<td>Humid</td>
<td>Quartz pieces</td>
</tr>
<tr>
<td>Granite</td>
<td>Quartz, orthoclase</td>
<td>Arid</td>
<td>Pieces of quartz and orthoclase</td>
</tr>
<tr>
<td>Cherty limestone</td>
<td>Calcite, chert, impurities</td>
<td>Humid</td>
<td>Chert, iron oxide, clay</td>
</tr>
<tr>
<td>Granite</td>
<td>Quartz, orthoclase</td>
<td>Humid, tropical</td>
<td>Clay, oxides</td>
</tr>
<tr>
<td>Muscovite schist</td>
<td>Muscovite, hornblende</td>
<td>Humid</td>
<td>Muscovite pieces, clay, oxides</td>
</tr>
</tbody>
</table>
Time

• In general, the longer a soil has been forming, the thicker it becomes and the less it resembles the parent material.

• If the parent materials are the same (e.g., glacial till), and the climate are the same (e.g., central north US), but the timing is different, the development of the soil profiles may be different. For example, In central north US, soil in central Indiana (Wisconsin age, ~8000-14000 years ago) has less clay accumulation in the B Horizon and the soil profile is not as thick as that in central Illinois (Illinoian to pre-Illinoian age, 100,000-1Ma ago). The smaller amount of clay makes younger soil (Wisconsin) more permeable and help drainage and more fertility.
topography

Steep slopes encourage runoff and erosion. Thus the soil profile thins near hilltops and thickens in the low lands.

vegetation

Plants hold soil in place with their roots. Plants also provide organic matter to the soil, contributing to soil fertility or water retention.
This photo is an outcrop of a glacial till deposit. Glacial till is a heterogeneous mixture of clay to boulder size particles deposited within or beneath glacial ice. The till type on this photo is a dense or basal till with lenses of looser, sandy material (sandy till), the soil type mapped in this area is the Montauk series [the solum (the A and B horizons) has been removed on this photo. photo location: Fearing Hill, Wareham, MA].
A photo of a glacial fluvial deposit (the topsoil and subsoil of a Hinckley soil has been removed) from a gravel pit. This photo shows the horizontal stratified layers of sand and gravel on the top of the photo called the topset beds or delta plain. The inclined or dipping layers of fine and coarse sand (visible on left part of photo) are called the foreset beds or delta slope. The foreset beds were deposited into a glacial lake, the contact of the topset and foreset beds (delta plain/delta slope) marks the former water level of the lake. town of Raynham, MA.
Soil Classification

There are six classification systems, each one is designed for a particular field.

1) Wentworth Scale
   • For Geology, not engineering geology;

3) USDA Scale
   • Agriculture;

3) BPR Scale
   • Road construction

4) ASTM Scale
   • Ceramic industry;

5) AASHTO Scale
   • Highway engineering;

6) USC Scale
   • Civil Engineering, construction;
(West, Figure 8.8)
Soil Classification (cont.)

1) Wentworth Scale

- For Geology, not engineering geology. Wentworth scale uses 2 as the base and mm as the primary unit. The subdivisions are based on a ratio of 2.

<table>
<thead>
<tr>
<th>φ-scale</th>
<th>-3φ</th>
<th>-2φ</th>
<th>-1φ</th>
<th>0φ</th>
<th>1φ</th>
<th>2φ</th>
<th>3φ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8</td>
<td>¼</td>
<td>½</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

-3 -2 -1 0 1 2 3
Figure 8.9  Frequency distribution curve based on the phi scale.
Soil Classification (cont.)

2) USDA Scale

- USDA scale intentionally sets silt/clay boundary lower than the Wentworth scale (0.004 mm) and ASTM scale (0.005 mm), it is 0.002 mm. The reason behind this classification is:
  - Fine-sized quartz and feldspar grains may occur at 0.005 mm, but definitely not smaller than 0.002 mm. However, quartz and feldspar are not plastic at all. Inclusion of these quartz grains into clay complicates many problems. USDA intends to coincide clay size with clay minerals.
Figure 8.10 Bureau of Public Roads textural classification chart.

Figure 8.11 USDA textural classification chart.

(West, Figures 8.10 and 8.11)
Soil Classification (cont.)

6) USC Scale

- USC scale call soil with particle size smaller than 0.075 mm fines. So there are plastic fines, and non-plastic fines.
- USC system is widely used in civil engineering except in highway and airport runway construction.
- Some abbreviations:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>G-gravel</td>
<td>L-low liquid limit (less plasticity)</td>
</tr>
<tr>
<td>S-sand</td>
<td>H-high liquid limit (high plasticity)</td>
</tr>
<tr>
<td>M-silt</td>
<td>Pt-peat, humus</td>
</tr>
<tr>
<td>C-clay</td>
<td>O-organic</td>
</tr>
<tr>
<td>W-well graded</td>
<td>P-poor graded</td>
</tr>
<tr>
<td>U-uniformly graded</td>
<td>GW-well graded gravel</td>
</tr>
<tr>
<td>GM-silty gravel</td>
<td>CH-high liquid limit clay</td>
</tr>
<tr>
<td>Depth</td>
<td>Blows/Ft.</td>
</tr>
<tr>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>SS - 1</td>
</tr>
<tr>
<td>10</td>
<td>SS - 2</td>
</tr>
<tr>
<td>15</td>
<td>SS - 3</td>
</tr>
<tr>
<td>20</td>
<td>SS - 4</td>
</tr>
<tr>
<td>25</td>
<td>SS - 5</td>
</tr>
</tbody>
</table>

Bottom of hole, 25 feet

Water in hole on completion, 12.5 feet

SS = Split Spoon Sample

**Figure 8.12** Drilling log of a soil boring.
Engineering properties of soil

- Compressibility
- Shear strength
- Bearing capacity
Soil hazards associated with construction

1, compressible soil

High organic soils: glacial deposits; flood plain, excessive settlement, low bearing capacity, low shear strength

2, collapsing soil

Loose sands and silts, occurred in

Sandy coastal plains; Sandy glacial deposits; Alluvial deposits of intermountain regions

3, expansive soil

Soils containing swelling clays, primarily smectite, expand when absorbing water and shrink when losing it. Damage to structures caused by expansive soils is one of the most costly natural hazard in the U.S.
Soil hazards associated with construction (cont.)

4, corrosive soil
High acidity (if resistivity $\rho < 700 \ \Omega m$)
Low acidity (if resistivity $\rho > 1750 \ \Omega m$)

5, fine texture soil

Rigid pavement pumping – removal of fines in subbase and make a void, caused by passage of heavy trucks.

6, saturated fine sand and silt

Earthquake induced liquefactions.

7, permeability of soil

It is good to have high permeability (k) soil for water supply, and low permeability soil for dam seal. Remember there are 9 orders of magnitude range in soil permeability!