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Chapter 2. Formation of Soils from Parent Materials

Overview

Soils vary greatly from one location to another around the world. This variation can largely be understood in terms of the way in which certain environmental factors of soil formation affect the four basic processes by which geologic parent materials are changed into soils.

Weathering of Rocks and Minerals

The earth's mantle was originally covered by water and solidified magma, the latter being comprised of **igneous rocks** such as granite and gabbro. These rocks in turn were made up of mixtures of specific **primary minerals** such as quartz, feldspars, micas, hornblende, and biotite. Weathering broke down the rocks and minerals, *destroying* some in the process, but also *synthesizing* new ones (**secondary minerals**). Some of the weathering products were transported by water and wind to new locations where they become sediments in lake or ocean bottoms. These sediments were later recemented into **sedimentary rocks** such as sandstone and shale. Some igneous and sedimentary rocks were later subjected to high pressures and temperatures bringing about a metamorphosis (change) in form and structure, and creating **metamorphic rocks**. Gneiss, schists, and slate are examples of metamorphic rocks.

Weathering Processes

(1) **Physical weathering** (disintegration) results in physical breakdown of the rock/minerals into smaller particles without significant change in chemical composition. Disintegration is enhanced by temperature changes and differential expansion of minerals, frost action and peeling of layers from the parent mass (**exfoliation**). Erosion, transport, and deposition by wind, water, and ice are physical processes that grind and breakdown the rock and mineral particles.

(2) **Biogeochemical weathering** (decomposition) results in the destruction of the primary minerals and in some cases the simultaneous generation of secondary minerals such as silicate clays. The latter are formed either by alteration of primary minerals or by recrystallization of decay products into new minerals. Biogeochemical breakdown is enhanced by the (a) **hydrolysis**, or the destruction of a mineral by reaction with H^+ and OH^- ions in water and (b) **hydration** or the chemical combining of the mineral with intact water molecules, [c] **complexation** of metal cations by organic ligands. **Oxidation** of elements such as iron or manganese in minerals helps breakdown rocks and releases secondary minerals. **Carbonation** and other reactions utilizing acids formed by plants and microbes (e.g. H_2CO_3 , HNO_3 , and H_2SO_4 and some organic acids) result in the formation of secondary minerals such as silicate clays. All these reactions require or are enhanced by the presence of water, and many of them may lead to the synthesis of secondary minerals.

Five Factors of Soil Formation

1. **Parent material**
2. **Climate**
3. **Living organisms**
4. **Topography**
5. **Time**

Parent materials are the starting point for soil development, and their nature profoundly influence soil properties, especially in areas where chemical weathering has not destroyed or greatly modified the

original minerals. Soil texture is often determined by the nature of the parent materials as are the rate and nature of some weathering processes. For example, limestones resist the acidifying processes while shales resist the rapid downward movement of water. Also, the type of silicate clays formed in a given area are commonly related to the nature of the parent materials.

Parent materials may have been formed in place from the native rock (residual or sedentary), or they may have been transported from one area to another by water, ice, wind or gravity. **Residual** parent materials are common in upland areas that have not been covered by materials transported from elsewhere. They are the most extensive of all parent materials.

Water-transported materials may have been deposited in former lake bottoms (**lacustrine**), alongside streams (**alluvial**), or in ocean bottoms that have since been elevated (**marine**). If deposited near the seashore or river bank they are generally coarse textured, but if deposited further from the shore and in still water, they are commonly fine in texture giving rise to soils high in silt and clay.

Parent materials transported by glaciers (ice) that once covered much of the world's northern latitudes include a mixture of rocks and minerals. Deposited by the melting glaciers, these heterogeneous materials are known collectively as **glacial till**. Some till is found in irregular deposits known as **moraines**. Coarse textured glacial **outwash** materials are another locally important parent material.

Wind blown (aeolian) materials have resulted from the action of strong winds that carried fine-textured materials from one area to another. These include, in order of decreasing particle size, dune sands, loess, and aerosolic dusts. The latter can move across oceans such that soils in North America may contain dust from China and those in South American contain dust from Africa. Parent materials that move down hill slopes by gravity (**colluvium**) are not very extensive, but are locally important. Another type of locally important parent material is the accumulated organic debris of partially decomposed plant tissues in which organic soils form, mainly in bogs and other wet areas.

Climate largely determines the nature of the weathering that occurs and profoundly influences the living organisms found in an area. **Temperature** and **precipitation** affect the rates of chemical, physical and biological processes responsible for weathering and for soil profile development. For every 10° C rise in temperature the rates of biochemical reactions double. Also, weathering reactions involve water. **Effective precipitation** in soil formation is the water that moves through the regolith. The greater the effective precipitation, the greater is the development of the soil profile. As a result, soils in desert areas are generally relatively shallow, being influenced mostly by mechanical weathering and by less intensive chemical reactions. Many soils of the humid tropics are deep, and in them most primary minerals have been destroyed by intensive weathering.

Climate also has a profound influence on the natural vegetation. By its effects on temperature, moisture, natural vegetation, and soil organisms, climate plays a major role in determining weathering patterns and in influencing the kinds of soils that develop.

Living organisms, especially natural vegetation, influence the development of soil characteristics in several ways. First, they are *sources of organic matter* essential for soil chemical and physical properties. The accumulation of organic matter in the upper layers of soil is one of the first steps in the development of soil profiles. Also, living organisms facilitate the *cycling of essential* plant nutrients. The nutrients are absorbed from the soil by plants, are returned to the soil surface in plant residues, and then back to the soil when soil organisms decompose the plant residues. Earthworms, termites, and rodents act as *mixing agents*, moving weathered materials and organic matter up and down the soil profile. Natural vegetation also helps *stabilize the soil* and protect it from the ravages of soil erosion.

Soils of grasslands tend to have higher organic matter contents than forested soils. This results in generally more stable soil aggregates in areas with natural grassland vegetation. Soils developed under pine forests are generally more acid than those formed under deciduous forests since pine tree needles are lower in non-acid cations such as Ca^{2+} , Mg^{2+} , and K^+ .

Topography influences the rate of runoff and erosion from the soil surface and consequently the infiltration of the water. Consequently, soils on hillsides are commonly not as deep as those on flat terrain, but the removal of excess water is more difficult in the flat lands. Excess water in depressed areas leads to the formation of peat bogs and in turn organic soils. Soils under shallow coastal waters

are called subaqueous soils.

The amount of time that parent materials have been subjected to weathering and soil forming processes influences soil properties. Residual parent materials have generally been subjected to soil forming processes longer than transported parent materials. Recently deposited alluvium alongside a stream has had too little time for significant soil profile development to take place. Likewise, soils developed from glacial parent materials and coastal plain areas are generally less weathered than those developed from residual materials.

Four major soil forming processes

1. **Transformations** such as rock weathering and organic matter decomposition that destroy some soil constituents and synthesize others.

2. **Translocations of** organic and inorganic materials out of the profile or from one horizon up or down to another. Often translocations result in accumulations of materials in a particular horizon, such as the accumulation of carbonates in the lower horizons of a semi-arid region soil.

3. **Additions** of materials such as plant residues, dust, and salts, to the soil profile from outside sources.

4. **Losses** of materials, such as water, eroded particles, oxidized organic matter, and leached salts from the soil profile.

The combined action of these processes brings about vertical differentiation in the regolith, and leads to the formation of distinct horizontal layers called soil horizons.

The Soil Profile

The layering described above gradually gives rise to natural bodies called *soils*, each of which has a characteristic sequence of soil horizons that is termed a **soil profile**. The master horizons of these profiles include the following:

O horizons: Organic horizons that form above the mineral soil.

A horizons: Topmost mineral horizons, darkened somewhat by organic matter accumulation. Some finer materials have moved downward.

E horizons: Zones of maximum leaching (eluviation) of clay and of oxides of Fe and Al, generally lighter in color than A horizon.

B horizons: Zones of accumulation (illuviation) of materials such as silicate clays and oxides of Fe and Al, and sulfates and carbonates of Ca, and Mg. Materials may have formed in place or may have moved in from other horizons.

C horizons: Material underlying the A, E, and B horizons that is generally little affected by the processes that formed the horizons above it. It may or may not be the same as the material from which the upper horizon formed.

R layers: Underlying consolidated rock.

Transition horizons: Transitional horizons between master horizons, designated by using both capital letters, the dominant horizon being listed first (e.g. AE, EB, BE, and BC).

Subordinate horizon designations help clarify the specific nature of a soil horizon. For example a Bt horizon has accumulated silicate clays, while a Bk horizon has accumulated carbonates.

Model Answers to Study Questions

- See Section 2.1 and Figure 2.4
During weathering the original rocks and minerals are *destroyed* or broken down into smaller particles or simpler compounds, but these products may also be combined so that new minerals are *synthesized*. Example: orthoclase breaks down to release potassium, aluminum and silicon into the weathering solution and from these components new minerals, perhaps silicate clays, are formed.
- See Section 2.1, equations 2.1-2.9.
During hydration reactions intact water molecules bind to the hydrating mineral.
During hydrolysis water molecules split into H⁺ and OH⁻ ions, with the H⁺ often replacing a metal cation from a mineral structure.
During dissolution, water molecules surround ions from the soluble mineral until they become dissociated from each other.
During carbonation, water dissolves carbon dioxide to form carbonic acid.
- See Figure 2.4 and Table 2.3
As the weathering of alumina-silicate minerals proceeds, the ratio of silicon to aluminum tends to decrease because silicon dissolves in the weathering solution much more readily than does aluminum. Therefore, a low ratio of silicon to aluminum in a soil usually indicates a highly weathered stage.
- See Figures 2.9, 2.11, 2.13, 2.14 and 2.15.
Example: Loess deposits cover thousands of km² in the central United States, but in a given landscape in this loess deposit, geologic erosion may cut down through the loess into underlying glacial till layers, exposing the latter as the main soil parent material in lower slope positions. See also Figure 19.4b for an example of the latter (Hennepin soil). Figure 2.15 illustrates how coastal plain layering can cause sandy soils to lie adjacent to clayey ones.
- See Sections 2.2 – 2.7.
One possible set of comparisons is given here in tabular form.

Factors of Soil Formation	Forested mountain	Grassland plain
parent material	residual sedimentary and igneous rocks	sedimentary rock, outwash, other
climate	cooler, more humid - more effective precipitation	more arid, warmer - less effective precipitation
biota	coniferous trees, under story ferns, shrubs, grasses	mainly perennial grasses, forbs, herds of grazing animals, prairie dogs
topography	steep	relatively level
time	relatively young due to rapid erosion losses	relatively old surfaces

- See Section 2.3.
Colluvium is material transported downhill mainly by gravity. It includes an unsorted jumble of all sizes of particles, often with sharp edges. Glacial till is material transported and dropped by glaciers and also includes an unsorted mixture of all particle sizes, but generally with rounded shapes. Alluvium is material transported by flowing river water and is usually sorted by particle size in difference horizontal layers with particles generally quite rounded in shape.

7. See Section 2.3, pp. 49-51 and Figures 2.19 - 2.21.
Loess is material transported and deposited by wind and consisting primarily of silt-sized particles. As a parent material, loess has a high capacity to hold water, but is generally quite permeable. Commonly, plant productivity is high and so is the rate of soil formation.
8. See Section 2.8.
Transformations might include weathering of mica to form clay and the decomposition of plant residues to form humus. Translocations might include the upward movement of salts from groundwater to the soil surface in arid regions, and the downward illuviation of clay from the surface horizons to the B horizons. Additions might include calcium added with the deposition of dust and organic matter added with the annual shedding of deciduous tree leaves. Losses might include cations leached down out of the profile and into the groundwater and clay particles from the soil surface eroded away by runoff water.
9. Information from all parts of the chapter may be applied to this answer. See also Figure 2.34.
If we assume that the age (time factor) is the same in both cases, then the soil differences will be mainly due to the biota and climate factors of soil formation. The soil under the cool humid pine forest will likely be acid, relatively deeply weathered, with a thick O horizon and probably a thin A horizon. The soil under the semiarid grassland will likely be more shallow, neutral to alkaline in reaction, with little O horizon, but a thick A horizon. Both soils are likely to be relatively coarse in texture.
10. See Figures 2.26, 2.34, 2.37
The soil on the forested mountainside might include these horizons: Oi-Oa-Oe-A-E-Bw-C.
The soil on the semiarid grassland plain might include these horizons: Oi-A1-A2-Bk-C.
Many other answers would be reasonable.
11. See Section 2.6.
The answer will vary with each location, but should include such changes as increasing thickness of A horizon, differences on development of the B horizon, color changes in the subsurface horizons (usually from bright reds and yellows in the upper members to grays and black in the lower ones), changes in parent material (e.g. colluvium near the bottom of the sequence). Changes in vegetation might be from trees to sedges, etc.

Multiple Choice Questions

(Circle the single best answer for each question.)

- Igneous rocks can best be characterized as:
 - rocks formed when molten magma solidifies
 - rocks containing both feldspars and micas
 - rocks formed from the recrystallization of sedimentary material
 - rocks containing a mixture of primary and secondary minerals
 - rocks found primarily near volcanoes.
- Which mineral is most resistant to weathering under humid temperate conditions?
 - dolomite
 - muscovite
 - gypsum
 - gibbsite
 - biotite.
- Which of the following is not a secondary mineral?
 - silicate clay
 - microcline
 - calcite
 - hematite
 - gypsum.
- Mechanical weathering processes result in:
 - the decomposition of primary minerals
 - the hydrolysis of minerals through frost action
 - the disintegration of rocks due to differential expansion of minerals
 - the oxidation of iron and manganese compounds
- Which of the following is not considered one of the five major factors influencing soil formation?
 - native parent materials
 - living organisms
 - climate
 - valence state
 - topography
- Residual parent materials are best described as _____.
 - materials formed under organic residues.
 - materials formed by weathering of rocks and minerals in place.
 - materials transported from one location to another by water, ice or wind.
 - materials more dominant in Iowa than in the Southern United States.
 - upland materials formed with relatively little chemical weathering.
- Glacial till is a term used to describe parent materials that:
 - were transported by water gushing from glacial fronts.
 - were laid down in the bottom of former glacial lakes.
 - were transported by high winds during glacial periods.
 - are sorted by rapidly flowing melt waters.
 - contain a heterogeneous mixture of mineral debris dropped by receding glaciers.
- If you wanted to find a soil where physical weathering dominated over chemical breakdown you would be most apt to find it in _____.
 - a desert region of Arizona
 - a humid region in Brazil
 - the hill lands of Georgia
 - a lacustrine deposit in Minnesota
 - a coastal plain area of Delaware
- Igneous, sedimentary, and metamorphic are three _____.
 - types of rocks
 - basic classes of soils
 - master horizon names
 - forms of minerals
 - processes of weathering
- The element most often involved in oxidation reactions as minerals weather is _____.
 - copper
 - silicon
 - aluminum
 - magnesium
 - iron

11. In which of the following horizons has the process of illuviation most likely occurred?
 A. O horizon B. C horizon C. A horizon D. E horizon E. B horizon
12. Organic matter accumulation is most pronounced in the _____.
 A. O horizon B. A horizon C. E horizon D. B horizon E. C horizon
13. Silicate clay accumulation is most common in the _____.
 A. A horizon B. B horizon C. C horizon D. O Horizon E. E horizon
14. Which of the following statements is not correct?
 A. Grasslands are found in semi-arid and sub-humid areas.
 B. Coniferous forests are found mostly in cool humid areas.
 C. The type of native vegetation is controlled primarily by climate.
 D. Dense forests are found soil profiles have prominent O horizons.
 E. Tropical forests protect the soil from excessive weathering.
15. Which of the following statements is correct?
 A. Soils on hillsides tend to be deeper than those on level lands.
 B. Lacustrine parent materials have been subject to weathering for shorter periods of time than residual parent materials nearby.
 C. Limestone parent materials enhance the process of acidification.
 D. Nutrient cycling in forested areas contributes little to soil formation.
 E. Calcium carbonate accumulation is more prominent in humid than in arid regions.
16. Secondary minerals are most prominent in the ____ fraction of soils.
 A. organic B. sand C. silt D. clay
17. The presence of rocks such as shale and sandstone indicate the existence of _____.
 A. a high water Table B. ancient seas C. old mountain ranges
 D. iron-rich minerals E. highly weathered soils
18. "Biotite-->clay-->iron oxide" represents a _____.
 A. catena B. weathering sequence C. silicate mineral sequence
 D. both A and B E. none of the above
19. Granite is an example of a(n) _____.
 A. primary mineral B. sedimentary rock C. secondary mineral
 D. igneous rock E. eolian parent material
20. The transformation of gneiss into mica, quartz, and feldspar crystals is an example of:
 A. physical weathering B. chemical weathering C. disintegration
 D. hydrolysis E. both A and C
21. The reaction: $\text{mica} + \text{H}_2\text{O} \rightarrow \text{K}^+ + \text{OH}^- + \text{acid clay}$ is an example of _____.
 A. hydrolysis B. acid solution weathering C. oxidation
 D. hydration E. exfoliation
22. Exfoliation is caused by changes in _____.
 A. hydration B. oxidation C. temperature
 D. carbon dioxide dissolution E. all of the above

23. The mixed angular gravel, rock, and soil found at the foot of a slope is typical of what type of parent material?
A. eolian B. colluvial C. fluvial D. glacial E. lacustrine
24. Alluvial fans are usually characterized by _____ soils.
A. sandy and gravelly B. clay textured
C. poorly drained D. nearly level

True or False Questions
(Write T or F after each question.)

25. Igneous rocks are formed when molten magma cools and solidifies.
26. Sandstones are good examples of metamorphic rocks.
27. Secondary minerals are recrystallized products of the chemical breakdown and/or alteration of primary minerals.
28. Iron and aluminum oxides are major components of igneous rocks.
29. Chemical weathering is accelerated by water, oxygen, and organic and inorganic acids moving down through the regolith.
30. Hydrolysis involves the splitting of water into its H^+ and OH^- components while hydration attaches intact water molecules to a compound.
31. The presence of iron in a mineral generally increases its resistance to chemical breakdown.
32. Alluvial parent materials are those that have been laid down in former lake bottoms.
33. Residual parent materials have formed in place and have not been transported from one area to another.
34. Glacial till is laid down by melt waters gushing out from the front of glaciers.
35. Marine sediments are typical parent materials in coastal plain areas.
36. Organic deposits are most common in areas where water flow over the soil surface is restricted.
37. Climate influences not only the rate of weathering but the type of native vegetation dominant in an area.
38. Living organisms affect soil formation primarily by their constraining the level of oxygen in the soil.
39. Residual parent materials have generally been subjected to weathering for a longer period of time than have lacustrine or alluvial parent materials.
40. The O horizons of a soil are dominantly organic horizons occurring above mineral horizons.
41. The A horizons are more apt to be cultivated than the E horizons.
42. In most B horizons one of the dominant processes of soil formation has been eluviation.

43. The C horizons are generally more completely weathered than the other horizons.
44. Even if all the glaciers present today in the world were to melt, the melt water would have no measurable effect on the level of the world's oceans.
45. Glacial till can be recognized by the distinct layering of different kinds of particles.
46. Soils developed in wind-blown parent materials such as loess are generally of little agricultural value.
47. Sapric and fibric are terms used to describe peat parent materials.
48. A soil developed in residual parent materials will likely have properties related to the properties of the rock below the C horizon.
49. A soil developed in transported parent materials will likely have properties related to the properties of the rock below the C horizon.
50. The topmost horizon in most humid region forest soils is the A horizon.
51. Eluviation of clay, iron, and other materials is the principal process responsible for the formation of an E horizon.
52. Weathering of rocks usually is most intense in the center of a rock fragment, and gradually decreases toward the outside.
53. The parent materials for most coastal plain soils are residual in nature.

Chapter 2 Answers

1. A
2. D
3. B
4. C
5. D
6. B
7. E
8. A
9. A
10. E
11. E
12. A
13. B
14. E
15. B
16. D
17. B

18. B
19. D
20. E
21. A
22. C
23. B
24. A
25. T
26. F
27. T
28. F
29. T
30. T
31. F
32. F
33. T
34. F

35. T
36. T
37. T
38. F
39. T
40. T
41. T
42. F
43. F
44. F
45. F
46. F
47. T
48. T
49. F
50. F
51. T
52. F
53. F

