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Formation of Natural Soil Deposits

1–1 INTRODUCTION

Soil is more or less taken for granted by the average person. It makes up the ground on which we live, it is for growing crops, and it makes us dirty. Beyond these observations, most people are not overly concerned with soil. There are, however, some people who *are* deeply concerned. These include certain engineers as well as geologists, contractors, hydrologists, farmers, agronomists, soil chemists, and others.

Most structures of all types rest either directly or indirectly upon soil, and proper analysis of the soil and design of the structure's foundation are necessary to ensure a safe structure free of undue settling and/or collapse. A comprehensive knowledge of the soil in a specific location is also important in many other contexts. Thus, study of soils should be an important component in the education of civil engineers.

Chapter 1 relates the formation of natural soil deposits; it describes the sources of soil. Chapter 2 introduces and defines various engineering properties of soil. Subsequent chapters deal with evaluation of these properties and with essential interrelationships of soil with structures of various types.

1–2 ROCKS—THE SOURCES OF SOILS

Soil is composed of particles, large and small, and it may be necessary to include as "soil" not only solid matter but also air and water. Normally, the particles are the result of weathering (disintegration and decomposition) of rocks and decay of vegetation. Some soil particles may, over a period of time, become consolidated under the weight of overlying material and become rock. In fact, cycles of rock distintegrating to form soil, soil becoming consolidated under great pressure and heat to form rock, rock disintegrating to form soil, and so on have occurred repeatedly throughout geologic time. The differentiation between soil and rock is not sharp; but from an engineering perspective, if material can be removed without blasting, it is usually considered to be “soil,” whereas if blasting is required, it might be regarded as “rock.”

Rocks can be classified into three basic groups that reflect their origin and/or method of formation: *igneous*, *sedimentary*, and *metamorphic*.

Igneous Rocks

Igneous rocks form when magma (molten matter) such as that produced by erupting volcanoes cools sufficiently to solidify. Volcanic action, normally referred to as *volcanism*, can occur beneath or upon the earth’s surface. Volcanoes probably produced the minority of earth’s igneous rocks, however. During the earth’s formative stages, its surface may well have been largely molten, thus not requiring magma to move to the surface from great depths. It is likely that great amounts of Precambrian rock formed in this fashion.

Igneous rocks can be coarse-grained or fine-grained, depending on whether cooling occurred slowly or rapidly. Relatively slow cooling occurs when magma is trapped in the crust below the earth’s surface (such as at the core of a mountain range), whereas more rapid cooling occurs if the magma reaches the surface while molten (e.g., lava flow).

Of coarse-grained igneous rocks, the most common is *granite*, a hard rock rich in quartz, widely used as a construction material and for monuments. Others are *syenites*, *diorites*, and *gabbros*. Most common of the fine-grained igneous rocks is *basalt*, a hard, dark-colored rock rich in ferromagnesian minerals and often used in road construction. Others are *rhyolites* and *andesites*.

Being generally hard, dense, and durable, igneous rocks often make good construction materials. Also, they typically have high bearing capacities and therefore make good foundation material.

Sedimentary Rocks

Sedimentary rocks compose the great majority of rocks found on the earth’s surface. They are formed when mineral particles, fragmented rock particles, and remains of certain organisms are transported by wind, water, and ice (with water being the predominant transporting agent) and deposited, typically in layers, to form sediments. Over a period of time as layers accumulate at a site, pressure on lower layers resulting from the weight of overlying strata hardens the deposits, forming sedimentary rocks. In addition, deposits may be solidified and cemented by certain minerals (e.g., silica, iron oxides, calcium carbonate). Sedimentary rocks can be identified easily when their layered appearance is observable. The most common sedimentary rocks are *shale, sandstone, limestone*, and *dolomite*.

Shale, the most abundant of the sedimentary rocks, is formed by consolidation of clays or silts. Organic matter or lime may also be present. Shales have a laminated structure and often exhibit a tendency to split along laminations. They can become soft and revert to clayey or silty material if soaked in water for a period of time. Shales vary in strength from soft (may be scratched with a fingernail and easily excavated) to hard (requiring explosives to excavate). Shales are sometimes referred to as *claystone* or *siltstone*, depending on whether they were formed from clays or silts, respectively.

Sandstone, consisting primarily of quartz, is formed by pressure and the cementing action of silica (SiO_2), calcite (calcium carbonate, $CaCO_3$), iron oxide, or clay. Strength and durability of sandstones vary widely depending on the kind of cementing material and degree of cementation as well as the amount of pressure involved.

Limestone is sedimentary rock composed primarily of calcium carbonate hardened underwater by cementing action (rather than pressure); it may contain some clays or organic materials within fissures or cavities. Like the strength of shales and sandstones, that of limestones varies considerably from soft to hard (and therefore durable), with actual strength depending largely on the rock's texture and degree of cementation. (A porous texture means lower strength.) Limestones occasionally have thin layers of sandstone and often contain fissures, cavities, and caverns, which may be empty or partly or fully filled with clay.

Dolomites are similar in grain structure and color to limestones and are, in fact, limestones in which the calcite ($CaCO_3$) interbonded with magnesium. Hence, the principal ingredient of dolomites is calcium magnesium carbonate [$CaMg(CO_3)_2$]. Dolomites and limestones can be differentiated by placing a drop of diluted hydrochloric acid on the rock. A quick reaction forming small white bubbles is indicative of limestone; no reaction, or a very slow one, means that the rock is dolomite.

As indicated, the degrees of strength and hardness of sedimentary rocks are variable, and engineering use of such rocks varies accordingly. Relatively hard shale makes a good foundation material. Sandstones are generally good construction materials. Limestone and dolomite, if strong, can be both good foundation and construction materials.

Metamorphic Rocks

Metamorphic rocks are much less common at the earth's surface than are sedimentary rocks. They are produced when sedimentary or igneous rocks literally change their texture and structure as well as mineral and chemical composition, as a result of heat, pressure, and shear. Granite metamorphoses to *gneiss*, a coarse-grained, banded rock. *Schist*, a medium- to coarse-grained rock, results from high-grade metamorphism of both basalt and shale. Low-grade metamorphism of shale produces *slate*, a fine-textured rock that splits into sheets. Sandstone is transformed to *quartzite*, a highly weather-resistant rock; limestone and dolomite change to *marble*, a hard rock capable of being highly polished. Gneiss, schist, and slate are *foliated* (layered); quartzite and marble are *nonfoliated*.

Metamorphic rocks can be hard and strong if unweathered. They can be good construction materials—marble is often used for buildings and monuments—but foliated metamorphic rocks often contain planes of weakness that can diminish strength. Metamorphic rocks sometimes contain weak layers between very hard layers.

1–3 ROCK WEATHERING AND SOIL FORMATION

As related in the preceding section, soil particles are the result of weathering of rocks and organic decomposition. Weathering is achieved by *mechanical* (*physical*) and *chemical* means.

Mechanical weathering disintegrates rocks into small particles by temperature changes, frost action, rainfall, running water, wind, ice, abrasion, and other physical phenomena. These cause rock distintegration by breaking, grinding, crushing, and so on. The effect of temperature change is especially important. Rocks subjected to large temperature variations expand and contract like other materials, possibly causing structural deterioration and eventual breakdown of rock material. When temperatures drop below the freezing point, water trapped in rock crevices freezes, expands, and can thereby break rock apart. Smaller particles produced by mechanical weathering maintain the same chemical composition as the original rock.

Chemical weathering causes chemical decomposition of rock, which can drastically change its physical and chemical characteristics. This type of weathering results from reactions of rock minerals with oxygen, water, acids, salts, and so on. It may include such processes as oxidation, solution (strictly speaking, solution is a physical process), carbonation, leaching, and hydrolysis. These cause chemical weathering actions that can (1) increase the volume of material, thereby causing subsequent material breakdown; (2) dissolve parts of rock matter, yielding voids that make remaining matter more susceptible to breaking; and (3) react with the cementing material, thereby loosening particles.

The type of soil produced by rock weathering is largely dependent on rock type. Of igneous rocks, granites tend to decompose to silty sands and sandy silts with some clays. Basalts and other rocks containing ferromagnesian minerals (but little or no silica) decompose primarily to clayey soils. With regard to sedimentary rocks, decomposed shales produce clays and silts, whereas sandstones again become sandy soils. Weathered limestones can produce a variety of soil types, with fine-grained ones being common. Of metamorphic rocks, gneiss and schist generally decompose to form silt–sand soils, whereas slate tends more to clayey soils. Weathered marble often produces fine-grained soils; quartzite decomposes to more coarse-grained soils, including both sands and gravels.

1–4 SOIL DEPOSITS

Soils produced by rock weathering can be categorized according to where they are ultimately deposited relative to the location of the parent rock. Some soils remain where they were formed, simply overlying the rock from which they came. These are known as *residual soils*. Others are transported from their place of origin and deposited elsewhere. They are called *transported soils*.

Residual Soils

Residual soils have general characteristics that depend in part on the type of rock from which they came. Particle sizes, shapes, and composition can vary widely, as do depths of residual soil deposits—all depending on the amount and type of weathering. The actual depth of a residual soil deposit depends on the rate at which rock weathering has occurred at the location and the presence or absence of any erosive agents that would have carried soil away.

Transported Soils

Transported soils are formed when rock weathers at one site and the particles are moved to another location. Some common transporting agents for particles are (1) gravity, (2) running water, (3) glaciers, and (4) wind. Transported soils can therefore be categorized with regard to these agents as *gravity deposits*, *alluvial deposits*, *glacial deposits*, and *wind deposits*.

Gravity Deposits. Gravity deposits are soil deposits transported by the effect of gravity. A common example is the landslide. Gravity deposits, which are not generally carried very far, tend to be loosely compacted and otherwise exhibit little change in the general character of soil material as a result of being transported.

Alluvial Deposits. Alluvial deposits, having been transported by moving water, are found in the vicinity of rivers. Rainwater falling on land areas runs overland, eroding and transporting soil and rock particles as it goes, and eventually enters a creek or river. Continuously moving water can carry particles and deposit them a considerable distance from their former location. All soils carried and deposited by flowing water are called *alluvial deposits*. Lack of vegetation may allow enormous amounts of erosion leading to vast alluvial deposits (e.g., the Mississippi Delta).

Rivers are capable of transporting particles of all sizes, ranging from very fine silts in suspension to, in some cases, large boulders. The greater the velocity of river flow, the larger will be the size of particles that can be carried. Hence, a sluggish creek may carry only fine-grained sediment, whereas a flooding river transports all particle sizes, including large rocks. The relationship between river velocity and size of particle carried also affects the manner in which particles are deposited. As river velocity decreases, relatively larger particles settle and are deposited first. If the velocity decreases further, the next-larger-size particles settle out.

Alluvial deposits are often composed of various soil types because different types of soil tend to mix as they are carried downstream. They do, however, tend to be layered because settling rates are proportional to particle size.

The nature of soil can be greatly influenced by past alluvial transport and deposits. For example, at a location where a river's velocity decreases, such as when the channel widens significantly or its slope decreases substantially, coarser soil particles settle, forming submerged, flat, triangular deposits known as *alluvial fans*. When flooding rivers, which normally carry a heavy sediment load, overflow their banks, the overflowing water experiences a decrease in velocity. Larger particles, such as sands and gravels, tend to settle more quickly; their deposits can form *natural levees* along riverbanks (see Figure 1–1). (These natural levees may someday be washed away by a more severe flood.) Smaller particles, such as silts and clays, settle less quickly, forming *floodplain deposits* in areas beyond the levees (Figure 1–1). (However, smaller rivers can have floodplain deposits without forming levees.)

Another type of alluvial deposit occurs when rivers meander (i.e., follow a winding and turning course). As water moves through a channel bend, velocity along the inside edge decreases, whereas that along the outer one increases. Consequently,

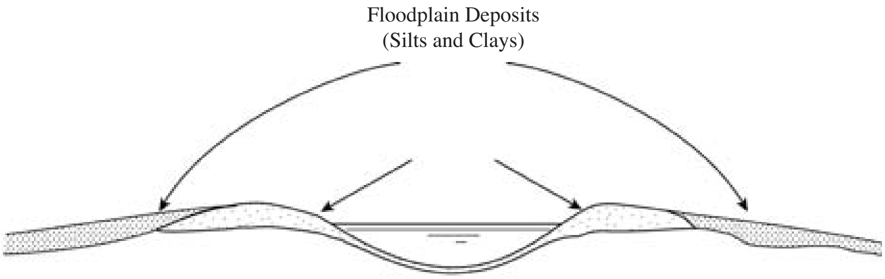
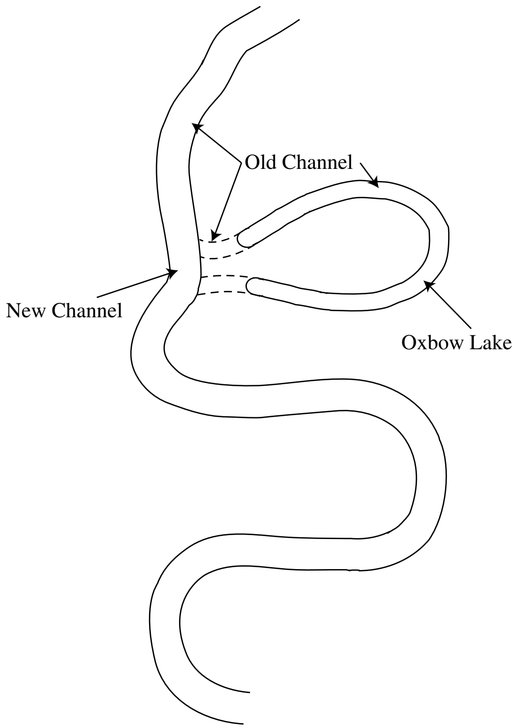


FIGURE 1–1 Natural levees and floodplain deposits.

particle erosion may occur along the outer edge with deposition along the inner edge. This action can, over a period of time, increase the amount of bend and significantly alter the river channel and adjacent land area. Eventually, the river may cut across a large bend, as shown in Figure 1–2, leaving the old channel bend isolated. Water remaining in the isolated bend forms an *oxbow lake*, which can eventually fill in with floodplain deposits (usually silty and organic materials). Ultimately, the entire filled-in oxbow lake may be covered by additional floodplain deposits, leaving a hidden deposit of undesirable, high plastic, and/or organic silt, silty clay, and peat.

FIGURE 1–2 Oxbow lake.



Sediments deposited at the mouths of creeks and rivers flowing into lakes, bays, or seas are known as *deltas*. Those deposited in lakes and seas are called *lacustrine* and *marine deposits*, respectively. These deposits tend to be loose and compressible and may contain organic material. They are therefore generally undesirable from an engineering point of view.

Glacial Deposits. Glacial deposits result, of course, from the action of glaciers. Many years ago (over 10,000), glaciers, enormous sheets of ice, moved southward across much of the northern United States (as well as Europe and other areas). As they progressed, virtually everything in their paths, including soils and rocks ranging in size from the finest clays to huge boulders, was picked up and transported. As they were being carried by glaciers, soils and rocks were mixed together, thrashed about, broken, crushed, and so on by enormous internal glacial pressures. Consequently, glacial deposits can contain all types of soils.

Some soil particles were directly deposited by moving glaciers; others were taken from glaciers by water flowing from the ice to be deposited in lakes or transported in rivers flowing away from the ice; still others were deposited *en masse* when glaciers ultimately melted and disappeared. Direct glacial deposits, known as *moraines*, are heterogeneous mixtures composed of all sizes of particles (from boulders to clay) that the ice accumulated as it traveled. *Eskers* are ridges or mounds of boulders, gravel, and sand formed when such materials flowing in streams on, within, or beneath glaciers were deposited as the stream's bed load.

The quality of soils in glacial deposits as foundations and construction materials is somewhat variable because of the different types of soils found in such deposits. Often these soils make good materials because of the intense compaction they have undergone, although those containing mostly clays are not as strong, are often compressible, and may therefore cause problems if used for foundations or construction materials.

Wind Deposits. Wind deposits (also known as *aeolian deposits*) obviously have wind as the transporting agent. Wind is a very important agent in certain areas and has the potential to move soil particles over large distances.

Winds can move sandy soil particles by rolling them along the ground as well as sending them short distances through the air. Wind-deposited sands are known as *dunes*, and they tend to occur in sandy desert areas and along sandy beaches on the downwind side. Sands from dunes can be used for certain construction purposes.

Fine-grained soils can be airborne over long distances by winds. Silty soils are more amenable than clayey soils to wind transport, however, because a clayey soil's bonding or cohesion reduces its wind erosion. A wind-deposited silt is known as *loess*, significant deposits of which are found in the general vicinity of the Mississippi and Missouri Rivers in the United States, and in Europe and Asia (especially northern China). Loess is generally a hard and stable soil when unsaturated because of cementation from calcium carbonate and iron oxide. It tends to lose its cementation when wetted, however, and to become soft and mushy. Loessial deposits typically have a yellow-brown (buff) color, low density, and relatively uniform grain size. These deposits are generally able to stand on vertical cuts and exhibit high vertical permeability. Because of their low strength when wet, however, special care must be taken during the design and construction of foundations over such deposits.

Ashes from erupting volcanoes can also produce wind deposits. Consisting of fine-sized igneous rock fragments, volcanic ash is light and porous, and deposits tend to decompose quickly, often changing into plastic clays. The great Mt. St. Helens eruption produced not lava but ash.

It should be noted in concluding this section that soil deposits seldom occur in nature in neat "packages"—that is, a soil of exactly the same type at all depths throughout a construction site. An area with "original" glacial deposits may subsequently have been overlain by alluvial deposits possessing different characteristics. Even if all the soil at a given job site is of the same deposit, its properties may vary from place to place throughout the site.

For these reasons, subsurface investigation of an area is extremely important. One cannot just look at the surface and know what is beneath. Using quantitative results obtained from subsurface investigation together with qualitative knowledge of the origins of the soil(s) at the site, geotechnical engineers can produce an adequate foundation design to ensure against failure or undue settling of a structure. (Subsurface investigation is covered in Chapter 3.)