SOILS

Their Origin and Their Existence

Developed by
FHWA Multi-regional Soils Training & Certification Group

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CREDITS

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PREFACE

The volume of knowledge about geology (the study of the earth), geomorphology (study of the physical forms of the earth), and pedology (study of soils) requires that many generalizations be made in this text. This course is designed to provide the student with broad knowledge about soil formation and soil characteristics. It will show how these characteristics can predict the performance of a soil for a specific engineering purpose. The information in this course will enable the technician to exercise improved evaluation techniques when analyzing the results of soils testing. This information will assist geotechnical personnel in analyzing test results as part of subgrade/foundation studies to determine the appropriate use of soils for highway construction. Knowledge of geology and soil mechanics (how soils behave) will enable the technician to predict the response of a specific soil to a specific test and to recognize test results which do not conform to normalcy.

Books on geology, soil mechanics and related subjects are readily available from libraries, book stores, professional societies, and government agencies. The authors of this training course encourage the technician to use these resources to supplement this material and to continue the study of soils.

INTRODUCTION

Humans have walked upon soil without much thought since earliest times. In many instances, soil has been treated with disdain. Many people consider soil just to be ordinary "dirt." They curse it when their vehicle becomes stuck in the mud. Mothers become upset when their children play in it and become "dirty." This mind set has spilled over into our language to the extent "dirty" and "soiled" have become synonymous with such words as stained, foul, filthy, nasty, sordid, and other derogatory words. We hear it daily in such phrases as "dirty politics" or "soiled reputation." We are bombarded constantly by the advertising industry trumpeting the value of each soap product in removing the dirt from our hands, hair, clothes, floors, and cars as though they are trying to eradicate soil from the face of the earth.

In reality, soil comprises much of the earth's surface and without this complex mix of mineral fragments, organic material, moisture, and gases, as well as the biological and chemical processes resulting from it, life as we know it would not exist on our planet. Soil is the upper layer of the earth's crust. Soil provides us with a continuous supply of food, lumber for homes, pigment for artists, medicine for health problems, clay for bricks and fine china. It contains our groundwater, provides support and construction material for our buildings, roads and airports, and other benefits unlimited in number.

Soil is a constantly changing substance. The beginning of organized study of this natural material has been lost in antiquity. However, we do know that humans have practiced agriculture for thousands of years. The knowledge gained from farming activities has led directly to extensive soil management techniques and practices. We also know that society has been involved in constructing sophisticated foundations and roadways with soils at least since Roman times. These construction activities have led to what is commonly known as soil mechanics (the study of soil behavior). Studies of the earth's crust have been brought about by various needs and interests. These studies have been used by different disciplines including, soil scientists, soil engineers, agricultural engineers, geologists, engineering geologists, architects, architectural engineers, geotechnical engineers, and geophysicists. All these fields of technology have been created for different purposes; however, they are all tied together by this one material, soil. There is much overlap in these disciplines. They all use information from soil samples tested under field and laboratory conditions.

As technicians we need to have an understanding, not only of the technical world of field and laboratory testing of soils, but also of the origin and nature of these materials. This knowledge will enable the technician to know where and how to select meaningful samples, so that the results of any test become more than just a number. A background in soil study will make test results take on real value. The technician will be able to correlate them to a particular soil and its condition and origin to rapidly determine if a result is reasonable (therefore, valid) for a particular soil.

Anyone without a background in soils may believe soils, like other materials used in construction, behave in a stable manner and that simple, routine tests can accurately predict the material's performance. A test result is just the beginning in the evaluation of a soil sample. Judgement is an absolute necessity in this process. Each soil, like human fingerprints, is unique. To understand the uniqueness of soils, let us start with their beginnings.

GEOLOGY - SHAPING THE EARTH'S SURFACE

The origin and development of the earth is a subject of much speculation and scientific investigation. Whether Earth is a result of the "Big Bang" or some other cosmic cataclysm, the end result has been the creation of a unique planetary body. The earth, 4.5 billion years old, is not a dead mass of rock whirling through space. It is a dynamic system comprised of various interrelated subsystems for which scientists are just beginning to develop an understanding.

STRUCTURE

The earth is an imperfect spheroid approximately 12 875 km (8000 mi) in diameter rotating on its axis, west to east, generating surface speeds at the equator in excess of 1 600 km (1000 mi) per hour. Chemical differentiation due to the internal heat of the earth caused by friction from compression and radioactive decay has resulted in identifiable layering. Moving from the surface toward the center, the earth is composed of a very thin crust, the mantle, and the core. During early stages of the planet's development, heavy elements, such as nickel and iron, sank to the earth's core while lighter elements such as aluminum, silicon, and oxygen migrated to the surface. This separation has resulted in materials at the surface of continents having average specific gravities of approximately 2.65, while the specific gravity within the core may be as high as 15.

The earth's atmosphere and water were formed later than the planet. Not until green algae evolved did oxygen begin to accumulate. Green algae performed in early earth much the way plants add to the oxygen supply today by absorbing carbon dioxide and releasing oxygen. The planet's water supply came from the condensation of gases released through volcanic activity. This process still continues at a steady rate.

The earth's surface layer is composed of numerous plates of crustal material literally floating in mantle material, like large rafts, much as wood floats on water. This is known as the principle of isostasy. These crustal materials are of two types. Basaltic material approximately 6 km (4 mi) thick lies beneath the oceans. The continental crust generally consists of granitic material an average of 35 km (22 mi) thick. Where mountains, high plateaus, and major sedimentary basins have formed, these continental rock masses may be as much as 70 km (40 mi) thick.

PLATE TECTONICS

The configuration, composition, and structure of the earth are best explained by a phenomenon termed plate tectonics. The lighter and rigid crustal material floating in the hot, melted upper layer of the mantle allows the crust to tear and become segmented into large irregular plates, (Figure 1). These plates, adrift in a sea of molten magma, move relative to one another at measurable rates of 10 - 100 mm/yr (0.4 - 4 in./yr). The continents, imbedded in these plates, move in unison giving rise to the term continental drift. Crustal plates exhibit three different types of boundaries:

- Shear Boundaries - These occur when plates slide by one another displacing crustal material along the shear (strike-slip fault). A well known example of this feature is the San Andreas Fault of California.

- Subduction Zones - These occur when plates collide forcing the margin of one plate under the other. This process drags crustal material downward where it is melted and returned to the crust as magma. Much of the volcanic activity around the Pacific Rim (commonly known as the Ring of Fire) is related to this process.

- Spreading Boundaries - These are areas where molten rock from depth rises and fills rifts left as plates separate. This occurs at mid-ocean ridges. As this molten rock filling cools and crystallizes new ocean crustal rock is formed. The best known feature of this type is the Mid-Atlantic Ridge.

The rising of molten materials at the mid-ocean ridges and the down-surging of the crustal material in the zones of subduction at the plates margins are part of a cycle which continually replenishes crustal rock. (Refer to Figure 2.) It is thought that due to temperature differences between the layers of the earth, thermal convection cells form with molten material rising from depth into the rifts along zones of separation. As these molten materials cool, they form new ocean crustal rock which is then pulled across the ocean floor and down into the subduction zones to be melted again. These new melts are then refined by heat and pressure. Due to the lower density, the granitic portions become continental crust by being ejected as lava during volcanic action or injected as batholiths (or similar features).

COMPOSITION

Igneous rocks are those formed by the cooling of magmas (complex siliceous solutions) which have risen from deep within the earth. Igneous rocks are of two basic types, intrusive and extrusive.

- Intrusive (Plutonic) - These are granitic rocks which make up the greater part of large intrusions such as batholiths. They are coarse grained as a result of being crystallized at depth while cooling slowly.

- Extrusive (Volcanic) - These are basaltic rocks which occur primarily as lava flows. They are fine grained to glassy due to the very rapid cooling and crystallization at the crust's surface.

Granite has a silica content of approximately 70%, while basalt contains approximately 50%. (Silica is what is commonly termed quartz [SiO_2]). Therefore, silicate mineral rocks are the building blocks of the planet. Because silica is highly resistant to weathering, it has a direct bearing on the development of land forms. This resistance to weathering also makes silica a major component of soils.

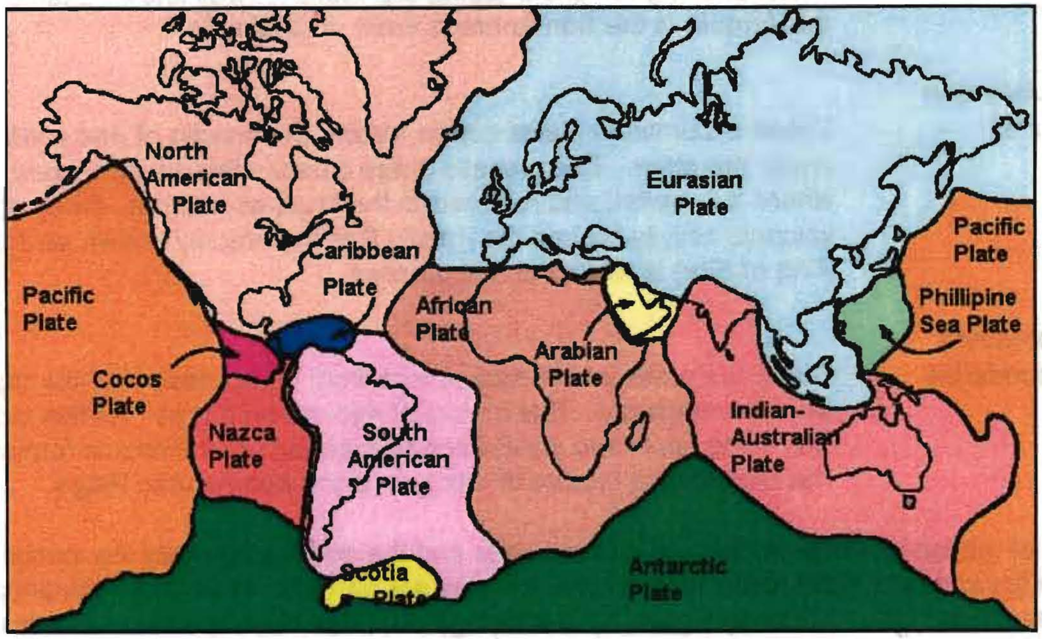


Figure 1
Plate Tectonics

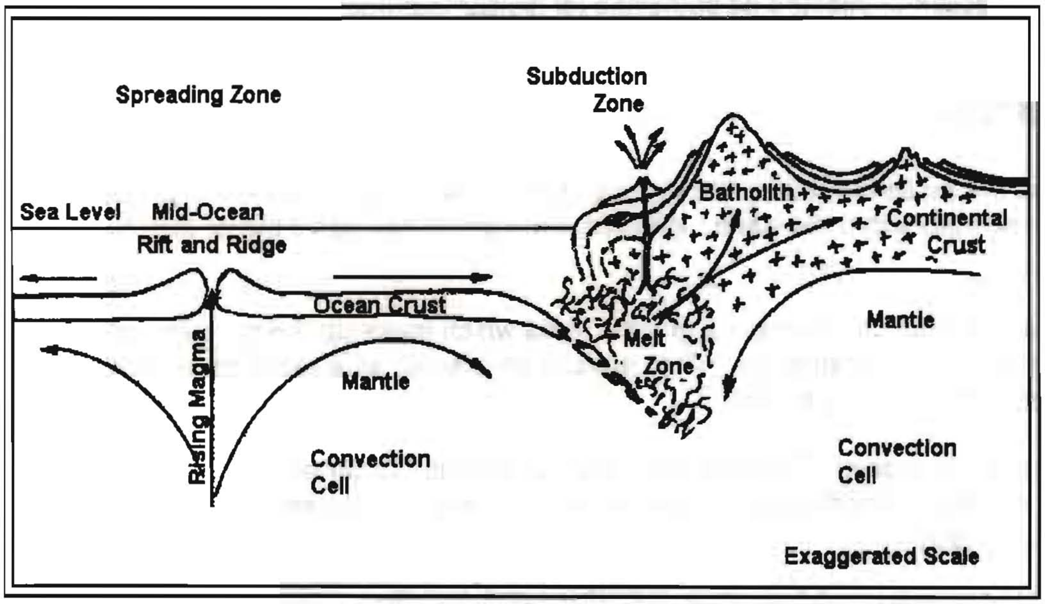


Figure 2
Idealized Cross Section of Plate Tectonics

PHYSIOGRAPHY

Plate tectonics create tremendous forces within the rocks of the earth's crust. As these plates collide, slide by, or override one another, huge upwellings of molten rock occur, mountain ranges rise, and significant crustal tears are created. Worldwide, the two dominant topographic features are the ocean basins and continents. The maximum relief between Mt. Everest (Himalayan Mountains), the highest continental elevation, and the deepest ocean trough (Philippine Deep) is approximately 19 km (12 mi). This, however, is a very small distance compared to the radius of the planet. Most relief is of very small magnitude and many areas of the continents are virtually flat. Exposure of the continental surfaces over long periods of geologic time to the deforming forces of plate tectonics and the ravages of climate have produced the surface that we see in our daily activities.

PHYSIOGRAPHY OF THE CONTINENTAL UNITED STATES

The continental United States is mostly a broad central plain lying between ranges of mountains to the west and east. These three major divisions are readily recognizable from geology, topography, climate, and biodiversity. Traveling east or west, going into or out of these areas, the changes are usually rather abrupt.

The central plains are comprised primarily of the high plains called the Great Plains and the Central Lowlands (high-grass prairies). Toward the south these areas transition into the coastal plain along the Gulf Coast. These plains and prairie areas may locally exhibit considerable relief from erosion; however, they are essentially flat with horizontally layered formations. Within this vast region there are some anomalies of limited area which disrupt its "flatness." These include the Arbuckle, Ouachita, and Ozark mountains of Oklahoma and Arkansas.

The Appalachian System, which forms the eastern border of the central plain, is a continuous series of small mountain ranges of parallel ridges and valleys created by severely folded strata which has also been heavily faulted. Much of the faulting is characterized by formations having been pushed up and over adjacent rocks (thrust faulting) indicating significant compression and resulting crustal shortening.

West of the central plains, the approximately 1600 km (1000 mi) wide cordilleran system rises much higher and with greater expanse than the Appalachian system of mountains to the east. These features, essentially parallel to the Pacific coast, result from a complex history of intrusive batholiths, extrusive lava flows, and folding with extensive faulting. This mountain region includes the Rocky Mountains, Cascade-Sierra Nevada Mountains, and the coast ranges near the Pacific Ocean. Between these individual mountain ranges are broad plateaus including the Colorado Plateau west of the southern Rockies and the Columbia Plateau between the Rockies and Cascades. This mountainous area is associated with the Pacific rim volcanic activity commonly referred to as the "Ring of Fire." It is also at the boundary of the Pacific and North American tectonic plates.

Within these three major physiographic regions, there are smaller areas with readily recognizable differences in landform, vegetation (Figure 3), and climate. Some exhibit deep canyons with high cliffs and streams with turbulent currents. Some are characterized by gentle slopes, rounded hills, and slow moving water. Others are essentially flat for extended distances. Each of these subdivisions has its own unique characteristics and similarities which allow their separation into geologically-based provinces (Figure 4).

The type of rock, the structure, landforms, erosional patterns, and soil types are all related to physiography and the resulting topography. Both are indicators of geological history. (Refer to Figure 5.) Studying this history provides the knowledge to comprehend the ever evolving crust of the earth. The soil sample in the testing laboratory relates directly to this history. The following are some basic concepts to be considered when interpreting landscapes.

- ❖ What we see at this moment has resulted from modifications to a former surface over geologic time.
- ❖ The same processes and gravitational laws that are in operation today have influenced landscape development throughout geologic time.
- ❖ Geology is a dominant factor in controlling the landscape which evolves in an area and is reflected in it.
- ❖ Each chemical and physical process develops its own characteristic landform.
- ❖ As erosion occurs, a sequence of landforms develops which are distinctive of their stage of development; either youth, maturity, or old age.
- ❖ Evolution of crustal surface is more complex than simple.
- ❖ Climate is a direct, significant contributor to surface evolution. Landscape, vegetation, and soils are dependent on this factor.
- ❖ Everything in nature tends to develop in cycles. Erosional cycle, hydrologic cycle, soil cycle, rock cycle, and life cycle are all examples of nature forming, changing state, reclaiming, and reforming.
- ❖ What we see as the crust's surface at the moment is the beginning of a new landscape.

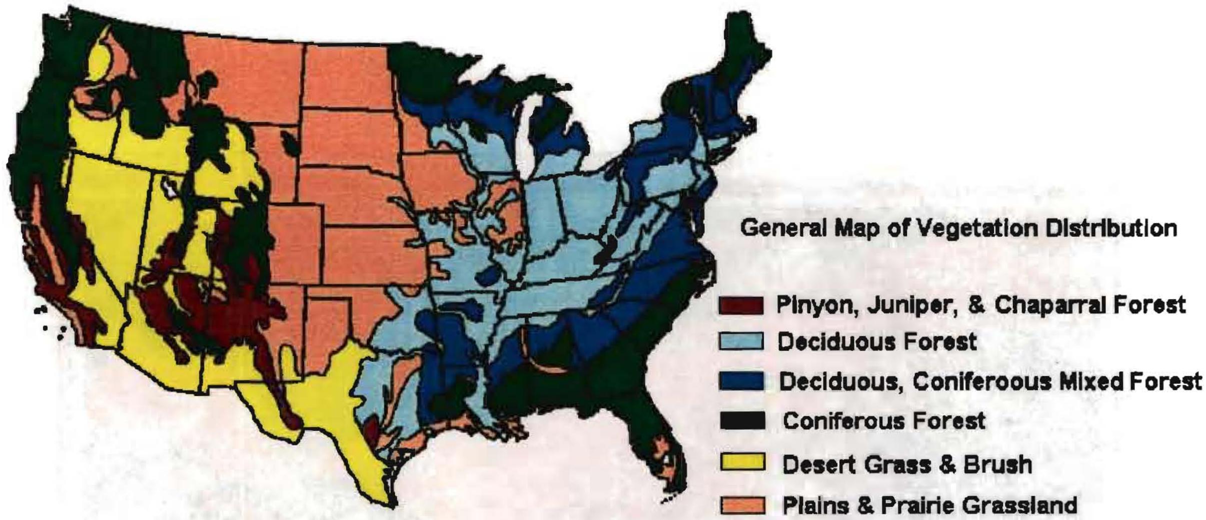


Figure 3
Vegetation Distribution

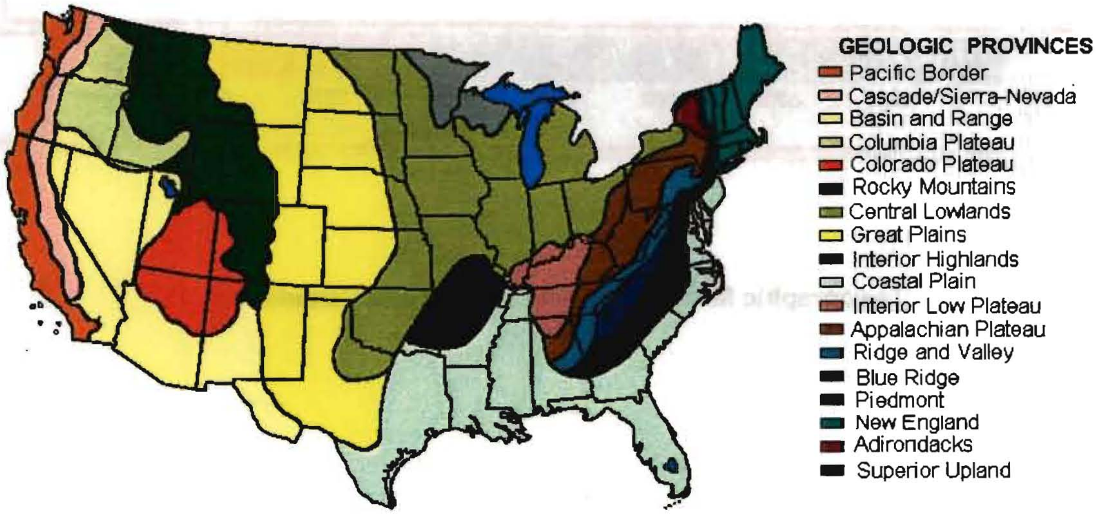
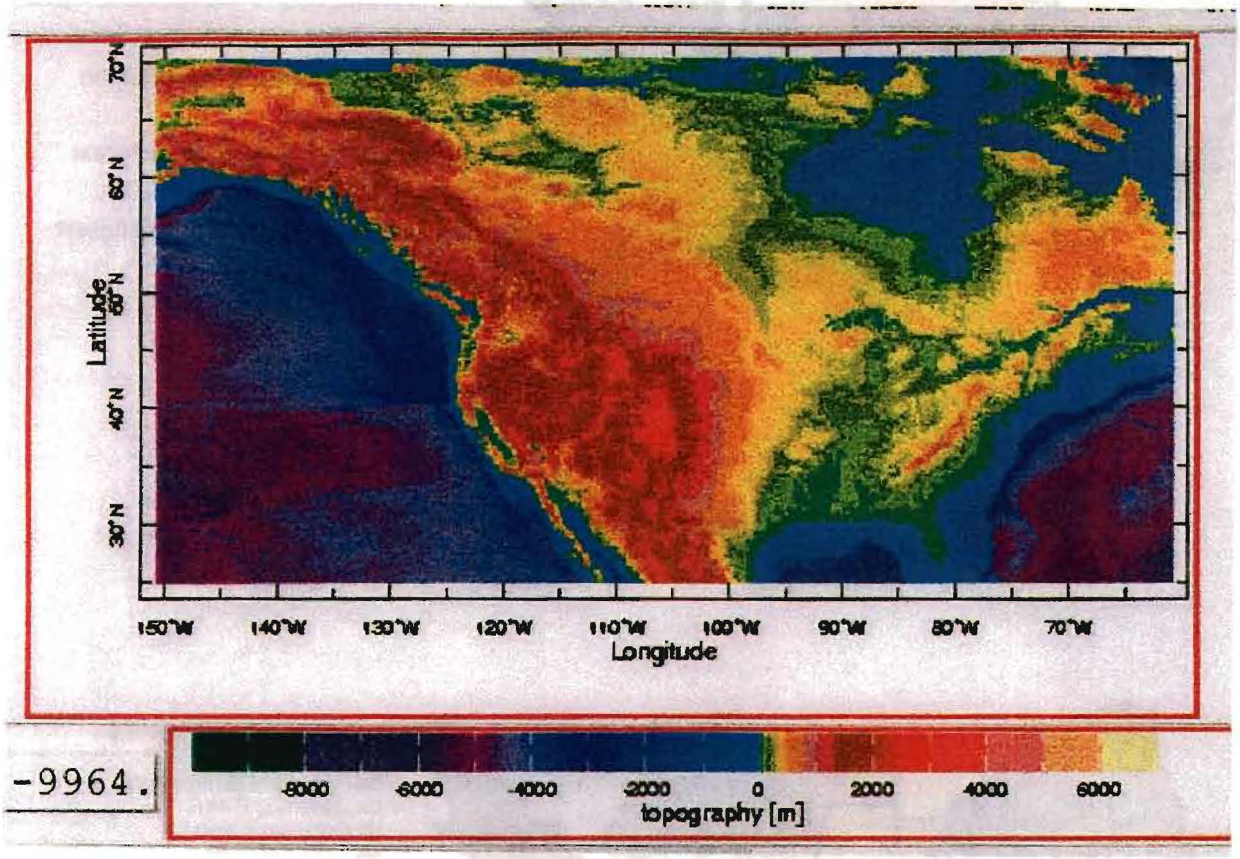


Figure 4
Geologic Provinces



Topographic Map of the United States and Canada
Figure 5

SOIL DEVELOPMENT

Each facet of society develops its own definition of soil depending on its interests and needs. Therefore, many different definitions have resulted. To the general public, soil is simply dirt. Webster's Dictionary defines soil as "the upper layer of earth that may be dug or plowed: the loose surface material of the earth in which plants grow." The Natural Resources Conservation Service, USDA, defines soil as "a three-dimensional body at the earth's surface. It is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthly parent material, as conditioned by relief over periods of time." ASTM D 653 defines soils as "(earth), sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter." This definition is generally accepted by geotechnical personnel involved in highway construction.

DEGRADATION

Soil creation begins with the breakup of rock mass. Rock masses are reduced to particle size (clastic state) by a complex phenomenon termed degradation. Degradation can be divided into three (3) major processes, which in nature overlap to varying degrees. These processes are weathering, mass wasting and erosion.

WEATHERING

Weathering is a complex of processes involving physical, chemical, and biological activities leading to the disintegration of mass rock. Weathering converts rock masses into soil.

Physical weathering is caused by the action of agents such as wind, water, freeze/thaw cycles, landslides, and earthquakes. It breaks particles from the parent bedrock. As these particles are moved by nature, their shapes are changed and they become increasingly smaller. Materials generated directly by physical weathering are commonly referred to as granular. These particles frequently continue to bear some characteristics of the parent rock.

Chemical weathering causes a complete change in the chemical and physical properties of the parent material. When water flows over and through rocks, some of the minerals are leached. These minerals, once precipitated, form new particles composed of mineral crystals which no longer have the characteristics of the parent rock. Agents of chemical weathering include oxidation, reduction, hydration, solution, and carbonization.

Biological weathering is a combination of physical and chemical breakdowns. Physical deterioration is primarily caused by roots of vegetation, although animal activity may also play a minor role. Chemical change is caused by organic acids and carbon dioxide supplied by plants. Bacterial activity also contributes to chemical change.

Mass Wasting

Mass wasting is the movement of rock debris down slope primarily under the direct influence of gravity. Water may be present to act as a lubricant and minor carrier, but is not necessary to the process. The common terms talus and colluvium are applied to rock fragments that accumulate in this process of degradation.

Erosion

Erosion, like the term soil, has been defined to mean different things to different disciplines. In all these definitions, there is usually an implication of transport. Regardless of the definition, there is a segment of this process that is degradation. Whether the transportation mechanism is wind, water, ice, or gravity, there is always a gradual breakdown of rock particles into ever smaller pieces. The grinding, bumping, and bouncing that takes place in transit are important in the process of degradation. Erosion can take place without weathering.

TRANSPORTATION

The results of degradation are rock fragments and materials dissolved in water. The resulting detritus is usually swept away by physical agents to become clastic sediments. The material in solution is carried away, ultimately to be added to the water of lakes and oceans. These dissolved materials then become deposits of an entirely different nature.

Is it difficult to visualize a large boulder the size of a house breaking loose from the Rocky Mountain batholith at the continental divide and moving down slope, breaking up with the pieces becoming smaller and smaller until some of the particles enter the drainage system to end up in the Mississippi River delta as sand, silt and clay? This is the continuing process that has been taking place for the eons of geologic time.

As the rock mass is reduced to a clastic state through degradation, nature can move the smaller particles more readily. This transportation effort is accomplished by wind, water, ice, and gravity working and reworking particles as they progress persistently to lower grade. Long periods of geologic time are required for these results. The transportation of particles is primarily accomplished by the following actions (Figure 6), alone or in combination.

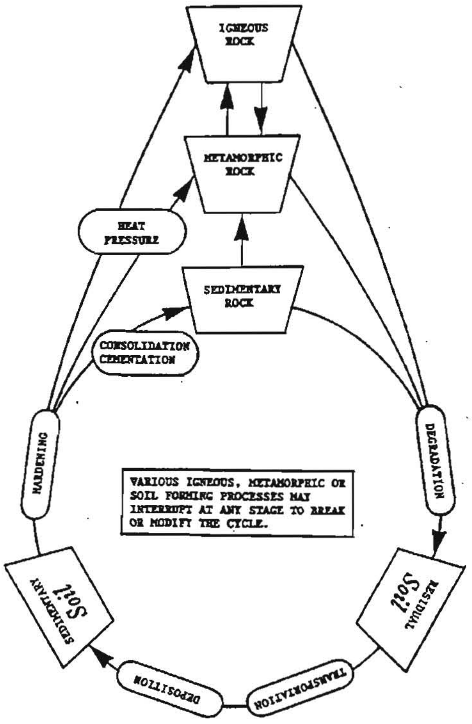
- **Traction** - the pushing, dragging or rolling of particles too large to be lifted and carried in the transport medium.
- **Saltation** - the bouncing of particles that are too large to be held in suspension.
- **Suspension** - the lifting of particles into the transporting medium.
- **Solution** - the incorporation of material into water in which the material actually becomes a chemical component of the moving liquid.

MAJOR PROCESSES OF DEGRADATION AND TRANSPORTATION					
Agent	**Assimilates Load of Weathered Material**	**Transport Method**	**Degradation During Transport**	**Resulting Features**[1]	
Water				**Erosional**	**Depositional**
Running Water Streams Sheet Floods	Hydraulic Action	Solution	Abrasion (Physical) Corrosion (Chemical)	Stream Valleys Water Falls Mesas	Flood Plains Alluvial Fans Deltas
Ground Water	Solution	Solution	Corrosion	Sink Holes Caves Karst Lakes	Stalactites Stalagmites Limestone
Waves & Currents Lakes Oceans Lagoons	Hydraulic Action	Traction Suspension Saltation Solution	Abrasion Corrosion	Sea Cliffs Tidal Channels Sea Caves	Beaches Off-Shore Bars Spits
Glaciers Continental Mountain	Scouring Plucking	Traction Suspension	Abrasion	Ice Scour Glacial Troughs Cirques	Moraines Eskers Erratics
Wind	Deflation	Traction Suspension Saltation	Abrasion	Hollows Ventifacts Desert Pavements	Sand Dunes Loess Sand Sheets

[1]Feature list is not all inclusive.

Figure 6

GENERALIZED ROCK/SOIL CYCLE



The chart above illustrates the origins and interrelationships of the various groups of rock/soil. The arrows indicate how each, through differing geological processes, is recycled into a rock or soil of a different type with totally different characteristics.

Igneous Rock - Those rocks formed by the cooling and hardening of molten magma from deeper areas of the earth. Molten material that is extruded onto the surface is known as lava. Granite and basalt are common igneous rocks.

Metamorphic Rock - Those rocks formed by tremendous heat and pressure which alter the original character of the previously existing rock. Slate, marble and quartzite are common rocks of this group.

Sedimentary Rock - Those rocks which are formed by either mechanical or chemical formation from degraded particles of other rock. These are rocks which have become hardened as a result of compression and/or cementation.

Mechanical Formation: Rocks of this group are formed from the detritus (fragments) of physical decomposition of other rock and include conglomerate, sandstone, and shale.

Chemical Formation: As rock decomposes, soluble minerals are leached by water and transported to other environments. Precipitation of these minerals from streams, springs, lakes, or oceans results in the formation of a group of rocks including limestone, chert, chalk, marl, salt, and gypsum.

Sedimentary Soil - These soils are unconsolidated materials which have resulted from the degradation of other rock. Subsequently, the rock fragments have been transported and deposited. Unique soils, across the nation, number in the thousands. Materials in this group are commonly referred to in terms of grain size and are important to the construction industry as gravel, sand, silt, and clay. Soils which are not transported are called **residual soils.**

Figure 7

Note that gravity is not listed as a transporting force. Gravity actually does not transport particles, but is always pulling particles toward the center of the earth and is a great influence in the movement of particles regardless of the other forces involved. Gravity causes downhill flow. In conjunction with transporting actions, gravity becomes a powerful tool to "plane" a surface or feature, significantly modifying it by reshaping and lowering elevations. These transporting agents cannot maintain their energy and chemical balance indefinitely. As transporting power diminishes, base level is reached, temperature, pressure, or chemical conditions change, and transported materials drop out and become deposits.

DEPOSITION

The remains of mass rock are deposited in the lower areas (relative elevation) of the earth's crust resulting in the elevation of those areas being raised. This process of deposition, in addition to diastrophism (mountain building) and vulcanism (volcanic activity), prevents degradation and transportation from ultimately reducing the earth's land areas to base level where they would be covered with water.

These deposits (detritus resulting from exposure of rock mass to the atmosphere) are the materials that, given the proper conditions and time, become what is commonly called soil. They may also become the beginning of new rock mass. If they become cemented, metamorphosed and melted, they can return to the crust as igneous, metamorphic, sedimentary, or volcanic rock (Figure 7). The student should aware that this cycle does not always progress in a uniform, linear fashion to successful completion, but is interrupted and sidetracked in erratic and complex ways, with infinite variations.

Soil is the result of natural actions (Figure 6) on these masses of rock. These actions result in a heterogenous mix of mineral fragments, organic matter, air, and water. Soil may be soft or hard, porous or dense, loosely or weakly cemented. The colors of soil may cover the spectrum; however, soils usually exhibit some shade of gray, white, or yellow.

As batholiths (granitic mountain cores), volcanic lava flows, sandstones, limestones, and other rock mass disintegrate, the resulting fragments (soils) can be categorized in terms of their environment, location, and the agents that created them.

- **Aeolian** - These soils are the result of fragments being transported and deposited by wind. These soil particles are usually relatively small, since wind does not have sufficient sustained energy to move large pieces of rock.

- **Alluvial** - These soils have been transported and deposited by the forces of moving water. Depending on the volume and velocity of the water, particles ranging in size from huge boulders to microscopic clays are moved in the process of creating these soils. Alluvial soils usually show distinct depositional layering and a reduction in particle size as the distance from the source increases. These materials represent much of the land surface.

- **Colluvial** - These materials involve the bulk movement of rock debris downslope under the direct influence of gravity. Varying amounts of water may be available, but water is not the major moving agent. Huge boulders routinely move down slope, colliding and grinding until particles of varying sizes accumulate at the bottom of mountains.

- **Glacial** - During periods of glaciation, ice picks up massive quantities of abraded material and transports them long distances. As the glacial ice melts, it deposits this debris.

- **Organic** - A soil generally created under a vegetative cover and under conditions that allow the accumulation of plant residue. This name can be applied to organic materials accumulating in marshes or bogs or where humus has been incorporated in soils such as topsoils.

- **Residual** - Residual soil is created when rock particles are not transported, but remain in their weathered position. These soils are unique in that normally no stratification is present. Rock fragments are similar to those in the bedrock immediately below and increase in size from top downward rather than laterally.

Immediately after deposition, rock fragments themselves begin to change due to the same processes which degrade rock mass. The weathering process to which the original rock mass was subjected is the most significant factor in producing the detritus end product. The end product will not necessarily bear any resemblance to the original parent material. As geological time passes, the differences between the products of the original parent material become increasingly more pronounced. The same rock mass can supply rock fragments to arid and humid climates, but different weathering conditions will result in two entirely different products.

In discussing soils, there is much written on the effect of parent material on the soil. The term "parent material" is used to refer to two distinctly different phases of soil development. One is the rock mass that produced the clastic deposit. After it has been deposited, the clastic material then becomes the parent material for the weathered soil. Weathered soil is the material with which we normally deal. Weathered soil is the material on which and with which our infrastructure is built.

From this point forward in this text, soil will be the term used to identify the material produced from weathered clastic material. Clastic material will now be termed parent material. The characteristics of any soil at any point of time are determined by the following.

- the climate to which the parent material has been subjected since deposition
- the physical and chemical composition of the parent material
- the relief
- the geological time over which natural forces have acted
- the animal and vegetative life (externally and internally)

CLIMATE

Climate is probably the most important factor in creating soil. Water, temperature and wind are the elements of soil modification. Wind is the least important. Generally, moisture availability is the dominate force in the maturing of soils. Under arid conditions, soil building is slow. Soil development is primarily caused by the physical forces of temperature and wind, because low moisture availability retards chemical activity. Since evaporation exceeds rainfall in these areas, ground water with its dissolved minerals is slowly brought to the surface through capillary action. As these mineral laden waters reach the surface and evaporate, the chemicals are left as a residue. Calcium carbonates are the most common of these chemicals. Other minerals formed by this process are borax, gypsum, and salt. These materials create hard crusts at the surfaces of coarse textured soils in these climatic zones. Caliche, a common construction material found in the Southwest, is a product of this environment.

Conditions of high humidity and temperature promote rapidly maturing soils. High rainfall quickly weathers minerals in the soils and aids the downward movement of clay and colloids. Plant remains decompose rapidly; therefore, highly organic soils do not readily form from vegetative cover. Acids produced during decomposition of organic materials promote the development of clay minerals and the reduction of carbonates resulting in clayey soils high in aluminum and iron. These soils are evident in the subtropical and tropical climates.

Thus, rainfall and evaporation tend to control the evolution of soil types. A line can be drawn from south to north, starting at the Gulf of Mexico in east Texas and extending northward to the Canadian border near the east boundary of the states of North and South Dakota. This line separates the continental United States into two sections. To the west of this line, the country receives less than 25 inches of rainfall per year; to the east, it receives more than 25 inches of rainfall per year. Correspondingly, soils high in aluminum and iron exist to the east of the line and soils high in carbonates are found to the west, Figure 8.

An interesting and important fact about climates is that mountains tend to reproduce climates in vertical zones, the effect of increasing altitude being similar to increasing latitude. Thus, the climate that produces a tundra soil at the top of a western mountain is similar to the climate that produces a tundra soil in Alaska with both soils being very similar. In addition to rainfall, temperature is an important factor in soil development. Temperature regulates the chemical and bacterial activity of soils. High temperature usually is a catalyst for chemical modification. Conversely, cold temperatures result in a cessation of chemical activity, especially when the ground is frozen. Thus, subtropical and tropical soils have undergone complete chemical alteration. Soils of the frozen tundra are composed primarily of mechanically produced mineral fragments with minimal chemical alteration. Biological activity in the soils follows patterns similar to that of temperature. Bacteria actively consume organic material in regions with high temperature and humidity, producing soils with minimal humus. In colder climates, bacterial activity is significantly reduced, resulting in soils with high organic content where there is sufficient moisture to grow vegetative cover.

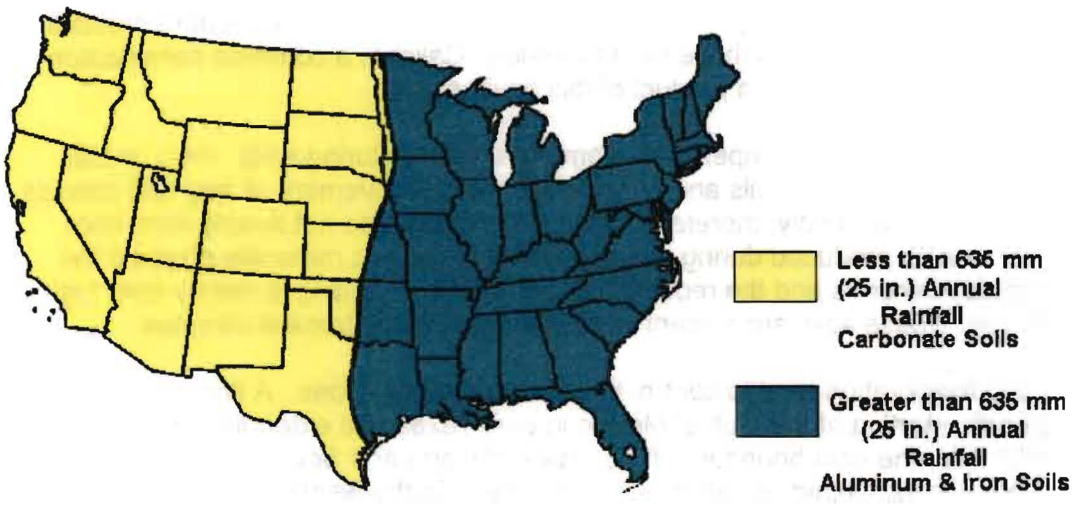


Figure 8
Soil Composition

PARENT MATERIAL (ROCK DETRITUS)

The parent material (residual or transported) is a passive contributor to the maturing soil mix. It only provides the minerals that are weathered into a particular soil. It is important to understand that parent material by itself does not determine the soil that will eventually develop. We have already seen that aridity and humidity are prime contributors in the development of soil types. The original size, shape, and mineral content of particles affect color, texture, permeability, mineralogy and erodibility of soils. Young, unweathered soils tend to be like the parent rock; however, with continued weathering that likeness eventually is lost. When rock detritus from the same or similar sources ends up in different climatic zones, the mineral fragments will eventually develop into soils of very different characteristics.

RELIEF

Relief influences soil formation by affecting internal and external drainage, erosion, deposition, temperature, and biological activities. Relief is a passive soil former. Where relief is great and slopes are steep, water drains rapidly resulting in a thin soil with less chemical activity, more erosion, and generally less biological influences. As slopes get flatter, soils retain more water, there is less erosion and life begins to increase. Flatlands with sufficient rainfall produce thick layers of soils, highly leached with thick layers of clay and minimal erosion. Soils that are formed in areas of greater relief are usually better drained and more highly oxidized with brown, yellow, or red colorations. Soils that form on flat bottom lands are very thick and poorly drained. Instead of oxidation, reduction takes place with less decay of vegetation allowing high percentages of organic to accumulate. These soils exhibit dark grey, blue, and black colorations. These soils are constantly water saturated and remain unstable.

Topography also influences soil formation. Slopes facing the warming and drying rays of the sun develop different soils than those on slopes facing away from the sun. Soils on slopes facing away from the sun retain more moisture at cooler temperatures and for longer periods of time.

GEOLOGIC TIME

Time is necessary for the development of soil. Without time passing, parent material equals soil. As time passes, all the soil forming agents take their toll on the parent material. The more time that passes, the more mature a soil becomes. The time required to produce a mature soil cannot be measured. It takes geologic time for nature to produce a mature soil in equilibrium. (Refer to Figure 9 for illustration of geological time scale.)

The last glaciers in what is today the continental United States retreated approximately 10,000 years ago. Since they melted, nature has been modifying the glacial till left behind. Most of those materials have not been completely weathered into their final form. There is no calendar schedule and so many factors are involved, including the possibility of cycle interruption, that any discussion of time required for soil development is speculative.

Era	Period	Epoch	Approximate Duration (Millions of Years)	Life Forms	Approximate Beginning (Millions of Years Ago)
	Quaternary	Holocene	10,000 years ago to present		
		Pleistocene	1.7		1.7
		Pliocene	9		12
Cenozoic		Miocene	14	Mankind	26
	Tertiary	Oligocene	12		38
		Eocene	16		54
		Paleocene	11		65
	Cretaceous		70	Placental Mammals	135
Mesozoic	Jurassic		55	Birds, Grasses & Cereals	190
	Triassic		35	Mammals & Flowering Plants	225
	Permian		55	Ginkgoes	280
	Pennsylvanian		40	Insects, Cycads & Conifers	
Carboniferous					320
	Mississippian		25	Reptiles & Primitive Gymnosperms	345
Paleozoic	Devonian		55	Amphibians & Vascular Plants	400
	Silurian		25		425
	Ordovician		75	Fishes & Mosses	500
	Cambrian		100		600
	Proterozoic			Invertebrates & Marine Algae	
Precambrian			3200		
	Archeozoic				3800

Geologic Time Scale
Figure 9

BIOLOGICAL (Fauna and Flora) ACTIVITY

Both plants and animals have significant impact on the development of soils and their ultimate character. Plants, animals, insects, bacteria, fungi, and other organisms, including humans, initiate physical, chemical, or a combination of these activities on soil. Bacteria, fungi, and other microorganism are primarily responsible for the decomposition of humus and the oxidation/reduction that affect the physical and chemical characteristics of soils. These kinds of activities are controlled by temperature. Chemical and physical action is strongest in warm, humid climates. The percent organic is commonly higher in poorly drained soils. Reduction activity is prevalent where water tables are high, resulting in gleyed soils. The better drained a soil is, the more oxidized it will be and the lower its organic content will be. The influence of animals, earthworms, burrowing animals, ants, etc., can also be important. They rework and aerate the soil, changing its texture and its chemistry. Plants bring calcium, magnesium, potassium, and other elements from lower horizons which are then added to the upper layers of soil as the plants drop leaves, die and decompose. This process changes the chemistry of soils, as well as physically altering soils through root action.

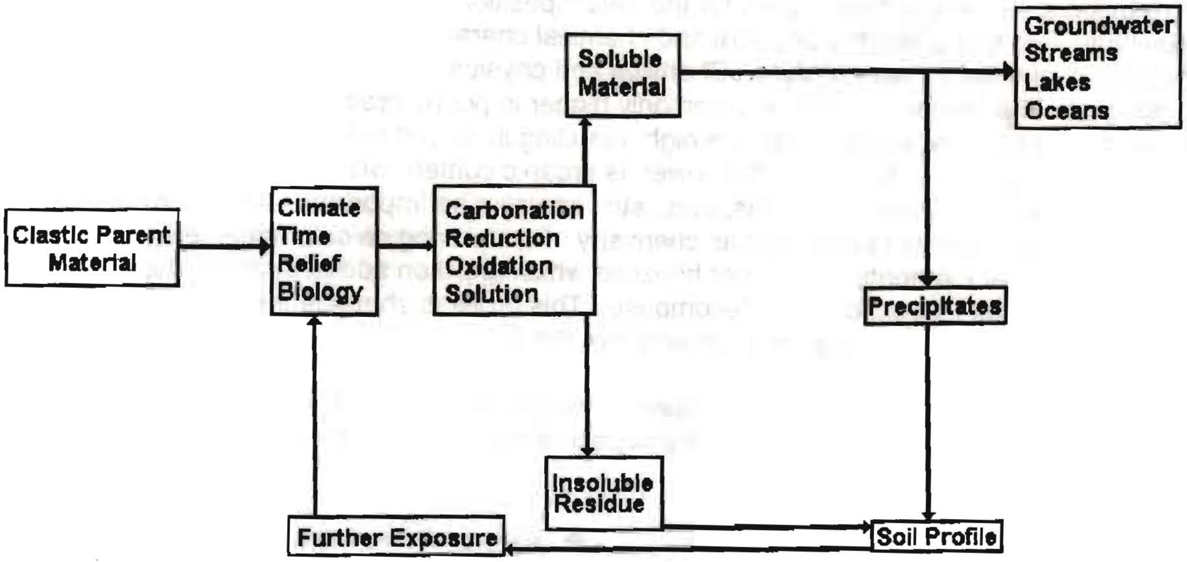
Humans and their activities have been profound in influencing soils and soil environments, especially in more recent times. Consider the impact of the following on the natural processes just discussed:

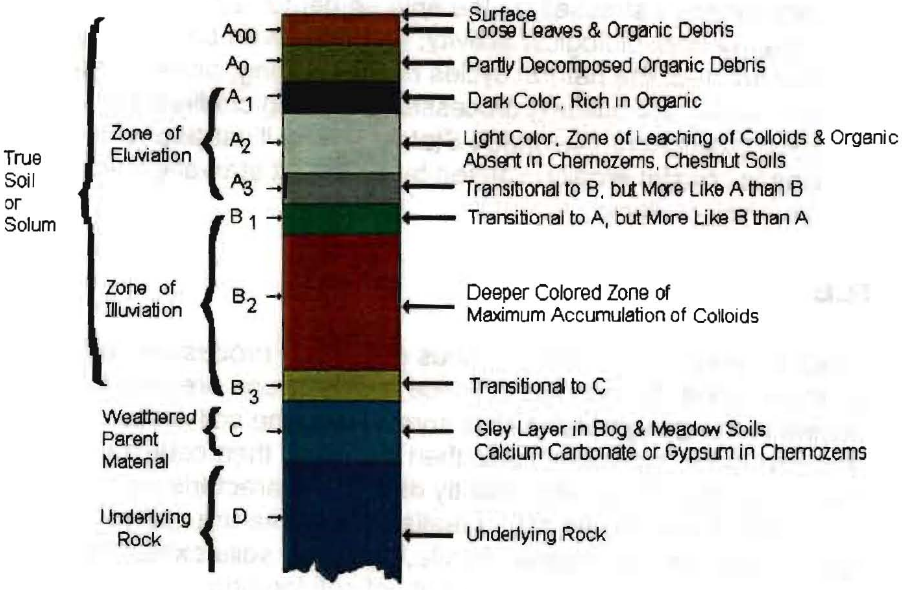
- cities
- forest clear cutting
- dams
- monoculture forests
- agriculture
- strip mining
- dredging
- levee systems
- cement/lime production
- aggregate production
- transportation systems
- stream channelization

Each of these modern activities is a method by which society is progressing, but each also gives birth to a new generation of stresses on the environmental factors of soil building. These activities change topography and biological activity, and may even be affecting climate. Time is impacted by the interruption of the natural cycles of soil building; parent material is being exposed and modified. All five soil building processes are being challenged. A major result is a significant shift in erosion throughout the United States. Prime illustrations are the "Dust Bowl" of the 1930's and dramatic coastal erosion caused by sediment starvation along the Gulf coast due to control of the Mississippi River.

SOIL PROFILE

In summary, soil, created and positioned by various geological processes, is constantly subjected to physical and chemical changes. These modifications are dependent on the soil forming factors present in the geographical area surrounding the soil itself. Through natural soil forming forces, what was once masses of rock, then boulders, then cobbles are now sands, silts, and clays which begin to take on significantly different characteristics resulting in what is scientifically termed a soil profile (Figure 10). Idealistically, a mature soil will exhibit three distinguishable major layers called horizons. In situ, however, soils exhibit highly variable soil profiles primarily depending on time and the intensity of soil forming processes. The three layers, which together may represent only the upper few meters of the earth's crust, are termed A Horizon, B Horizon, and C Horizon.





Idealized Soil Profile

Figure 10
Soil Profile Development

A Horizon - The A horizon is the upper layer of soils immediately exposed to the most intense weathering. This is the material upon which we are dependent for our food supply and is of intense interest to the agricultural engineer. Where there is sufficient rainfall, the A horizon is a zone of higher organic content, usually leached of fine materials, and darker in color than the underlying layers. To geotechnical personnel, it is not considered good construction material due to its inherent instability.

B Horizon - This horizon immediately underlies a zone of transition separating the A and C horizons. Chemicals, minerals, and some organic material are leached from the upper A horizon percolating downward and collecting at this level. This process results in a higher clay/colloid content as well as a richer chemical mix than in the A horizon. These conditions also make soil materials from the B horizon suspect as useful in highway and foundation engineering.

C Horizon - This layer is separated from the B Horizon by another transitional zone that has neither the characteristics of the more weathered and complex B horizon nor the C horizon The C horizon is the parent material from which both the A horizon and B horizon are formed. This horizon may be composed of a wide variety of materials from rock to reworked soft sediments. These parent materials are the least weathered of the soil profile and are, therefore, the most stable. The C horizon soils are of most interest to geotechnical personnel since they generally provide support for our buildings and transportation system. Also, most of the excavated soil materials used in the construction of earthen structures such as dams and embankments originate in this horizon.

The A and B horizons, in combination, compose the true soil (solum). These soils are derived from parent material which is represented by the C horizon. These solum materials, through the complex weathering processes previously discussed as soil building forces, are generally inferior in quality, questionable in usability, and generally unstable due to the higher clay/colloid contents, complex chemistry, and inclusion of organic contents. At a minimum, special design considerations must be employed to overcome the negative characteristics of the materials from these two horizons before they can be used in construction. Understanding of and attention to the soil profile provides insurance that data from soil mechanics tests from a particular horizon and soil will only be compared to the results from tests completed on that soil and horizon from other locations. Otherwise, meaningless assumptions and misguided judgements will be made. **Compositing soils or data horizontally or vertically can be disastrous when designing for soil use.**

Color

Color is a major characteristic in evaluating soils, soil profiles and keeping track of samples. Color is usually not considered an engineering parameter; however, engineering assessment can be well served by considering this factor. Natural colors recorded in the field during sampling give the testing technician and the designer a distinct advantage when comparing and grouping soils. Color patterns such as banding, marbling, and mottling, are indicators of performance and should be recorded with other field data at the time a sample is retrieved. The intensity of soil color changes as moisture content varies; colors are readily destroyed by handling, drying and preparation that produces a homogenous blend of separate soil particles obliterating all of the original color or color patterns.

Color is an indicator of certain soil chemicals and mineral particles. Black to dark brown usually results from organic matter. Reds are due to the presence of iron in a well-drained soil that is highly oxidized resulting in hematite or siderite. Yellow-brown is also primarily a result of iron. This color is usually associated with the mineral limonite that occurs in soils with less drainage and less complete oxidation. Gray and blue soils result when soils are poorly drained. Yellow mottling sometimes occurs with these colors. The darker gray and blue (gleyed) soils are generally produced below permanent water tables; a result of reduction rather than oxidation.

All soil colors should be determined using the standard for soil surveys known as Munsel color charts. These charts are based on hue (rainbow color), value (lightness/darkness of color) and chroma (strength of hue). Color determination should be made only on damp soil. If the soil is excessively dry, it is appropriate to dampen the soil to accurately determine color.

SOIL IDENTIFICATION

After decades of intense observations by soil scientists and agricultural engineers, a system has been developed and refined based on soil characteristics and soil profiles that has universal acceptance and demonstrable use to the geotechnical efforts in transportation design and testing. This system, known as the U.S. Department of Agriculture Soil Classification, began in Russia during the 19th Century and is becoming widely accepted as the standard for identifying soils and grouping soils with like characteristics. The following quote from the PCA Soil Primer defines the value of this system to the transportation industry.

> "Highway engineers found that this system and the resulting valuable soil information could be used in identifying soils, after which they could classify them for engineering purposes in their own work. Therefore, while the U.S. Department of Agriculture system is called a soil classification system for purposes of nomenclature and use by the agricultural engineer, it is used as a soil identification system by the highway engineer. This system is based on the fact that soils with the same weather (rainfall and temperature ranges), the same topography (hillside, hilltop, or valley) and the same drainage characteristics (water table height, speed of drainage, and so forth) will grow the same type of vegetation and be the same kind of soil. This is illustrated by the fact that the black wheat-belt soils of the West are the same as the black wheat-belt soils of Russia, Argentina, and other countries. The system is important basically because a subgrade of a particular soil series, horizon, and grain size will perform the same wherever it occurs since such important factors as rainfall, freezing, groundwater table, and capillarity of the soil are part of the identification system. In no other system in use are these important factors employed directly. The system's value and use can be extended widely when the engineering properties, such as load-carrying capacity, mud-pumping characteristics, and cement requirements for soil-cement, are determined for a particular soil. This is because soils of the same grain size, horizon, and series are the same and will function the same wherever they occur. Therefore, a North Carolina engineer and a Texas engineer, after each has identified a soil in his or her own area by this system, could exchange accurate pavement design and performance data."

Note that the emphasis is on the use of the USDA system for soil identification, not classification as a replacement for AASHTO, ASTM or other engineering classification.

This system has been under continual refinement since its inception and in 1965 major changes were made in terminology. Therefore, when reviewing USDA soil information it is best to be familiar with terms pre-and post-1965. Information is readily available from the Natural Resources Conservation Service, USDA. The system is now divided into six (6) category levels; orders (11), suborders (53), great groups (261), subgroups (approximately 1900), families (approximately 6755), and series (greater than 17000) based on soil profile and soil characteristics. Each succeeding level further defines unique characteristics of that category. The eleven (11) orders generalized in Figure 10 are:

Alfisol - soils with aluminum and iron formed under primarily deciduous forests with a well-developed B Horizon containing leached clay

Aridisol - soils with calcium, gypsum or salt hardpan formed in arid climates

Entisol - soils of recent origin which exhibit minimal profile formation. This order includes tundra soils over permafrost that are serious engineering problems.

Histosol - bog soils containing peat and various organic materials. Severe engineering problems are associated with these soils.

Inceptisol - soils with indistinct horizons showing only beginning soil formation

Mollisol - soft, dark and crumbly A Horizon and the B Horizon exhibits clayey nature; well developed profile under grass vegetation

Oxisol - soil composed primarily of oxides, red B Horizon formed in tropical and subtropical climates; less than 0.02% of the soils in the United States fall into this group.

Spodsol - soils developed generally under coniferous forests on low clay parent material, most commonly resulting in an amorphous layer of aluminum and organic mixture.

Utilsol - soils with very well developed profile with a red to yellow B Horizon high in clay. Highly weathered, acid and developed under forest or grass.

Vertisol - nontypical profile showing vertical mixing due to high shrink/swell characteristics caused by high clay contents. Very serious engineering problems result.

Andisols - residual soil over volcanic material with poor profile development.

The lower subdivisions, including the soil series, are of the most interest to the geotechnical investigator. A soil series represents soils that are essentially the same with very similar profiles. Each series is divided into soil types by name. The Natural Resources Conservation Service has mapped almost the entire United States and published manuals of these soil

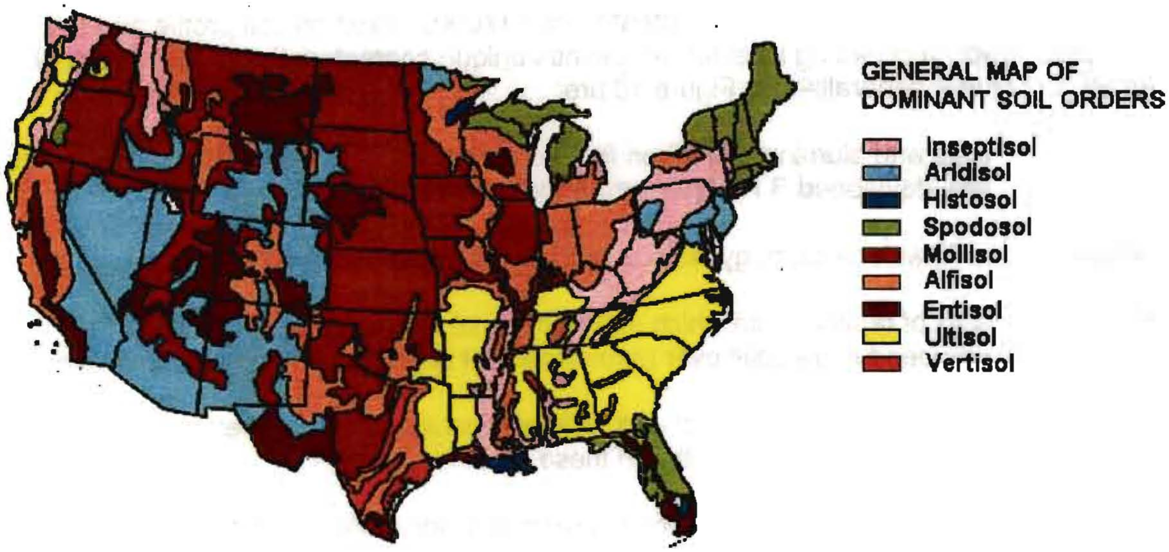


Figure 11
Dominant Soil Orders

surveys. The manuals have details for many professions from geology to agriculture to highway engineering. Each manual is specific to a county/parish and has two levels of mapping; a General Soil Map (Fig. 12) and soil types mapped on aerial photos (Fig. 13). This information is a significant assist to the technician or engineer in planning testing regimens and comparing results to in situ soils. Other engineering data provided by these manuals for geotechnical use in evaluating and using test results include:

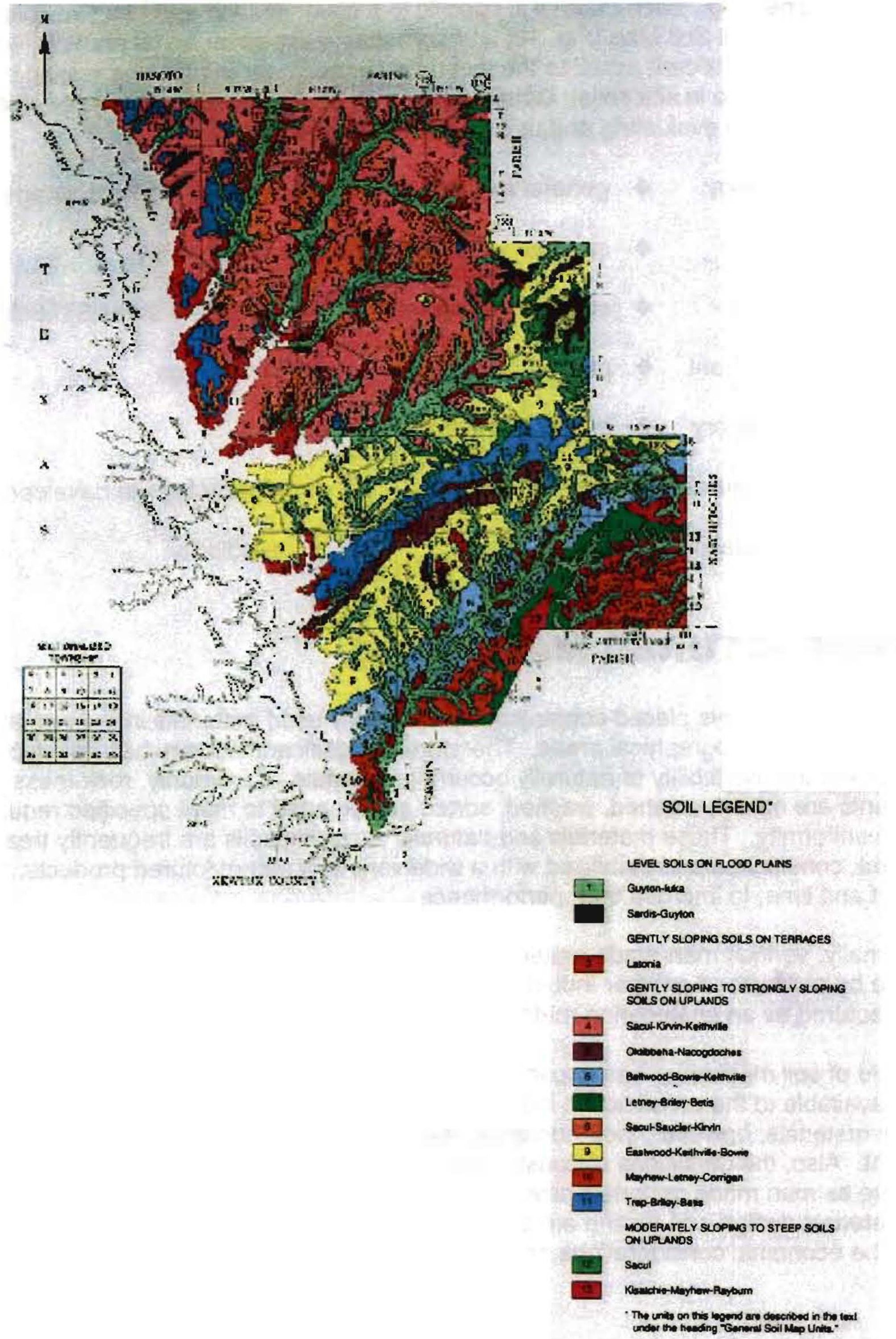
- basic geology
- general mineralogy
- surface slope (drainage)
- density
- internal drainage
- permeability
- water tables
- shrink-swell potential
- AASHTO and ASTM classifications
- organic content
- pH
- Atterbergs
- flooding history
- quality of material for roads
- corrosion characteristics
- quality for site development
- typical gradations
- erodibility

MANUFACTURED MATERIALS

Nature has not always placed construction's frequently used materials in appropriate abundance in all geographical areas. Therefore, a significant industry has developed to supplement the availability of naturally occurring materials. Commonly, rock mass and fragments are mined, crushed, washed, sorted and blended to meet specified requirements and ensure uniformity. These materials and naturally occurring soils are frequently treated, modified, conditioned and stabilized with a wide variety of manufactured products, primarily cement and lime, to improve their performance.

Additionally, various man-made materials are available for use in construction. These materials may be by-products of another industry (e.g., blast furnace slag) or be specifically manufactured as an engineering material (soil and shale fused at high temperatures).

The field of soil mechanics has expanded as additional manufactured materials have been made available to the construction industry. Testing regimens are generally similar to those of natural materials; however, their numerical test results and behavior may be significantly different. Also, the definitions of construction materials have expanded and become more inclusive as man made materials have proliferated. Project design, construction techniques, and materials design and testing are evolving to accommodate these materials, which also affect the economic considerations of the construction industry.



General Soil Map
(Sabine Parish, LA)
Figure 12

Soil Types Mapped on Aerial Photo
Figure 13

Economic Considerations

The construction of new roads and reconstruction of existing roads is a challenging and expensive endeavor. Road construction typically requires the use of significant quantities of aggregates in building the base and surface of a pavement, whether that be rigid or flexible. Aggregates are so prevalent in road construction, that this single use consumes over half the annual production of virgin aggregates in the U.S. This huge appetite for aggregate resources during the last 100 years of industrial development has severely depleted the supply of high-quality aggregate materials. Many areas which have traditionally had adequate supplies have experienced shortages. Metropolitan areas are especially vulnerable to scarce aggregate supplies because of depletion due to high demand in a small geographic area, and zoning restrictions near population centers. Additionally, environmental constraints make it more difficult and expensive to operate aggregate quarries. Rural areas are not immune either. Demand for increasingly scarce resources has raised costs substantially. The absence of concentrated demand in remote areas may require the purchase of aggregates from distant sources.

These factors make it incumbent upon those who design and construct pavements to carefully choose their construction materials. Whereas in years past, a designer might have selected a crushed aggregate base or subbase without much thought to alternative materials, the designer now needs to consider making most efficient use of locally available products, even if these are not high-quality soils or aggregates.

Consequently, the focus on using marginal or inferior materials has necessitated the development of methods to improve them so that they can be used in road construction. It is usually more economical to improve in-place materials than to remove and replace them with imported materials of higher quality. Cement and lime are commonly used as additives to improve less than ideal materials to make them usable for roadbuilding. Every road must be placed, at some point, on existing soils. Cement, lime, and other additives allow more soils to be used as the principal load-bearing element in the pavement structure.

SUMMARY

The goal of this section of the training material is to provide the student information on the origin of soils and to supply data on the types of soil which exist in specific areas of the continental United States, as well as the reasons that these soils are found in these locations. This information will enable the soil technician to predict the type of soil that is typical of a geographic area. The course has demonstrated by maps how vegetation, climate, topography and the location of dominant soil groups are closely related. It has also introduced information provided by the Natural Resources Conservation Service that can be used to further recognize soil type. This background knowledge will be of assistance to the soil technician in determining the validity of any testing regimen and subsequent numerical results and to make informed decisions regarding soil. Now the focus turns to testing and how to ensure the validity, accuracy and significance of the numerical results.

GLOSSARY

aeolian - in terms of soil generation, caused by wind erosion and transport

alluvial - in terms of soil generation, caused by water erosion and transport

arid - having little rainfall

basalt - igneous rock that has been ejected by volcanic activity to the surface of the earth's crust

batholith - large (greater than 40 square miles), intrusive, igneous mass of crystallized granitic rock, which usually form mountain cores

biological weathering - deterioration of parent material into soil caused by both chemical and physical forces, especially that of animal and plant activities

borax - a white crystalline mineral compound composed of a hydrated sodium borate ($Na_2B_4O_7$) that forms on the surface of stony soil in arid regions as a result of evaporation

calcium carbonate - a compound ($CaCO_3$) found in nature as calcite and aragonite and in combination in soil or rocks, such as limestone and caliche

caliche - a crust of calcium carbonate that forms on the stony soil of arid regions as a result of evaporation

capillary action - the attraction of water to a surface which causes it to rise against the force of gravity through surface tension.

carbonation - the dissolving of carbon dioxide in water to form carbonic acid, which reacts with calcium or other elements to form carbonates (e.g., limestone)

chemical weathering - deterioration of parent material into soil through chemical changes (e.g., carbonation, leaching, oxidation)

clastic - made up of fragments of preexisting rock

colluvium - rock detritus and soil accumulated at the foot of a slope

continental divide - the elevated divide that separates the directional flow of water to opposite sides effectively dividing the surface drainage of a continent.

continental drift - the movement of continents around the earth through geologic time due to plate tectonics

core - the central mass of high density material at the center of the earth

crust - the outer layer of the earth's structure directly in contact with the atmosphere

crustal plates - see **tectonic plates**

degradation - disintegration

deposition - the process carried out by wind, ice and water of moving material from one location to another

detritus - loose material (e.g., rock fragments) that results directly from disintegration

diastrophism - the process of deformation that produces the earth's crust, its continents and ocean basins, plateaus and mountains, strata folds, and faults

erosion - wearing away

extrusion - molten material (magma) from deep within the earth which has been ejected onto the surface through volcanic activity

fauna - animal or animal life

flora - plant life

geology - the science that deals with the history of the earth, especially the study of rock forms

geotechnical - having to do with the properties of soils

glacial - having to do with the those parts of geologic time from Precambrian onward when a much larger portion of the earth was covered with sheets of ice

gleyed soils - soil that formed under poor drainage; resulting in the reduction of iron and other elements in the profile and in gray and mottled colors, usually gray with yellow

granite - a light colored predominately siliceous rock normally found in igneous intrusions

granular - having a grainy texture

gypsum - a widely distributed mineral ($CaSO_4$) consisting of calcium sulfate that forms on the stony soil of arid regions as a result of evaporation

heterogenous- consisting of dissimilar components; nonuniform blend

horizon soil - a layer of soil produced by soil forming processes, lying approximately parallel to the surface, having distinct characteristics

humid - characterized by perceptible moisture; in climate terminology, exhibits rainfall between 40 - 80 inches per year

humus - a brown or black complex variable material resulting from partial decomposition of plant or animal matter and forming the more stable organic portion of a soil

hydration - a reaction of other chemical with those of water

igneous - resulting from the intrusion or extrusion of magma or the activity of volcanoes; rocks formed from molten magma

intrusion - molten crustal material that is injected into other rock through fissures and bedding planes

isostasy - general equilibrium in the earth's crust maintained by a yielding flow of rock material in the mantle

leach - to dissolve and remove soluble compounds from a substance by the action of water percolating through soils

magma - molten rock

mantle - the layer of the earth's structure lying immediately below the earth's crust

mass wasting- the movement of rock debris downslope under the direct influence of gravity

metamorphic - the type of rocks produced by a pronounced change of pressure, heat and water, resulting in a more compact and more highly crystalline condition

munsell color- a designation of color by degrees of hue value and chroma

nomenclature- a system of terms used in a particular discipline

organic - plant and animal residue in the soil in various stages of decomposition

oxidation - the process of chemically changing a compound through exposure to oxygen; reactions in which oxygen chemically reacts with a metal forming an oxide

parent rock - the original rock formation; either the original rock mass or the clastic material in which soil forms

permeability - the quality of a soil that enables water to move through the profile

physical weathering - deterioration caused by agents such as wind, water, and ice

plate tectonics - the movement of the earth's crust divided into large pieces which float on a viscous material in the mantle

reduction - reaction, which occurs below the water table, which results in the freeing of a metal from its oxide; the opposite of oxidation

relief - the relative elevations of the land surface; topography

saltation - the bouncing of particles too large to be held in suspension

sedimentary rock - formed from materials transported by moving water, air or ice or chemically precipitated

shear boundary - the point of contact between two tectonic plates which move laterally to each other, resulting in and strike slip faults at their edges

solum - the altered layer of soil above the parent material that includes the A and B horizons

solution - the process by which a solid, liquid or gaseous substance is homogeneously mixed with a liquid

spreading boundary - occurs where two tectonic plates are moving away from each other

subduction zone - occurs where two tectonic plates are moving toward each other causing crustal material to be pushed beneath the plates

suspension - a substance in which the particles are mixed, but not dissolved in a liquid

talus - a slope formed by an accumulation of rock debris; rock debris at the base of a cliff

topography - the configuration of a surface including its relief and the position of its natural and man-made features

traction - the pushing, dragging or rolling of particles to large to be lifted by the transporting force

true soil - detritus which has been weathered to the point that it has an identifiable layering into specific horizons

tundra - a level or undulating treeless plain, characteristic of arctic and subarctic regions; consists of black mucky soil with a permanently frozen subsoil

vulcanism - (also volcanism); the power or action of a volcano

weathering - the action of the elements in altering the texture, composition or form of exposed objects; the physical disintegration and chemical decomposition of earth materials