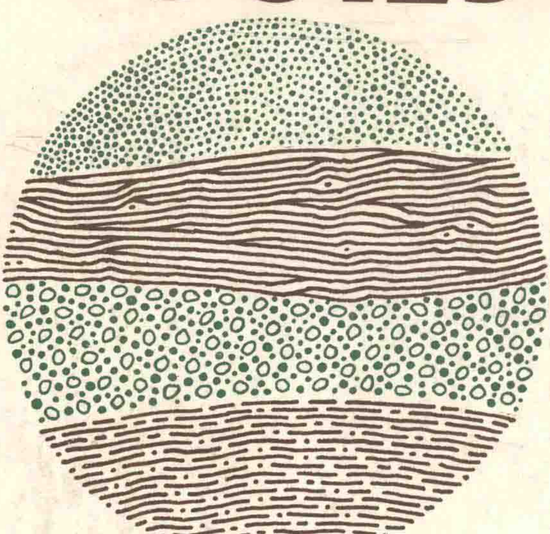
Donald Steila

THE GEOGRAPHY OF SOILS



Formation, Distribution, and Management

The Geography of Soils

formation, distribution, and management

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The Geography of Soils

To my wife Becky
and
my daughter Stephanie Cristina

Preface

Throughout the United States there has been a rapidly developing interest in environmental quality and the recognition of the important role which soil serves as one of man's primary resources. As a consequence many Liberal Arts students are now including an introductory soil science course in their curriculums. In the process of teaching such a course—*Geography of Soils*—to students with limited training in the natural sciences, it became apparent that a need existed for a textbook written at a level comprehensible to the nonspecialist, but one that was not superficial in scope. It is my sincere hope that I have approached meeting these objectives.

Many individuals have assisted in the development of this book. Special recognition should be given to Dr. Jack Blok (Director, ECU Cartographic Laboratory), who personally directed the production of all graphic renderings, and to the East Carolina University Staff Cartographers Robert Corbo and Steven Moore. Professors Ronald Swager and Vernon Smith provided assistance when schedules were rushed. Andy Goodwin read the chapters and made valuable contributions to each one. Georgia Arend was a research aide and typed the final manuscript. Fellow colleagues and graduate students at the University of Georgia, University of Arizona, and East Carolina University provided suggestions for improvement. Most important in the production of this manuscript, however, has been my family, who gave constant encouragement and were understanding when research and writing demanded much of my time.

The Geography of Soils

Contents

Preface *xi*

Introduction *1*

1

The Origin and Significance of the Soil's Inorganic Constituents *3*

Minerals and Parent Material, 3

2

The Organic Fraction of the Soil *22*

Soil Organisms, 22
Soil Organic Matter, 33
Organic Material and Soil Color, 38

3

Soil Porosity, Moisture, and Atmosphere *39*

Pore Space, 39
Soil Moisture, 42
Soil Atmosphere, 50

4

Site and Time Affecting Soil Characteristics *51*

Topographic Position, 51
The Soil Profile: A Factor of Time, 57

5

Soil Classification *63*

United States Comprehensive Soil Classification System, 67

6

Entisols, Vertisols, and Inceptisols *78*

Entisols, 78
Vertisols, 82
Inceptisols, 87
Land-Use and Management Problems, 90

7

Aridisols *94*

Climate and Vegetation, 94
Pedogenesis, 100
Land Utilization and Management Problems, 104

8

Mollisols *109*

Climate and Vegetation, 110
Pedogenesis, 113
Land Utilization and Management Problems, 118

9

Spodosols *122*

Climate and Native Vegetation, 123
Pedogenesis, 126
Land Utilization and Management Problems, 130

10

Alfisols and Ultisols *135*

Pedogenesis, 138
Alfisols, 141
Ultisols, 143
Land Utilization and Management Problems, 145

11

Oxisols *150*

Climate and Native Vegetation, 151
Pedogenesis, 156
Land Utilization and Management Problems, 158

12

Histosols *165*

Land-Use and Management Problems, 168

Appendix: Descriptive Soil Profile Symbols *171*

Glossary *173*

Bibliography *211*

Index *217*

Introduction 030894

> Next to the pursuit of peace, the really greatest challenge to the human family is the race between food supply and population increase. That race tonight is being lost.[1]

It long has been recognized that the world's production of food is lagging behind the population's rapid increase. The time required for the earth's number of inhabitants to double decreases with the passing of each year. It took at least a million years for the human population to reach its size in 1650. Only 200 years later, in 1850, this number had doubled. Presently, it is doubling in only 35 years. If recent trends continue a population of more than 6 billion by the year 2000 is estimated even if population growth is slowed.

This burgeoning population will require additional living space and a considerable increase in food production to meet its projected needs. Reporting in *The World Food Problem*, the President's Science Advisory Committee stated: "The scale, severity, and duration of the world food problem are so great that a massive, long-range, innovative effort unprecedented in human history will be required to master it."[2] The greatest pressures upon the land are expected to occur in the developing countries of the world. By 1985 India will be

[1] President Lyndon B. Johnson, State of the Union Message, January 10, 1967.

[2] President's Science Advisory Committee, *The World Food Problem*, vol. 1, *Report of the Panel on the World Food Supply* (Washington, D.C.: U.S. Govt. Ptg. Office).

faced with an 88 to 108 percent increase in food needs due to increased population; Brazil's food needs are estimated to increase by 91 to 104 percent; and Pakistan's by 118 to 146 percent. In each of these cases the lower percentage value assumes a 30 percent reduction in fertility while the higher value is derived from current population trends. These percentages do not reflect increased food requirements to improve dietary deficiencies, but simply the quantity needed to sustain future population growth at current levels of consumption.

It seems safe to estimate that by the year 2000 the world's population will require at least twice the present food supplies. The ability to meet this demand ultimately rests with the soils of the continental landmasses. Next to air and water, soil is probably the most fundamental earth resource that man has.

Soil serves as an anchorage for plants and as their nutrient reservoir. Both organic and inorganic in composition, soil is the loose surface material of the earth in which many complex biological, chemical, and physical processes take place. Stated most simply, soil is made up of four components: (1) organic matter, (2) inorganic material, (3) water, and (4) air. Each of these components varies from site to site in both character and amount. This variation is due to the interaction of climate and vegetation with inorganic materials on different geomorphic surfaces. When these interactions occur within relatively homogeneous areas, the soils of the region have certain characteristics in common. However, smaller scale environmental differences within a region can additionally impart a unique character to individual soil units.

The Origin and Significance of the Soil's Inorganic Constituents

1

MINERALS AND PARENT MATERIAL

An ideal loam soil is comprised of approximately 45 percent mineral matter. This mineral portion is the basic framework of the soil, serving as both an anchorage and a nutrient reservoir for plants. As such, the origin and characteristics of minerals are of prime concern to the *pedologist* (soil scientist).

A mineral is generally defined as a naturally occurring element or compound formed by inorganic processes and having a crystalline structure. Most of the earth's minerals are aggregated, or clustered, into types of rock. For example, granite is a common rock type that is composed of many interlocking crystalline minerals, including quartz, micas, and orthoclase and plagioclase feldspars. While each mineral has unique characteristics, every one had its origin in exactly the same way.

As the earth evolved from a molten sphere into a solid globe, cooling took place. All that cooling actually involved was a reduction in the activity of the *ions*[1] that comprised the *magma* (molten rock). With decreased activity, the ions responded to their electrical attractions and became bonded together in a fixed position, producing solid crystalline minerals. The composition of the magma and the resultant minerals was exactly the same, but in the solid state

[1] An ion is an atom, group of atoms, or compound that is electrically charged as a result of the loss or gain of electrons.

the ions were arranged according to a definite pattern, or crystalline structure.

All of the naturally occurring elements (special combinations of the protons, neutrons, and electrons) now recognized on earth were present in the molten mass from which the earth formed. Eight elements dominated the composition of the magma, however, and they now make up over 98.5 percent of the earth's crust by weight (Figure 1.1).

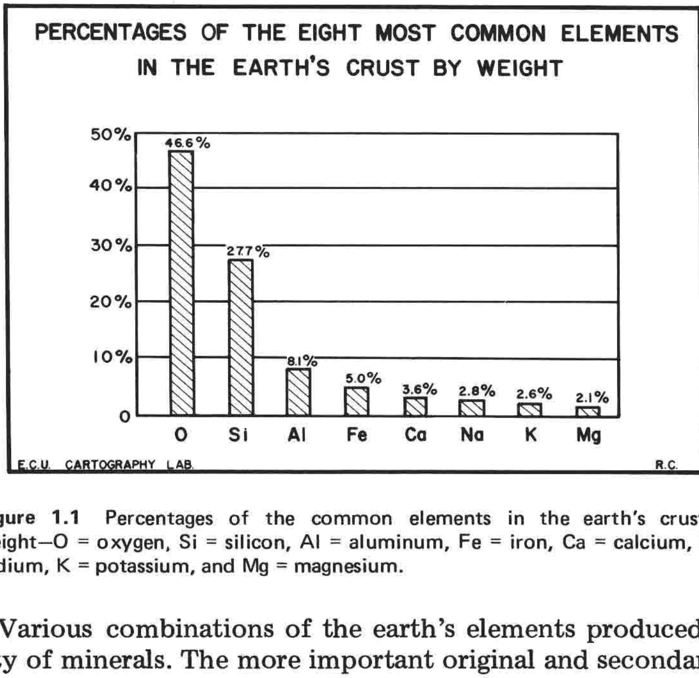

Figure 1.1 Percentages of the common elements in the earth's crust by weight—O = oxygen, Si = silicon, Al = aluminum, Fe = iron, Ca = calcium, Na = sodium, K = potassium, and Mg = magnesium.

Various combinations of the earth's elements produced a wide variety of minerals. The more important original and secondary types are outlined in Table 1. Original minerals have been produced dominantly in primate rock types—that is, *igneous*; however, the secondary minerals are primarily the result of weathering (including the formation of sedimentary rocks). As they occur in their aggregate structure, as rock, original and secondary minerals form the bulk of the earth's outer crust. When minerals, through subsequent weathering, are released from their bond with adjacent mineral crystals they may be available to supply the major bulk of soil material and the nutrient needs of plants.

Parent Material and Its Transformation

The processes leading to the development of a true soil require a considerable length of time. Numerous alterations must be per-

Table 1 Selected Original and Secondary Minerals

Original Minerals	
Name	Formula*
Quartz	SiO_2
Microcline	$KAlSi_3O_8$
Orthoclase	$KAlSi_3O_8$
Na-plagioclase	$NaAlSi_3O_8$
Ca-plagioclase	$CaAlSi_3O_8$
Muscovite	$KAl_3Si_3O_{10}(OH)_2$
Biotite	$KAl(Mg\cdot Fe)_3Si_3O_{10}(OH)_2$
Horneblende	$Ca_2Al_2Mg_2Fe_3,Si_6O(OH)_2$
Augite	$Ca_2(Al\cdot Fe)_4(Mg\cdot Fe)_4Si_6O_{24}$

Secondary Minerals	
Name	Formula
Calcite	$CaCO_3$
Dolomite	$CaMg(CO3)_2$
Gypsum	$CaSO_4\cdot 2H_2O$
Apatite	$Ca_5(PO_4)_3\cdot(Cl,F)$
Limonite	$Fe_2O_3\cdot 3H_2O$
Hematite	Fe_2O_3
Gibbsite	$Al_2O_3\cdot 3H_2O$
Clay minerals	Al-silicates

*For those unfamiliar with chemical formulae for minerals the following example may be helpful: Quartz has the formula SiO_2. This indicates a chemical bond between 1 silicon atom (Si) and 2 oxygen atoms (O_2).

formed on the surface layer of the earth's crust before a soil capable of supporting plant life is developed. Such changes normally involve the *disintegration* and *decomposition* of exposed rock material. Disintegration signifies a reduction in size of the original material, while decomposition refers to the chemical alteration of minerals. Collectively, the processes of disintegration and decomposition are called *weathering*.

Since a soil's characteristics can be strongly dependent upon the materials in the underlying collection of minerals, the original mineral complex from which a soil is formed (and is still forming) is called the soil's *parent material*.

There are two basic groups of inorganic parent material. One is known as *sedentary* (residual) and the other *transported*. A sedentary parent material is one that is native to the site. Suppose, for example, that a granite outcrop is weathering in place, without any significant removal of material. The soil that is formed will be composed of the residual products of the parent material and will, therefore, be considered sedentary (Figure 1.2). On the other hand, many soils occur on inorganic material that originated somewhere else. A river such as the Mississippi, when overflowing its banks, may deposit sediments that have been transported hundreds, even thousands, of miles. Such parent material is not sedentary (Figure 1.2). Besides running water, gravity (down slope movement), glacial ice, waves and offshore currents, and wind may carry inorganic material to a foreign site. Collectively, this type of parent material is said to be transported.

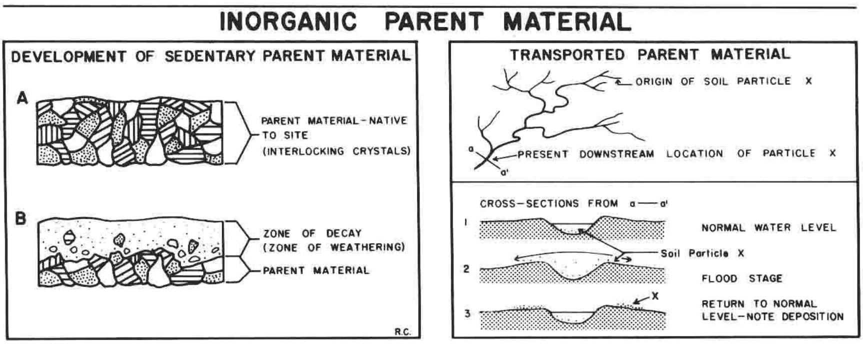

Figure 1.2 Examples of the difference between sedentary and transported parent material.

Weathering Processes

When affected by weathering, solid rock is broken into smaller rock fragments and ultimately into the individual minerals that originally comprised the rock structure. As size is altered minerals also can be modified or completely changed chemically. These processes that either release or alter particles and make them available for soil development fall into two broad groups—*mechanical* and *chemical weathering*.

We know that mechanical processes involve a physical reduction in the size of rocks and a separating out of the minerals. Several factors are significant:

Unloading. This is a process in which the removal of overlying rocks or sediment reduces pressure on the freshly exposed rock, permitting it to expand, thereby producing cracks and fissures.

Temperature variation. Since each mineral expands and contracts at a different rate when heated or cooled, rocks in environments that experience wide diurnal (daily) temperature ranges usually develop stresses between the surface mineral bonds—eventually weakening and separating individual crystals. However, this aspect of weathering is significant only when moisture is present, even in minute amounts.

The intense heat of forest and brush fires can raise surface rock temperatures dramatically within a few minutes, causing a steep temperature gradient in the upper rock layer and contributing to severe rock rupture. Frost shattering occurs in regions where there are periodic freezes. Water freezing into cracks, crevices, and pore spaces exerts tremendous pressure as it expands, and this can pry apart or even shatter massive rocks.

Plants and animals. Plant roots penetrating into cracks and crevices exert a prying effect on rock material as they develop, and animals burrowing or dislodging earth fragments also aid the process of physical disintegration. However, the influence of plants and animals is minor compared to the other mechanical weathering processes.

Chemical weathering, on the other hand, covers a group of processes in which minerals are altered in composition and reduced in size, transforming the original material into something different. The main processes involved are hydrolysis, hydration, oxidation, and carbonation. Seldom do they operate individually, but rather, are interrelated. If this were not the case, weathering would be an extremely slow process.

Hydrolysis. This refers to the process in which dissociated H^+ (hydrogen) and OH^- (hydroxyl) ions of water react with many rock-forming minerals. The effect of water in altering minerals is without doubt the dominant chemical weathering activity. Following is an example of the alteration of the mineral orthoclase. When precipitation (H_2O) comes into contact with the mineral orthoclase [$K(AlSi_3O_8)$], the hydrogen ion from the water may disrupt the mineral's crystal structure, producing an aluminosilicic acid ($HAlSi_3O_8$) and a hydroxide (KOH). The aluminosilicic acid, which is unstable, undergoes further change, which may result in the formation of clay minerals through recrystallization.

Hydration. When water combines chemically with other molecules, hydration occurs. Although this process may change the mineral structure, it often affects only the surfaces and edges of mineral grains without modifying their overall structure. An example of mineral conversion is the change of anhydrite ($CaSO_4$) in the presence of water (H_2O) to gypsum ($CaSO_4 \cdot 2H_2O$).

Oxidation. In this process oxygen combines with compounds in the rocks to form oxides. As oxidation takes place, the original