62D CONGRESS : : 3D SESSION

DECEMBER 2, 1912-MARCH 4, 1913

HOUSE DOCUMENTS

VOL. 70

WASHINGTON : : GOVERNMENT PRINTING OFFICE : : 1913

62D CONGRESS
3d Session

HOUSE OF REPRESENTATIVES

DOCUMENT
No. 1421

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN NO. 85.

MILTON WHITNEY, Chief.

A STUDY OF THE SOILS OF THE UNITED STATES.

BY

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Scientist in Soil Survey.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1913.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., February 16, 1912.

Sir: I have the honor to transmit herewith a report entitled "A Study of the Soils of the United States."

This report was written by Dr. George N. Coffey, as a thesis submitted in partial satisfaction of the requirements for the degree of doctor of philosophy at the George Washington University, before leaving the Department of Agriculture to take up the study of Ohio soils for the Ohio experiment station. In it Dr. Coffey has put together in orderly arrangement the accumulated results of his long service in the Bureau of Soils of this department. He entered the service in 1900, and during the 11 years of his connection with the bureau he held all the positions in the Soil Survey Division from the lowest to the highest. He did detailed mapping in the field for several years and in areas scattered widely over the country. As inspector of soil mapping in the field he had an opportunity to study a still wider range of soils and soil conditions than he had while engaged in detailed field work. His work as a member of the committee on soil correlation gave him further knowledge and experience in soil classification.

The Bureau of Soils at the present time groups soils on the basis of soil-forming processes and geographic conditions, substantially as shown on the soil province maps issued in connection with Bulletins 55 and 78. This primary grouping is thus based upon the origin and process of formation rather than upon the characteristics of the soils themselves.

In the detailed map of an area actually surveyed the soils are differentiated into types and series on the basis of the characteristics of the soil itself, regard being had always to the province or origin and process map. In this way only has it been found possible to avoid the difficulties which Dr. Coffey's map seems to show as inevitable in an attempt, at the present time and with our limited knowledge, to construct a general map based upon the characteristics of the soil itself. Nevertheless the report and map are presented for publication, as it is important that we may clearly see more than one of the many sides of the difficult problem of soil classification.

I recommend that it be published as Bulletin No. 85 of the series of this bureau. In publishing it, however, the Bureau of Soils does so for the purpose of offering it to the scientific world as a contribution to the subject, without indorsing the scheme of classification proposed and without accepting all the conclusions drawn from the facts cited.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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A STUDY OF THE SOILS OF THE UNITED STATES.

INTRODUCTION.

No industry is so vital to the well-being of a nation as agriculture and nothing so vital to agriculture as the soil. From its treasury it has been estimated[1] that we drew last year (1909) more than $8,926,000,000, and its possibilities are as yet only partially realized. There are still in this country millions of acres which have never felt the plow, while those which are now under cultivation can, by the application of scientific principles, be made to produce many times the present value of their products. How to use and not abuse this great resource is the most important problem which faces the farmer of to-day—one worthy of the best efforts of our most profound and learned scientists; for upon its solution depends the future prosperity of the nation.

When Liebig presented the mineral theory of plant nutrition many thought that the problem of soil fertility had been fully and finally settled. This work gave a great stimulus to the study of the soil in the laboratory, while equally important field investigations were given little attention. Only within comparatively recent years has the importance of the study of the obvious field differences in soils been recognized and undertaken in a systematic manner, but enough has already been accomplished to show the value of this line of investigation. More than 800 different types, each possessed of definite and peculiar characteristics have already been discovered in the progress of the soil-survey work in the United States, although only a relatively small percentage of this country has been covered at the present time. The existence of such a great number of types calls attention to the need of a study of the differences which are here represented in order that their influence upon the growth of plants may be understood. That these variations do have a marked influence is becoming more and more evident as these investigations are pushed forward.

One great need in agricultural work to-day is the more general recognition of the individuality of soils; a fuller realization of the true meaning of soil differences. Much valuable time and money have been wasted trying to draw definite conclusions from experi-

[1] Report of the Secretary of Agriculture, 1910, p. 7.

NOTE.—The author wishes to acknowledge his indebtedness to Dr. George P. Merrill for many helpful suggestions and kindly criticisms received during the preparation of this paper.

ments conducted upon entirely dissimilar soils. Many of the contradictory and seemingly inexplicable results obtained by different investigators, or even by the same investigator, are undoubtedly due to fundamental soil differences which would have been evident from a comparative field examination. Hilgard has said, "The history of plat experiments shows so common and unpardonable neglect on the part of experimenters to ascertain definitely the fundamental physical and chemical conditions, that their general unsatisfactoriness is easily accounted for on that score alone."[1] While a field study will not furnish all of this information, much of it can not be secured in any other manner.

The failure to recognize that the results secured upon one type do not necessarily hold true for another is responsible, in some measure at least, for the distrust which farmers often show toward the work of scientific investigators, as well as for the unsettled and unsatisfactory condition of the great problem of soil fertility. A farmer is told that a certain method of cultivation, certain varieties of crops, certain kinds of fertilizers, will give the best results. He goes home and tries these, but the results are not what he expected. Why? Probably because the soil on his farm is entirely different from that upon which his adviser's experiments were conducted.

It is often possible to learn something of a man's opinion about a question by consulting his friends, but it is not safe to depend upon them entirely for information. He and he alone can give definite and positive knowledge in regard to what he thinks. So with soils. Each type must be questioned separately and individually. The answer given may then be safely recommended for a similar soil, but may not apply upon one of a different character. The classifying, mapping, and correlating of the soils of the country, as a fundamental basis for the study of all those problems in which the soil forms one of the limiting factors, thus becomes of the very greatest importance and will prove of inestimable value to the advancement of agriculture.

The old idea of soil investigation was to collect samples, examine them in the laboratory, and see what differences could there be determined; the newer idea is to study the characteristics and properties of soils in the field, classify them according to obvious differences, and, with this information in hand, use the laboratory as a means of ascertaining the cause of such variations as can not be determined in the field. This method of attacking soil problems is the reverse of the usual practice, but because of the great difficulty in duplicating field conditions, it is believed that a field examination should precede laboratory studies. The field observations can thus be used as a check upon laboratory investigation and as an aid in their inter-

[1] Agricultural Science, vol. 6, p. 327.

pretation. If this plan had been followed in the past, it would have prevented the publication of many erroneous conclusions deduced from laboratory studies alone. Field studies furnish "a safe and necessary anchor with which to keep the laboratory experimenter from being dashed against the rock of pure speculation."[1] The classifying and mapping of the various soil types, together with the study of the conditions and processes under which they have been formed, will furnish essential and invaluable data for the conduct of laboratory investigations. Nature's great laboratory is in the field, and a study of her methods can not fail to offer many valuable suggestions, and in some cases, is the only means of solving her problems. It is through a combination of field and laboratory investigations that an understanding of this extremely complex body—the soil—can be reached.

Realizing this fact, it is the purpose of this paper to describe briefly the character of the soils in different parts of the United States as determined by extensive field observations and to give, some at least, of the reasons for the variation from one section to another. To furnish a clearer understanding of the subject matter a preliminary discussion of the distinctive characteristics of the soil, its principal constituents, the factors which determine the proportion of these constituents, and therefore its character, will be given. This will be followed with a brief discussion of the principles of soil classification. These principles will be applied and a general classification and description of the more important soils of the United States given.

NATURE AND ORIGIN OF THE SOIL.

DEFINITION.

The land surface of the earth is almost everywhere covered by a thin mantle of unconsolidated material. There are places along the shore, on steep mountain sides, or other situations exposed to excessive erosion, in river beds, and in regions of recent glacial or volcanic activity, where the bare, hard rock forms the surface, but such instances are not common occurrences and usually cover only very small areas, so that it may be said that the entire land surface consists of unconsolidated material. Although the horizontal distribution of this material is so very wide, its vertical range is relatively very small, and it really comprises only a thin veneer over the consolidated rock beneath.

Some writers, especially geologists, are inclined to use the term soil in its broadest sense to include all of this mantle, or regolith, as it has been termed by Merrill,[2] but the agricultural meaning is much

[1] Paper by H. J. Wheeler in Proceedings of American Society of Agronomy, vol. 1, p. 44.
[2] Rocks, Rock-Weathering and Soils, p. 299.

more restricted. Although the soil consists largely of degenerated rock, not all unconsolidated rock can be considered as soil. This material must be acted upon by life in some form before it becomes a true soil. Until this action has taken place it is best to think of it as unconsolidated rock, although it may be readily converted into soil by the influence of organic agencies. The soil may, therefore, be considered as the superficial, unconsolidated mantle of disintegrated and more or less decomposed rock material, which, acted upon by organic agencies and mixed with varying amounts of organic matter, may furnish conditions necessary for the growth of plants. In this conception the soil is an independent, natural body, a bio-geological formation, differing essentially from the rock which underlies it, although closely related to it. It is the one great formation in which the organic and inorganic kingdoms meet and derives its distinctive character from this union.

In this medium profound physical, chemical, and biological changes are constantly taking place. As the influence of life is greater near the surface, this portion of the regolith usually shows its effect most markedly, and this fact has led to the popular designation of the first few inches, which have been darkened by organic matter, as "soil," while the underlying part is termed "subsoil." The line of demarcation represents the depth to which most of the roots of grasses and other small forms of vegetation have penetrated. Below this depth the influence of organic agencies markedly decreases and gradually diminishes until it is no longer evident, and the subsoil merges into the underlying rock. This distinction between soil and subsoil is one of undoubted practical importance. It is especially marked in the humid regions, while in the arid it is much less evident, owing to the existence of different climatic conditions and resultant soil processes. The term soil is thus used in a broad and in a restricted sense. Its exact meaning can usually be determined from the context, but whenever ambiguity might arise it is well to use a qualifying term, as surface soil.

CONSTITUENTS.

From the foregoing, then, the soil is seen to be composed of mineral and organic matter, the former usually predominating. In the case of peat and muck soils the organic matter may reach as high as 75 per cent by weight, or even more, but the average soil would probably show less than 3 or 4 per cent of the entire mass to be of organic origin. The inorganic portion, being thus so greatly in excess, determines very largely the properties of the soil.

INORGANIC.

The mineral matter of the soil varies in both physical nature and chemical composition. Physically the particles may differ in size,

shape, weight, color, etc., while chemically they may be as varient as the rocks from which they have been derived through degeneration.

Physical composition.—From the physical standpoint the principal inorganic constituents of the soil are sand, silt, and clay, although there may also be present, as stones or gravel, larger pieces of the rocks. All mineral particles less than 2 mm. in diameter, but not smaller than 0.05 mm., are classed as sand.[1] This practically means that macroscopic particles will be included in this grade. Sand possesses practically no coherency, and its addition to a soil will therefore make it looser and more porous.

Silt includes particles within the limits 0.05 and 0.005 mm., too small to be seen readily with the naked eye. Pure silt possesses very little coherency and is of a floury or mealy nature. While it will not give plasticity to a soil, it causes it to be very much more retentive of moisture and less open and leachy than sand.

All particles less than 0.005 mm. are classed as clay.[2] To it are due some of the most important properties of the soil. Without it soils are so loose that they are easily driven about by the wind, and so porous and leachy as to be often almost or entirely unfit for useful culture. Plasticity and adhesiveness are to be attributed to it. No other inorganic constituent has nearly so marked an influence in determining the character of the soil. In other words, the addition of a certain percentage of clay will have a more pronounced effect upon the texture, for example, than the addition of a similar amount of any of the other grades. Its plasticity, its "retentiveness of moisture, as well as of gases and of solids dissolved in water, imparting these important properties to soils containing it," explain its great influence as a soil ingredient.

Since all of the fine earth is included in the above three classes, it follows that an increase or decrease in one grade must be accompanied by a corresponding decrease or increase in one or both of the other grades. The relative proportion of the particles of different sizes determines the texture, which is the most important physical property of the soil, while the arrangement of these particles constitutes the structure.

Chemical composition.—In chemical composition the inorganic matter varies according to the kind and relative proportion of the various minerals of which it is composed. Quartz or silica greatly predominates in nearly all soils, this oxid alone constituting, according to Clarke,[3] 59.89 per cent of the crust of the earth.

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[1] The sizes as used here and elsewhere in this paper are those adopted by the Bureau of Soils, U. S. Department of Agriculture.

[2] "Clay" is used in the strictly physical sense. It is clearly recognized, however, that the clay is not alike in all soils and that soils having the same percentage of particles of this size vary in plasticity and other properties, although all soils having more than one-third of this grade will be "heavy" or "clay" soils.

[3] U. S. Geol. Survey, Prof. Paper No. 14, p. 108.

The mineralogical nature of the soil depends very largely upon the petrographic character of the rock from which it has been derived. There is always a tendency, however, for the more soluble and more easily decomposed minerals to be leached out in the change from rock to soil unless the processes are almost entirely mechanical. For this reason there is usually a relative increase in the proportion of difficultly soluble material like quartz. The contrast between the composition of the rock and the derivative soil is most pronounced in the case of the purer limestones, which are composed almost entirely of the relatively soluble mineral calcite ($CaCO_3$). While this fact causes soils to be more alike in chemical composition than the rocks from which they have been derived, still the character of the latter has a pronounced influence in determining the physical, chemical, and biological properties of the resultant soils.

Experiments have shown that there are 13 or 14 elements, or compounds of these elements, which participate in the normal growth of plants or are at least always present. These are potassium, sodium, calcium, magnesium, iron, manganese, phosphorus, sulphur, silicon, chlorin, carbon, hydrogen, oxygen, and nitrogen. Of these the first 10 are obtained from the mineral matter of the soil, the other 4 coming from the air, the soil water, or the organic matter. Since the discovery of these facts most of the efforts of chemical soil investigators have been directed toward determining the amount, especially the "available" amount, of these elements present in the soil, particularly potash (K_2O), phosphoric acid (P_2O_5), lime (CaO), and nitrogen (N), these being the constituents which were considered as liable to be deficient. For this reason, any statement in regard to chemical composition is almost necessarily restricted to these compounds.

In a recent publication Whitney [1] has brought together "the results of all the analyses, made in the United States by the 'acid-digestion' method [2] during the past 18 years so far as they have been found in the literature." The following table gives the average by States of the analyses contained in this publication:

[1] A Study of Crop Yields and Soil Composition in Relation to Soil Productivity, by Milton Whitney, Bul. 57, Bureau of Soils, U. S. Dept. of Agr.

[2] The "official method" does not show whether the lime (CaO) exists in the form of silicate or carbonate. In the opinion of the author very little, if any, lime carbonate occurs in the surface soils of the humid regions, and the determination of lime by this method may be misleading, since it is the lime as carbonate which exerts the most important influence.

Average chemical composition of the soils of the United States by States.

State.	Number of samples.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Alabama	4	0.35	0.06	0.16	0.25
Arizona	22	.83	.13	2.79	1.83
Arkansas	6	.26	.08	.10	.14
California	115	.75	.15	1.90	1.61
Colorado	30	.62	.20	2.00	.64
Connecticut	1	.23	.22	.32	.78
District of Columbia	4	.42	.08	.39	.06
Florida	88	.03	.15	.31	.05
Georgia	2	.13	.09	.13	.15
Idaho	37	.61	.36	1.35	.98
Illinois	5	.38	.10	.61	.60
Indiana	13	.37	.28	.17	.13
Iowa	2	.35	.12	.99	.62
Kansas	7	.51	.11	1.07	.39
Kentucky	92	.35	.27	.18	.12
Louisiana	18	.51	.09	.44	.59
Maine	1	.14	.17	.....	.....
Maryland	14	.45	.15	.35	.16
Massachusetts	1	.15	.14	.53	.66
Michigan	40	1.06	.32	1.27	.55
Minnesota	163	.36	.23	1.16	.52
Mississippi	276	.31	.10	.80	.29
Missouri	8	1.45	.07	.54	.38
Montana	2	.74	.18	.92	1.01
Nebraska	15	.48	.28	1.15	.43
Nevada	48	.63	.32	4.34	1.50
New Hampshire	5	.93	.15	.70	.51
New Jersey	2	1.15	.77	.66	1.12
New York	16	.55	.10	.58	.74
North Carolina	2	.09	.04	.16	.03
North Dakota	25	.57	.27	1.97	.37
Ohio	57	.25	.13	.29	.39
Oklahoma	3	.52	.05	.72	.13
Oregon	136	.30	.25	.98	.60
Pennsylvania	24	.43	.13	.28	.54
Rhode Island	7	.15	.09	.54	.26
South Carolina	11	.13	.12	.10	.15
South Dakota	2	.38	.15	.69	.61
Tennessee	144	.28	.12	.20	.27
Texas	117	.41	.09	2.78	.45
Utah	55	.88	.20	5.66	.78
Virginia	2	.54	.23	.12	.09
Washington	194	.33	.12	1.29	.33
West Virginia	14	.53	.14	.16	.....
Wisconsin	13	.65	.17	.96	.58
Wyoming	9	.63	.17	2.25	1.22

In general it will be noted that there are marked variations in chemical composition and that the soils of the arid to subhumid States show considerably larger percentages, especially of lime and magnesia, than those of the humid States, while those of the Southeastern States are usually low in all constituents.

Some peculiarities appear in this table which can probably be accounted for by a variation in the strength of the acid used, by the analyses having been made by different analysts, or by the samples not being representative of the principal soils in the State. For example, the average percentages for Michigan, with the possible exception of magnesium, are very much higher than the surrounding States, although there is no apparent reason why this should be so. The percentages in New Jersey are likewise high, but only two samples were analyzed, and these may represent soils derived from greensand marl.

In pushing this line of investigation other mineralogical and chemical studies have often been very largely neglected, the idea seeming to be that the only important chemical differences consist in a variation in the amount of plant food present, either in "available" or "unavailable" form. In the case of lime it has been clearly demonstrated that while it consists of two of the essential plant-food elements its importance does not depend upon this fact alone, but also upon the various effects which it has upon the physical, chemical, and biological activities which proceed in the soil. It has, therefore, both a direct and an indirect action upon the growth of plants. Because of these various and pronounced influences it is chemically the most important of the mineral soil constituents.

Since it has been definitely shown that the importance of lime is not due entirely or even largely to its satisfying one of the food requirements of plants, it seems very probable that other mineral ingredients, even those which are not considered as essential plant foods, may act in a similar manner, one of the most probable effects being an indirect action upon the higher plants through the medium of lower forms of life.

It is probable that many secondary minerals are formed as a result of synthetic processes. Chemical changes are always taking place, old compounds are being broken down and new ones formed in order to bring about a more nearly stable condition. Many of these changes and conditions are very imperfectly understood. It is certain, however, that differences in the mineralogical and chemical composition of the earthy material have a profound influence in determining the character of the soil and that these must be more clearly understood before definite knowledge of its nature can be secured.

ORGANIC.

While the proportion of organic material in most soils is relatively small, its influence upon the growth of plants is very pronounced. In the form known as humus[1] it is one of the three (lime and clay being the other two) most important soil constituents—one which may often be deficient, especially in the arid and timbered regions. The organic portion of soils, consisting of the remains of plant and animal life, exists in various forms and stages of decomposition, about which very little is definitely known.[2]

The condition in which the organic matter exists is probably of as great, or even greater, significance than the actual quantity. Both the condition and the quantity are dependent largely upon the char-

[1] This term is used rather indefinitely in agricultural literature, sometimes as the equivalent of organic matter. In this paper it will be used as above to denote the black organic matter which gives the dark color to the prairie soils.

[2] See Bulletins Nos. 49, 53, 70, 74, 77, 80, and 83, Bureau of Soils, U. S. Dept. of Agr.

acter of the inorganic portion. The most beneficial form is that of humus, which gives the dark color so characteristic in the black prairie regions. Just exactly what form this is can not now be stated definitely, but that it is different in some way from that either in swamp or timbered soils is not to be questioned. In the swamp soils, which may be as black as the prairie, the dark color is caused by partially decomposed organic matter, due to arrested decomposition as a result of poor aeration, and rapidly disappears under drainage and cultivation. In the prairie soils decomposition has gone much further and the organic product is in a much more stable form. This is shown by the fact that little change in color takes place even after many years of cultivation. In the timbered regions the processes of decomposition are unlike either of the above, and a different character of organic matter is found. This is of a lighter color and in a less humified condition, so that an equal amount does not give as dark a shade as in the prairie soils.

These differences are due to the unlike conditions under which decomposition has taken place, or failed to take place, and will be discussed further in connection with the processes of soil formation.

FACTORS WHICH DETERMINE THE CHARACTER OF THE SOIL.

Since the soil varies so much as regards both its inorganic and organic constituents, marked differences in character must necessarily result from the almost indefinite number of combinations which may be found. All these differences, however, may be traced to two sets of factors: First, the character of the rock or material from which the soil has been derived; and, second, the processes or agencies by means of which this material has been changed from mere rock or rock débris into a medium suitable for the growth of plants. The former has to do with soil-forming material, the latter with soil-forming agencies. To these two groups of factors are to be attributed the numerous variations in soil conditions found over various parts of the earth.

The importance of distinguishing between these two groups of factors can not be too strongly emphasized. The tendency in the past has been to stress the former to the neglect of the latter, and this has resulted in classifying together soils of very dissimilar character, simply because they were derived from the same rocks, or from rocks which have been formed in the same manner. The influence of the rock might be likened to heredity and that of the processes of formation to environment. The character of the soil can no more be determined from a study of the rock alone than that of a man from a study of his ancestors. It is well, therefore, to consider the processes that are concerned in soil formation and the

effects which they have upon its character separately from the influences of the material upon which they are acting and the variations due to this latter cause.[1]

SOIL-FORMING AGENCIES.

Many agencies and processes are concerned in the changing of rocks to soils, but most of these vary with the moisture and temperature, so that these two may be considered as having the greatest influence in determining its character.

Moisture.—The most important agency of soil formation is moisture, not only because of the direct influence which it exerts, but also because nearly all the processes of soil formation vary with the rainfall. Water is nature's great solvent, and regions of heavy precipitation generally consist of lixiviated soils, the more soluble material having been leached out by the carbonated waters. For this reason soils of arid and humid regions are always markedly dissimilar, although they may be formed from identically the same rocks.

A compilation by Hilgard[2] of analyses of the soils of the humid and arid regions not derived from limestones gave the results in the following table:

Average chemical composition of soils of the humid and arid regions.

Region.	Insoluble residue.	Potash.	Soda.	Lime.	Magnesia.	Peroxid of iron.	Phosphoric acid.	Water and organic matter.	Humus.
Humid	84.17	0.21	0.14	0.13	0.29	3.33	0.12	4.40	1.22
Arid	69.16	.67	.35	1.43	1.27	5.48	.16	5.15	1.03

On page 11 is given an average by States of a large number of chemical analyses. An average for the States situated principally in the arid, prairie, and timbered humid regions, respectively, gives the following results:

Average chemical composition of the soils of the arid, prairie, and timbered humid regions.

Region.	Number of Samples.	K_2O.	P_2O_5.	CaO.	MgO.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Arid	318	0.71	0.21	2.65	1.20
Prairie	215	.43	.18	1.09	.51
Timbered humid	743	.37	.16	.41	.37

[1] The purpose in this paper is not so much to go into a discussion of the exact nature of these processes, which has been well done by many writers, but rather to emphasize the differences in the soils which have resulted from variations in these processes.

[2] Soils, by E. W. Hilgard, p. 377.

While the percentages here depart considerably from those quoted from Hilgard they agree in showing a much larger percentage in the arid than in the humid soils.

In the Field Operations of the Bureau of Soils for 1901 are given the "soluble salts"[1] for all the samples of which mechanical analyses were made. An average of the analyses given here shows the following results:

Average percentage of soluble salts in the soils of the arid, prairie, and timbered humid regions.

Region.	Number samples.	Soluble salts.
		Per cent.
Arid	155	0.333
Prairie	12	.048
Timbered humid	200	.013

A mere glance at this table is sufficient to show the much greater amount of soluble material in the soils from the arid regions as compared with those from the humid. The number of samples of prairie soils is not sufficient to give anything like a true average, but shows that the percentage here is between that of the other two.

On pages 87 to 91 of this paper is given a mineralogical analysis of the sand and silt in a number of the most important soil series. An average of the series in the arid, prairie, and timbered humid sections gives the following percentages of minerals other than quartz:

Average percentages of minerals other than quartz in the soils of the arid, prairie, and timbered humid regions.

Region.	Number of samples.	Minerals other than quartz in the—	
		Sand.	Silt.
		Per cent.	*Per cent.*
Arid	30	37	39
Prairie	40	20	29
Timbered humid	160	8	12

This table brings out quite strikingly the difference in soils formed under humid and arid conditions and agrees with the others which show a much larger percentage of soluble matter in the latter than in the former. It shows, also, the more siliceous nature of the sands in the humid region. While other agencies or causes have been

[1] The "'soluble salts' represent the amount of mineral matter, determined by the electrolytic method, calculated as sodium chloride, dissolved when the soil is mixed with 10 parts by weight of water and shaken for one hour at room temperature."

partly instrumental in bringing about this contrast in the soils of the two regions, there is no doubt that it is primarily due to differences in the amount of precipitation, the arid soils being much less leached than the humid.

An unleached or calcareous condition, combined with a sufficient amount of moisture to give a luxuriant growth of vegetation is most favorable to the accumulation of a large percentage of humus. These conditions are found in the transition zone between the humid and the arid regions and here is located the great group of Dark-colored Prairie soils. Few differences in soils are comparable in importance to those between these black soils and the soils of the arid region on the one side and of the more humid on the other. This will be emphasized further when the subject of soil classification is taken up.

Moisture is essential for most of the chemical changes that take place in the degeneration of the rocks. Lack of moisture, therefore, causes a decrease in decomposition and a relative increase in disintegration so that the result is the predominance of mechanical agencies in all sections of deficient rainfall. Consequently, in an arid climate the soils are generally low in clay, while in a humid region a greater amount of decomposition has taken place and a larger number of fine particles have been formed, thus giving rise to soils of heavier texture.[1]

Water is also a very efficient agent of transportation, and in addition to the direct formation of the large group of alluvial soils, may also effect morphological changes by the displacement of the soil particles. By the washing out or down [2] of the finer particles very great changes in the texture may be brought about.

It is very common, therefore, to find marked contrasts in texture between the surface soil and subsoil in regions of heavy precipitation. This is especially pronounced where the material is made up of particles that vary much in size, while it is much less evident where the soil grains are almost uniform. For example, the sandy clays of the Lafayette formation give a very sandy surface soil, usually changing very abruptly into a sandy clay subsoil, while the loess, composed almost entirely of silt, shows very little difference in texture between the surface soil and subsoil. This is brought out very clearly by a comparison of the percentage of clay in the soils and subsoils of the two formations obtained by averaging a large number of mechanical analyses.

[1] Of course, the actual amount of clay present will depend to a large extent upon the character of the rock, but the above statement will hold true for soils derived from similar rocks. If soils are derived from unconsolidated material the contrast will not be so marked.

[2] Most writers lay nearly all the emphasis upon the latter, but according to the author's observations the former is by far the more important.

Percentage of clay in the soils and subsoils of types derived from the Lafayette and Loess formations.

Formation.	Proportion of clay in—	
	Soil.	Subsoil.
	Per cent.	*Per cent.*
Lafayette	8	32
Loess	15	20

The carrying power of water increases as the sixth power of the velocity therefore any factor, like topography, that tends to increase or decrease the velocity will cause a variation in the amount of displacement that will take place. The effect of this is that on level areas the fine material is not removed very far below the surface. As the slope increases so does the depth until the velocity of the water becomes sufficient to carry even the coarser sands, in which case the entire surface material is removed and the heavier subsoil exposed. In this manner very marked variations in soil texture are brought about. The differences in the Orangeburg sand, sandy loam, and clay, which are derived principally from the red sandy clays of the Lafayette, are, for example, due to exactly these processes.

Attention has already been called to the very profound chemical differences which exist between soils in regions of light and of heavy rainfall. Others of almost equal importance, although affecting less extensive areas, may result from dissimilar drainage conditions. This is well illustrated upon the eastern shore of Maryland,[1] where three very distinct groups, or series, of soils have been formed as a result of different drainage conditions. Where good drainage is established the yellow-brown soils of the Sassafras series occur; where water stands practically all the year, the black Portsmouth soils are found; and where intermediate or alternate wet and dry conditions exist the white soils of the Elkton series have been developed.

In the case of the black soils the difference is due largely to an accumulation of organic matter under poor conditions of aeration. In the white soils[2] chemical changes in the mineral matter[3] have been induced, largely through the action of the so-called humus acids. According to Hilgard[4] these reduce "the ferric hydrate to

[1] See Soil Survey of Easton Area, Maryland, by H. H. Bennett and party, Field Operations, Bureau of Soils, 1907, p. 137.

[2] In addition to the Elkton soils just cited might be mentioned the Worsham sandy loam, formed from granites and gneisses, the Guthrie silt loam, derived from limestones, and the Waverly soils, consisting of recent alluvial deposits. Small areas of these white soils have also been seen in the Memphis silt loam, which is a typical Loess formation, while the Marion silt loam might also be considered as of this formation.

[3] Compare mineralogical composition of Sassafras and Elkton soils in the Table on p. 95.

[4] Soils, by E. W. Hilgard, p. 285.

ferrous salts, oxidizing away the humus, and accumulating in the form of inert concretions most or all of the lime, iron, and phosphoric acid of the soil mass." So profound are the changes which may be brought about that almost identical soils may be formed from very dissimilar material and vice versa.

An intermittent wet and dry condition will not give these white soils unless the underlying material is noncalcareous. If the soil contain considerable lime carbonate it will become darker instead of lighter in color, as the organic matter will be changed into humus. This peculiar variety of white soil is seldom found outside of the humid regions, because the conditions necessary to its formation do not exist elsewhere.

The principal effects of moisture upon soils as here emphasized are (1) to induce profound chemical changes (*a*) by leaching out the more soluble mineral matter, and (*b*) by differences in drainage; (2) to influence the amount and character of the organic matter (*a*) by arresting decomposition as in swamps, and (*b*) by small amount of leaching, causing it to assume the very stable form which gives the dark color to the soils of the prairie regions; and (3) to produce differences in the texture (*a*) by variation in decomposition, and (*b*) by mechanical displacement of the particles, especially the finer.

Temperature.—That heat expands and cold contracts is well known. Likewise the fact that different substances have different coefficients of expansion. Since rocks consist of mineral aggregates, each of which has its own ratio of expansion or contraction, changes in temperature will produce such strain upon the rocks as to aid very materially in their disintegration. This effect will be greatest where the diurnal or annual range of temperature is at a maximum. The former is found in desert regions and the latter in northern latitudes.

Since an increase in temperature also increases the solvent power of water, so that a warm, moist region is most favorable to decomposition, the mechanical processes of soil formation are relatively more pronounced in dry and in cold climates. This has an influence upon both the physical and chemical composition. It tends to give to the soils of the warm, humid regions (1) a larger amount of clay, because of the more thorough decomposition, which is essential to reduce the particles to the finest subdivisions, and (2) to cause them to be more thoroughly leached of their more soluble constituents. All other conditions being similar, a region of uniformly high temperature will have heavier (especially subsoils), more lixiviated soils, than a colder region of marked extremes in temperature.

Soils formed by the predominance of decomposition processes are characterized, as a rule, by brilliant, contrasting colorings, which are absent in cold or dry regions, unless they exist in the underlying formations. Red soils, which are almost entirely absent in the northern

and arid portions of the United States, are very frequent in the southern, while in tropical regions red becomes the prevailing color. Where decomposition, leaching, and trituration have gone on to such an extent that the soils are composed almost entirely of silica, they may become very light gray or almost white, especially in the surface soils, where organic matter helps to reduce the iron compounds.

The above changes have taken place largely during the transition from rock to soil, but there are others, either resulting from these or going on in the soil itself, that are probably of equal importance, although most often overlooked. Among these may be mentioned differences (1) in structure and erosion as a result of freezing and thawing and (2) in the amount and character of the organic matter. The latter is in part dependent upon the former.

Freezing and thawing loosens up the soil and gives it a more open, porous structure and better tilth. In northern latitudes the soil is frozen to a depth of several feet, but the depth decreases southward until in the latitude of North Carolina it amounts to only a few inches, while as far south as Florida even the surface is practically never frozen. The effect is more pronounced in the subsoils than in the surface soils, because the latter are loosened up by cultivation, while the former are seldom disturbed by other than natural forces.

It is a well-known fact that erosion is much more pronounced in the South than in the North. This is due in a large measure to climatic influences, of which freezing is one of the most important. In the North erosion is almost entirely prevented by freezing during the winter, while in the South it is very active because of the general absence of vegetative covering at this season of the year. In the latter section freezing and thawing, together with cultivation, loosen up the surface soil to a depth of a few inches, but the subsoil is left in such a compact condition that a rapid rainfall can not be absorbed and must run off, carrying the soil with it. The more open structure of the subsoil in the North, due in a large measure to the deep freezing, allows all or nearly all of the water to be absorbed, especially in cultivated fields, and less erosion takes place. The conditions in the North are favorable to the formation of a sod which protects the surface from washing.

SOIL-FORMING MATERIAL.

While the various processes of soil formation have a profound influence in determining the character of the soil, difference in the rocks or soil-forming material also produces important variations in its nature. When it is recognized that the rocks are not only the source of the inorganic portion of the soil, but also have an effect upon the amount and character of the organic portion, this fact becomes very evident. Because of this relation between the soil and

the underlying rock it has often been asserted that a geological map would answer as a soil map. In some cases the resemblance between the two is very striking, while in others very little or no similarity is evident. A good example of the former may be seen by comparing the soil map of Grainger County, Tenn., with the geological folio covering the same area, while an equally good example of the latter may be seen by reference to the soil and geological maps covering some of the counties on the Eastern Shore of Maryland.

In Tennessee the same geological formation is fairly uniform in character over large areas, although the separate formations are very markedly dissimilar. In Maryland each formation shows considerable variations, though portions may be very similar in character to another formation. In addition, differences in the drainage conditions, with the consequent variations in the soil-forming processes, have resulted in very pronounced modifications in the resultant soils.

Then, again, different geological formations may be identical in mineralogical composition, and, under the action of similar processes, will therefore give rise to similar soils, while the same formation may vary sufficiently in its physical and chemical nature to cause most important changes in the soils. The Tertiary and Quaternary deposits in the Panhandle of Texas, for example, are so similar that they can not be separated, except by the fossils. A lithological map would undoubtedly show closer resemblance to a soil map than a geological, but differences in the processes by means of which underlying rocks are converted into actual soils, as has been already emphasized in this paper, would often produce marked dissimilarities in the maps, even in this case.

Another factor which needs to be emphasized also is that a soil map is based almost entirely upon the character of the surface 3 or 4 feet of material, while a geologist would hardly consider such a layer of sufficient depth to indicate on a geological map. In Tama County, Iowa, the loess mantles the northern portion of the county to a depth of 3 to 6 feet, but is not indicated on the geological map, although shown in the southern portion, where it is deeper and overlies an older glaciation.

In geological classification the fundamental idea is age, in soil classification the character of the material. It may be stated, therefore, that in areas where the processes of soil formation are practically uniform, and the differences in geological formations represent differences in the character, rather than the age of the material, there will be a very close resemblance between a geological and a soil map. Where these conditions do not exist, then no definite relation between the two need be expected and usually does not exist.

It is not intended in this connection to go into a detailed discussion of the numerous kinds of rocks as soil formers, as this more properly

belongs to the detailed description of the various soils, but there are some things which can be discussed to better advantage now than later.

Emphasis needs to be laid upon the point that in soil studies rocks are to be viewed simply as the source of the inorganic portion of the soil and that those differences which are most influential in determining the content of the relatively most important soil constituents, such as lime, sand, and clay, must be given most consideration. Actual differences in character rather than the age or the method of formation of the material should be stressed most. These differences usually represent, and in fact are often the direct result of, variations in the rocks, and for this reason the latter should be carefully studied; but when they do not influence the character of the soil they should be subordinated or entirely eliminated from the equation.

In considering differences in rocks it is well to keep in mind that they are due, as in the case of soils, to two sets of factors: First, the composition of the material out of which the rocks were formed, and, second, the processes of their formation. Both of these sets of factors have had their effect, sometimes one, sometimes the other predominating. Because certain deposits have been formed by the same agency does not necessarily mean that they are similar. Very different rocks may have been formed by the same agency and very similar rocks by a different agency.

Take, for example, the unconsolidated deposits formed by glacial action. These deposits have certain characteristics which distinguish them from those laid down by water, but differences in the rocks which have been ground up by the ice may cause wide variations in the nature of the glacial material. Where the mantle of drift is thin the influence of the underlying rock is predominant. In parts of New England, for example, thin glacial drift on granite gives the Gloucester soils; in the Hudson River Valley thin drift on limestone gives the Dover soils and on slates the Dutchess; in southern and western New York thin drift on shales and sandstones gives the Volusia. Practically all the glaciated section of the United States east of Ohio, and to a less extent west of this State, has only a thin covering of drift.

Likewise alluvial deposits vary with the character of the rocks from which the material composing them has been eroded. A very striking example is found in Texas. The large streams, like the Red, Brazos, and Colorado, which issue from the Permian Red Beds, have red soils along them, while the Trinity and Navasota, which rise in the black waxy lands, are bordered by very black soils. Farther west the Rio Grande and some other streams coming from the arid regions have light-colored, very calcareous deposits within the zone of their influence.

As the alluvial material varies according to the character of the rocks in the country through which the streams flow, or have flowed, the character of all sedimentary rocks will depend more or less upon the nature of the material brought down by the streams at the time of their formation. Of course, the material may have been further modified by wave action, as was undoubtedly the case in most of the deposits of the Atlantic Coastal Plains.

Emphasis has already been laid upon the important part which climatic factors play in soil formation. Their influence is no less evident in determining the composition of many of the rocks, especially those of sedimentary origin. Deposits composed of material brought down from the arid regions contain, as a rule, a much larger percentage of soluble matter than those from humid regions. This is well illustrated in the Tertiary formations of the Coastal Plains. As one passes from Louisiana southwestward through Texas toward the Rio Grande a gradual change in the material is very noticeable. The percentage of other minerals than quartz, as well as the amount of lime and other soluble matter, increases until near the Mexican border conditions very different from those in Louisiana are found. This change is due largely to the fact that the material has been brought from more and more arid regions as one passes toward the Southwest.

Many of the sandstones and shales of the Great Plains region are composed of rock material which, under the arid conditions, was broken up very largely by mechanical agencies, and their mineralogical composition is therefore not very unlike that of the glacial drift which was ground up by the action of ice. For this reason the two formations give rise to almost similar soils, although the rocks are of different origin.

Some of the factors which are considered of much importance from the standpoint of rock classification may be of little or no consequence when viewed from that of the soil. Rocks belonging to widely separated groups and having different names may give rise to very similar or even identical soils. The composition of granite and gneiss, for example, is essentially the same, the distinction between the two being made upon structure and origin. When these are broken down and converted into soil it is usually impossible to distinguish between the resultant products. Fragments of granite or gneiss may be transported and deposited so as to form an arkose sandstone, which upon weathering will give a soil very similar to that derived from the original rock. An example may be seen in the Triassic basin west of Richmond, Va., and also in North Carolina. Better illustrations, however, can be found in the more arid sections, where the breaking down of the rocks is accomplished almost entirely by mechanical

agencies with little change in the chemical composition. Secondary rocks may be formed of this material which will give soils indistinguishable from those derived directly from the original rocks. In this way practically the same type may be of residual, colluvial, sedimentary, or even alluvial origin.

On the other hand, rocks having the same name do not necessarily give rise to the same type of soil, even when the processes of weathering are identical. In the Piedmont Plateau granite sometimes yields a red clay, sometimes a sandy loam with a red clay subsoil, and again a sandy loam with a yellow clay subsoil. The presence or absence of certain secondary minerals or even a change in the proportion of the essential constituents, is largely responsible for these variations, although erosion, by removing the rock material almost as rapidly as broken down, thus lessening the relative effect of decomposition, has often had a decided effect. A small percentage of quartz with a large amount of feldspar and hornblende; or some other iron-bearing mineral, tends to give the red clay, while a binary granite composed of quartz and feldspar weathers into a very siliceous, sandy soil with a yellow clay subsoil. In the case of limestone the impurities largely determine the nature of the residual product, although they may constitute only a very small percentage of the original rock.

Considerable space has been given to this discussion because of a more or less general failure to recognize the importance of many of these factors in arriving at a true conception of the nature, properties, and relation of soils.

CLASSIFICATION OF SOILS.

NEED OF CLASSIFICATION.

From the foregoing discussion it is evident that many influences and factors have been instrumental in giving to the soil its present properties and characteristics. Numerous kinds of rocks or soil material, subjected to the action of so many agencies and processes, with an ever-changing degree of intensity, have resulted in the formation of many varieties or types of soil, related to each other in various ways.

In the study of soils, as well as any other subject which has to do with a large number of individuals, classification is of the utmost importance in order that the various and complex relations may be shown as far as practicable. A complete and perfect classification will give an epitome of our knowledge in regard to any subject. Such, however, can not be made until a thorough understanding of the properties and characteristics of the objects to be classified is had—a condition far from being attained in our present imperfect

knowledge of soils. Much valuable work, however, has been done and the knowledge thus obtained is being used as an aid to further studies. No more fundamental work than the proper classification and correlation of the soils of the country confronts soil investigators to-day, for this information is essential to the final solution of some of the most important questions with which they have to deal. Natural phenomena are always difficult to classify, because the various individuals merge into others by almost or entirely imperceptible gradations. No sharp lines of division exist, and such as are drawn must be more or less arbitrary. This fact is as truly applicable to soils as to any other great group of natural objects.

The need of arranging soils so as to show their relation to one another has long been recognized and some system of classification has been employed whenever the study of the soils of any extensive area has been undertaken. Different investigators, looking at the problem from different viewpoints, have used different bases of classification, each of which presents some important relation. One of the principal difficulties with most systems has been that they are founded upon one group of factors alone, while others of equal or even greater magnitude have been entirely neglected. A satisfactory system must be such that all of the important relations will be indicated, else it will not answer the needs of an enlightened agriculture.

PRINCIPAL BASES OF CLASSIFICATION.

In order to secure as full and clear an understanding of this subject as possible it is well to consider the principal bases, or systems, which have been used in classifying soils. These may be grouped under the following heads: (1) Geological, including (*a*) the age, (*b*) the kind of rock, or lithological, and (*c*) the agency of rock formation, or dynamic; (2) physical, including (*a*) texture, (*b*) structure, and (*c*) color; (3) chemical; (4) vegetation, especially native, or ecological; (5) processes of soil formation, or climatic; and (6) a combination of all these.

GEOLOGICAL.

The geological basis of classification has been used very extensively in many countries and by many investigators. Most of the earlier soil work in this country consisted largely in descriptions of soils of the different geological formations. In France[1] and Japan,[2] especially at the present time, the main soil divisions are based upon the geological formations which are then divided according to physical

[1] See Rapport sur les Cartes Agronomiques par M. Adolphe Carnot, Ministère de l'Agriculture, Bulletin, 1893.

[2] See various maps published by the agronomic section of the Imperial Geological Office of Japan.

characteristics. The geological basis of soil classification has usually been approached from the viewpoint of the age of the material, its mineralogical character or the agency of its formation.

Age of rock.—As most of the earlier work upon soils was done by geologists, and as age is the principal factor upon which geological divisions are based, the classifying of soils according to the geological formation from which they have been derived naturally resulted. Peters,[1] for example, in his work upon the soils of Kentucky, divided them into Silurian soils, Subcarboniferous soils, Carboniferous soils, Quaternary soils, Recent Soils, etc.

The same idea of age is involved in the separation of glacial soils according to the different advances of the ice, as has been done by Hopkins [2] in Illinois and Stevenson [3] in Iowa. The principal reason for this separation is the greater amount of leaching to which the earlier glaciations have been subjected. This does not depend, however, entirely upon the length of time that the material has been exposed. The topography of the country, the permeability of the material, as well as the climatic conditions, have much to do with this also. The geologists themselves are often uncertain as to the time and number of advances of the ice, so that it is not wise to follow these separations very far; too many other factors have relatively so much greater influence upon the nature of the soil.

In general, it might be said that, so far as age has actually produced differences in the soil, it should be given due weight in classification, but when such is not the case it should be entirely ignored.

Kind of rock, or lithological.—As the soil consists very largely of mineral matter formed from the breaking down of the rocks, its nature must necessarily depend to a large extent upon the kind of rock from which this material has come. This has led to the classification of soils according to the kind of rock from which they have been derived. Thus we have granite soils, shale soils, limestone soils, etc., expressive of the relation existing between the rock and the derivative soil.

If the same kind of rock always gave the same kind of soil, and the same kind of soil was always derived from the same kind of rock, this classification might answer all practical requirements. Such, however, is not the case, as was shown in the discussion of the relation of soils to the underlying formation, and while this classification embodies essential features, it is incomplete and therefore in itself unsatisfactory.

Agency of deposition.—Probably the most frequent basis of classification is what is commonly termed "origin," although in this con-

[1] Geological Survey of Kentucky, 1885, vol. 2, p. 160.

[2] The Fertility in Illinois Soils, by Cyril G. Hopkins and James H. Pettitt. Bul. 123, Illinois Experiment Station. See especially soil map and pp. 193–194 and 257.

[3] The Principal Soil Areas of Iowa, by W. H. Stevenson, Bul. 82, Iowa Experiment Station.

nection the term is used with a somewhat restricted meaning. In this system the soils are usually divided into residual or sedentary and transported, according to whether they are derived from the breaking down of the underlying rock or from material which has been transported since it was broken down. The latter are further divided into (1) colluvial, (2) alluvial, (3) æolian, and (4) glacial, according to the agency of transportation.

While the above division has been used by many investigators, scarcely any two agree as to the exact line of separation. Merrill,[1] for example, uses colluvial deposits to "include those heterogeneous aggregates of rock detritus commonly designated as talus and cliff débris," and states that they are "comparatively limited in their extent." He practically confines them to gravitational deposits. Hilgard,[2] on the other hand, says that "when the soil mass formed by weathering has been removed from the original site to such a degree as to cause it to intermingle with the materials of other rocks or layers, as is usually the case on hillsides and in undulating uplands generally, as a result of rolling or sliding down, washing of rains, sweeping of wind, etc., the mixed soil, which will usually be found to contain angular fragments of various rocks and is destitute of any definite structure is designated as a colluvial one." The latter definition is thus seen to be much more inclusive than the former.

Most investigators are agreed that sedentary or residual soils consist of those which are formed in place, but there is a difference of opinion as to what constitutes formed in place. The more common usage is to confine residual soils to those derived from hardened rocks, while those formed from unconsolidated deposits are called transported, and these terms are used in this sense in this report. However, the soils derived from the unconsolidated sandy clays and clays of the Atlantic Coastal Plains are as truly formed in place as those from older consolidated rocks. In a strict sense, only the most recent alluvial soils are transported soils; practically all others are derived from the underlying material, although this may have been previously transported by water, wind, or ice.

Differences in the agencies of transportation of soil material necessarily determine to a certain extent its character and, consequently, the nature of the resultant soil, but differences in the physical, mineralogical, and chemical composition of the material transported, together with changes produced by variations in the soil-forming processes, may so overshadow these, in some cases at least, as to render them almost if not entirely negligible.

This classification takes into consideration only one phase of the origin of soils, the geological, while the biological and climatological

[1] Rocks, Rock-weathering, and Soils, by Geo. P. Merrill, p. 319.
[2] Soils, by E. W. Hilgard, p. 12.

are omitted. In short, it fails to show some of the most important physical, chemical, and biological relations between soils, relations of the utmost significance to the agriculturist, in whose interest any system of soil classification is primarily made.

PHYSICAL PROPERTIES.

That soils differ in physical properties and that these differences have an influence upon the growth of plants has long been recognized by practical agriculturists as well as scientific soil investigators, but it is only within comparatively recent years that the importance of these properties has been appreciated. The work of Whitney, King, and Hilgard has done much to bring about this result. The three most important physical properties to be considered in soil classification are texture, structure, and color.

Texture.—The term "texture" is employed somewhat loosely in soil literature. As used in this paper it has reference to the relative proportion of the different grades or sizes of particles, while structure refers to the arrangement of these particles. The necessity of distinguishing between the two is at once evident. The former remains practically constant, while the latter is continually changing. Every time a field is plowed the structure is changed, and every rain that falls afterwards makes additional changes in the arrangement of the particles. As texture is a property that remains practically constant, it can be used as a basis of classification, but only those differences in structure which are due to the inherent character of the material can be considered.

According to texture, soils are divided into a number of classes, as sand, sandy loam, loam, clay loam, and clay. The number of classes will depend upon conditions. Whenever the difference in texture is sufficient materially to influence plant growth, a separation, if practicable, should be made, although the fineness to which these divisions shall be carried depends upon the amount of detail desired. The five classes just given are the ones most commonly recognized, but in detailed work three or four times this number have to be made. In addition, the presence of stones or gravel necessitates the introduction of stony and gravelly members of the different classes also. There is need of large textural groupings, with subdivision of each group, in order that this classification may be adapted to any amount of detail to which one may wish to go.

The diagram given below shows the distribution of the material as obtained by averaging the mechanical analyses of a large number of soils in the 12 most important soil classes. It does not necessarily represent the most typical distribution.[1]

[1] See Physical Principles of Soil Classification, by George N. Coffey, Proceedings of the American Society of Agronomy, vol. 1, p. 181.

This textural classification is undoubtedly of the very greatest importance, and any system of which it does not form a part can not be satisfactory. On the other hand, the fact that in this system texture is the only factor considered and the further fact that it has

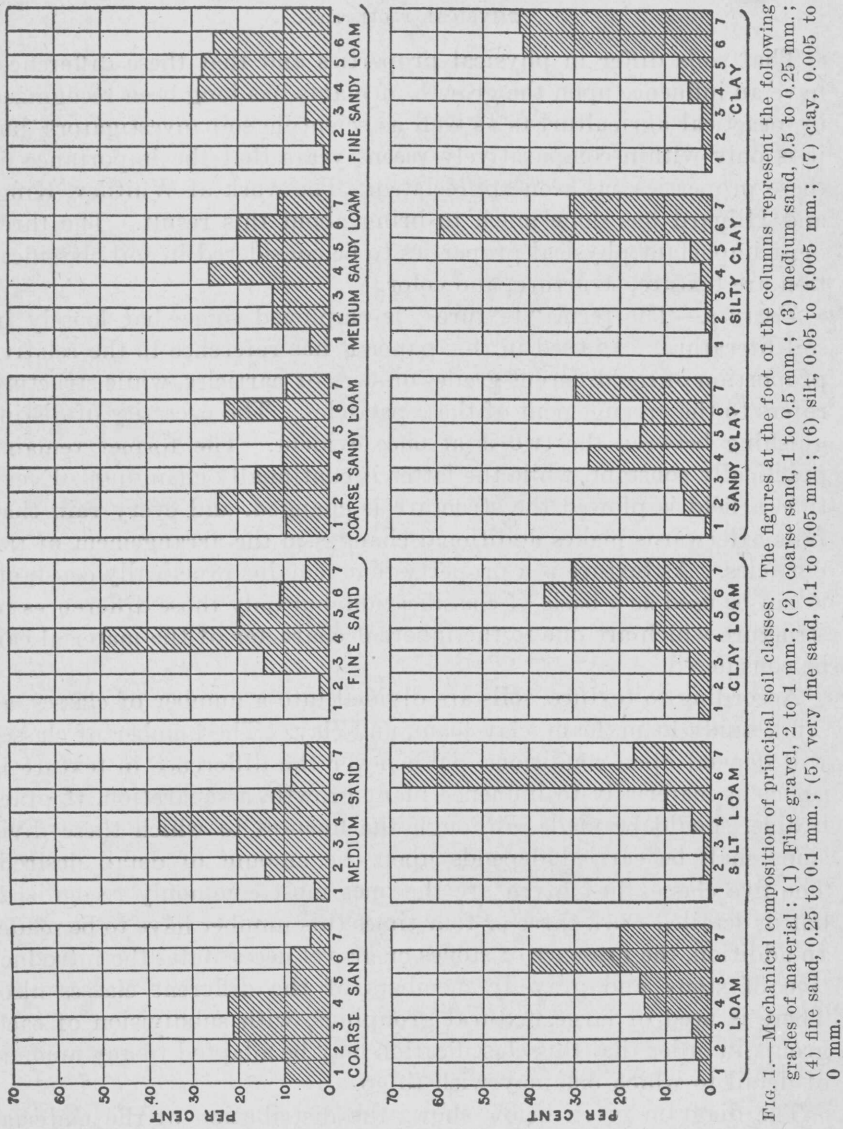

FIG. 1.—Mechanical composition of principal soil classes. The figures at the foot of the columns represent the following grades of material: (1) Fine gravel, 2 to 1 mm.; (2) coarse sand, 1 to 0.5 mm.; (3) medium sand, 0.5 to 0.25 mm.; (4) fine sand, 0.25 to 0.1 mm.; (5) very fine sand, 0.1 to 0.05 mm.; (6) silt, 0.05 to 0.005 mm.; (7) clay, 0.005 to 0 mm.

been found necessary to recognize as many as 50 to 75 types having the same texture, shows that it can not in itself answer all the requirements. The importance of considering other differences besides texture can not be too strongly emphasized.

Structure.—Structure, or the arrangement of the particles, is another very important property of the soil, although one which is really very little understood. Porous or impervious, loose or compact are terms used to express differences in structure. While some of the differences in structure may be so artificial and transitory, like those induced by plowing, that they can not enter into the question of classification, still there are others which seem to be inherent in the nature of the mineral matter and no amount of manipulation can entirely eliminate them. The particles in some soils fit very closely together and good tilth is maintained with difficulty, while in others the arrangement is loose and cultivation easy. Numerous observations prove that subsoils, which shrink and swell a great deal as the result of a change in moisture conditions, are nearly always impervious. The cause of this is probably the presence of a large amount of "colloidal clay." Such differences in structure are easily discernable in the field, and while further study is needed to explain the cause, or causes, they should certainly be recognized in detailed soil mapping.

Color.—Color is one of the most obvious physical properties of the soil, one used by practical farmers as an index to its character from time immemorial. A black color has come to be almost synonymous with productiveness. "Red soils," "gray soils," "brown soils," "white soils," etc., are terms in very common use. In itself color may be of very little importance, but as an indicator of physical and chemical conditions it is of the greatest moment. The practical agriculturist will no more class together soils markedly dissimilar in color than the ethnologist would consider a white and a black man as belonging to the same race.

In judging soils by their color one must always consider to what this color is due, else entirely erroneous conclusions may be reached. In a humid region, for example, a white color is indicative of a soil poor in lime and "available" phosphoric acid as well as of low agricultural value. In an arid region this appearance is often due to the presence of large amounts of lime, and such soils are usually very productive when supplied with moisture.

While color is properly classed as a physical characteristic of the soil, probably its greatest significance is as an indicator of chemical differences. By its use it is often possible to detect differences which the present methods of chemical analysis are unable to explain. When its importance in chemical analysis is considered one can readily understand how valuable a factor it may be in judging of differences in the chemical condition of the soil constituents. In analytical chemistry certain colors are indicative of certain elements or compounds. The same is doubtless true of soils, although the conditions here are so complicated that the assumption may often be impossible of proof.

CHEMICAL PROPERTIES.

A great many chemical analyses of soils have been made and classifications according to the percentage of the different elements of plant food found in them have been undertaken. The mineral theory of plant nutrition advanced by Liebig gave the greatest stimulus to this line of soil investigation.

That differences in chemical composition have a marked influence upon soil fertility is not to be questioned, but no method of soil analysis has ever been devised by means of which the fertility of the soil can be determined with certainty a priori. There are so many factors which have an influence upon the growth of plants besides the mere amount of plant food present that the determination of this alone can never be used as a safe and sure guide to its agricultural possibilities. Even if a method could be devised, only a very small part of the soil in a field can be analyzed, and it is therefore necessary to use other means of distinguishing differences, else there is no way of knowing whether the surrounding soils are similar in character, and unless this is true the chemical analysis would be of practically no value. Chemical analyses may be used in the laboratory as a means of studying the causes of differences in soils, but a practical classification must be based upon those obvious differences which can be determined in the field. For example, one of the most important chemical differences in soils relates to their calcareous or noncalcareous nature. Several laboratory methods have been devised for determining this question, none of which are entirely satisfactory, and Hilgard[1] states that "the decisive feature in this matter must evidently be the native vegetation, which expresses the nature of the land much more clearly and authoritatively than any arbitrary definition or nomenclature can possibly claim to do. A soil must be considered as being calcareous whenever it naturally supports the vegetation (calciphile) characteristic of calcareous soils." It is possible, however, for a soil to be calcareous in the deeper subsoil and noncalcareous near the surface, so that it would support a deep-rooted calciphile and a shallow-rooted calcifuge vegetation. The writer doubts whether a soil should be considered as truly calcareous unless it has a sufficient amount of lime carbonate to give the dark tint to the humus, provided moisture conditions are favorable.

It is nearly always possible for a soil expert to detect, by means of color, origin, native vegetation, or crop growth, the existence of important chemical differences in soils, although he may not be able with our present methods to explain the exact cause or nature of the differences. If they can not be detected by these means they are not usually of sufficient importance to justify giving them consideration in soil classification.

[1] Soils, by E. W. Hilgard, p. 496.

NATIVE VEGETATION.

The most important function of the soil is the support of plant life. The kind of plant life which is found is dependent more or less upon the character of the soil, and this fact has been made use of by some investigators as a basis of classification. One of the most ardent advocates of this basis is Hilgard, who used it in the Tenth Census as the principal foundation for dividing the soils of the Cotton States into broad groups and regions. In his recent book on "Soils" the same author has devoted the entire fourth part to a discussion of "Soils and Native Vegetation." Peters used it to some extent in his work upon the soils of Arkansas and Kentucky, and other investigators have given it more or less attention. Hilgard laid especial emphasis upon the native vegetation. The same principle, however, has been applied in classifying soils according to the crops grown upon them. Thus we have corn soils, cotton soils, wheat soils, pineapple soils, etc. The character of the crop grown, however, depends too much upon economic conditions to use this as a basis of soil classification. A study of the adaptation of soils to different crops is very profitable, and the Germans especially have done much work along this line, but it is more a classification of land than of soil.

There is no doubt that a change in native vegetation is usually indicative of a change in soils, but there are striking exceptions. In many instances where there is a marked difference in the natural timber growth it is possible to find differences in the soils to explain it, but in other instances markedly different soils will show the same character of timber growth. The post and black-jack oaks seem to thrive best upon soils subject to drought. This condition may be found in both deep sands and impervious clays and these trees are found upon both kinds of soil.

It is also a well-known fact that where one kind of timber growth is removed trees of a different genus often take possession of the land. It is a matter of common observation that when fields originally covered with deciduous trees, like the oak, are abandoned, there almost invariably springs up a growth of pine, and this is so common that the tree has received the name of "old-field pine."

A fundamental essential of scientific classification is that it must be based upon inherent and invariable properties of the materials classified. Classifying soils according to native vegetation is therefore going at the matter backwards; it is putting the effect before the cause. It is better to determine the cause of the change in the vegetative covering, and, if found to be due to a variation in the soil, base the classification upon this; otherwise the destruction of the vegetation will destroy the foundation of the system. Vegetation should, therefore, be used as an indicator of agricultural value and an aid in rather than a basis of classification.

CLIMATIC.

That soils formed under arid and humid conditions are essentially and strikingly different in character is clearly recognized by all investigators who have made any study of the subject. As has already been pointed out, this is primarily due to differences in the processes of weathering resulting from the markedly dissimilar climatic conditions, especially moisture, although temperature also has an influence. This contrast in the soils of different climates has led to their classification upon this basis, or, more strictly speaking, upon the differences which have resulted from a dissimilarity in climatic conditions.

While American and other investigators have generally recognized the influence of climatic factors in soil formation, Russian workers, especially Dokouchayev, who is credited with founding a new school of soil investigation, have laid greatest emphasis upon the importance of climate in soil classification. With them it is given first place, because all processes of soil formation or weathering vary more or less with the climate, and therefore soils formed under markedly dissimilar climatic conditions will be very unlike in character. The climatic classification coincides to a certain extent with the chemical and geological classification. According to this classification, the world has been divided into the following "soil zones:"[1]

(1) Laterite soils, or soils of the warm, humid Tropics and Subtropics.

(2) Eolian dust soils, formed in continental regions of dry climate.

(3) Soils of the dry or desert steppes.

(4) Chernozems, formed in connection with herbaceous steppes and prairies of the temperate or cold temperate zones.

(5) Soils of the wooded steppes and of the deciduous forests, resembling the chernozems, but distinguished by conditions of origin.

(6) Peat soils and Podzols, properly soils of a cold temperature. They are typically developed under the mixed forests and are ordinarily accompanied by "ortsteins."

(7) Soils of the tundras, formed upon the clay and sandy tundras.

COMBINATION.

Since all of these viewpoints represent more or less important relations between soils, it is evident that any system based upon one set of factors alone is not entirely satisfactory, and attempts have therefore been made to construct a system by combining one or more of these.

In France, for example, a commission was appointed in 1893 to report upon all matters connected with the making of agricultural maps. This commission[2] recommended that geological maps be

[1] See Etude des sols de la Russie, by N. Sibirtzev, Seventh International Geological Congress, St. Petersburg, 1897. Also Russian Soil Investigations, Expt. Sta., Record, Vol. XII, pp. 704–712 and 807–888.

[2] Rapport sur les Cartes Agronomiques, par M. Adolphe Carnot, Ministère de l'Agriculture, Bulletin, 1893.

used as the basis, and that the variation in sand, clay, lime, and humus of the geological formation be shown by the initial letter of the proper ingredient.

Pagnoul[1] classified soils according to the amount of humus, lime, sand, and clay. They are divided (1) into ordinary soils, having less than 50 per cent of humus, and (2) humus soils, having more than 50 per cent of humus. Ordinary soils are subdivided into calcareous, clayey, and sandy, and a combination of these gives further subdivisions.

In Germany the Prussian Geological Survey has constructed many "Geologisch-agronomischen" maps. In the general description of these it is stated that "the explanation accompanying each colored map contains a geological and an agricultural part. In the latter the weathering processes and the nature of the several soils are described. These are divided into groups according to the chief soil components, and are loamy, sandy, clayey, humaceous, calcareous, etc.

The classification used upon the Japanese maps is based upon geology, which is shown in colors, while the physical characteristics—sand, loam, clay, etc.—are indicated by hatching over the colors. By means of symbols the soils are divided into those "rich in humus" and those "moderately rich in humus." The Japanese classification is therefore much like that of the French and Germans.

As already pointed out, the Russians make their primary classification upon the origin of the soil—not so much the geological as the climatic and organic origin. Taking the origin as the starting point, the classification is elaborated and further subdivisions made according to differences in texture or other physical and chemical properties.

The system of classification used by the Bureau of Soils of the United States Department of Agriculture is founded upon those differences which are obvious in a field examination. In one sense it is therefore largely physical, but many of these differences are due to geological, chemical, or biological causes, and it is therefore proper to say that these factors are also given a place. In fact, all features which have any obvious influence upon plant growth are taken into consideration.

From a study of the soils in various parts of the United States, it has been found possible to divide the country into a number of provinces, each of which contains soils peculiar to itself. This is due to a similarity in the geological processes by which the soil material in these provinces has been formed. Thirteen such provinces have thus far been recognized.[2]

[1] Les Terres Arables du Pas-de-Calais, par A. Pagnoul.

[2] See "Soils of the United States," by Milton Whitney, Bul. 55, Bureau of Soils, U. S. Dept. Agr., p. 27.

Owing to variation in the source of the material or in the processes of weathering, soils may differ in character and appearance, although formed by similar processes. The soils of a given province are therefore further divided into series, which consist of soils very similar in all characteristics except texture. Soils are made up of particles of various sizes or grades, and the relative proportions of the different grades determine the texture. Different divisions of soils based upon texture have thus been established, and the soil series is subdivided into different classes. A combination of the series and class characteristics constitutes a type, which is the unit of soil classification. An example will suffice to illustrate the system:

Province	Piedmont Plateau.
Series	Cecil.
Class	Clay.
Type	Cecil clay.

IDEAL.

The ideal classification would be one in which the individual types are grouped in a number of divisions, each larger grouping representing more and more distant relationships in the soils. Thus in one of the major divisions there would occur no type which closely resembles any soil in any of the other divisions. The working out of such a system in detail would require a complete knowledge of the soil and of the relative influence upon plant growth of the numerous factors which constitute soil differences. Such knowledge is far from realization, if not indeed absolutely unattainable.

In making such a classification it would be necessary to recognize inherent differences in the soil itself as the fundamental idea; to consider it as a natural body having a definite genesis and distinct nature of its own and occupying an independent position in the formations constituting the surface of the earth. The various constituents which make up this bio-geological formation would have to be studied and their relative influence upon ecological relations determined. The major divisions should then represent differences in the most influential of these constituents and further subdivisions made upon those of less consequence.

The task is made more difficult by the fact that the relative importance of the various differences may change with a change in any of the other interdependable factors or conditions. In regions of dry farming, for example, texture is of very great importance because of its pronounced influence upon soil moisture, which is the determining factor in successful agriculture in the semiarid regions. In an irrigated district, on the other hand, the moisture supply is under human control, and texture, therefore, loses its prominent position.

Likewise differences which have a decided effect upon the growth of one plant may have little significance if some other crop be grown. Alfalfa will not do well upon any soil that does not contain a considerable amount of lime, but wheat or corn will grow upon both calcareous and noncalcareous soils, although there is strong evidence to show that the same variety will not produce equally well on both. On account of these and other difficulties, it seems that it will never be possible to construct an ideal system of classification, although it is well to have it in mind and to make our classification correspond as nearly as possible to the ideal one.

GENETIC.

In the first part of this paper it was shown that all differences in soils are due to variations either in the processes of derivation or in the character of the material from which they have been formed through weathering; in other words, to origin in the broad sense of that term. A classification based upon differences due to these two sets of factors may, therefore, be termed genetic. The question naturally arises as to which of these shall constitute the basis for the larger groupings.

In considering the constituents of the soils the great importance of humus, lime, and clay was pointed out, and in view of their preeminent influence in determining the relation of the soil to crops, it is evident that the larger division should represent, as far as possible, differences in the proportion of these constituents. The study of the soils of a large area like that of the United States shows that the percentage of humus and lime, and to a less extent of clay, depends very largely upon the amount of leaching which has taken place, and, therefore, the processes of derivation rather than the character of the material should be used as the basis for the larger divisions. As these constituents vary with the climate, especially the amount of precipitation, the major divisions, while representing variations in the most important constituents, will correspond rather closely to climatic regions. For convenience, therefore, we might say that the primary divisions are based upon climate, although strictly speaking they are based upon differences in the soil which are due to variations in the processes of formation resulting from dissimilar climatic conditions.

Emphasis, however, should be laid upon the fact that differences in climate are of importance in soil classification only in so far as they have produced variations in the nature of the soil. Other factors may come in and intensify or diminish the action of the processes sufficiently to make it impossible to draw the line of division strictly upon the amount of precipitation. In Alabama and Mississippi, for example, the very calcareous and only slightly consolidated nature

of the Selma chalk (Cretaceous) has caused the formation of Dark-colored Prairie soils in a region where the rainfall is approximately twice the average of that in the great prairie belt. In the limestone valleys of the Appalachian region the rainfall is no greater than in Alabama, but the hard nature of the rock makes necessary a long lapse of time for its degeneration, and the lime, which is essential in the formation of the dark prairie soils, is leached out. These Prairie soils in Alabama and Mississippi should be grouped with other Prairie soils, though they lie in a region of much greater rainfall.

Differences in topography and in the nature, especially the texture, of the material will also have an influence upon the amount of leaching that will result from a given rainfall. As these determine almost entirely the amount of moisture which remains in or upon the soil, they bring about marked variations in its character. Constant saturation, for example, will cause the accumulation of organic matter and result in the formation of Black Swamp soils or, in extreme cases, of muck and peat.

While these variations in the processes of soil formation thus give rise to differences in the percentage of lime and organic matter, they also affect other essential, although less important, soil constituents. The best illustration is the large amount of soluble salts found in connection with lime in the arid regions. A grouping of the soils upon differences due to the soil-forming processes, or climatic origin, will not only represent marked contrasts in the important soil constituents—lime and humus—but will also coincide with variations in many other ingredients. As the climatic conditions are generally fairly uniform over extensive areas the major divisions will usually embrace large stretches of country and represent such profound dissimilarities in both soil and climate, which constitute the two parts of a plant's environment, that the variety of crop suited to the soils of one division need not be expected to do well in another.

Upon the above factors or differences the soils of the United States can be divided into a number of divisions, each division being distinguished by soils having certain more or less well-defined characteristics. As the climatic conditions change gradually rather than abruptly from one section of the country to another, the soils of one region will likewise merge into those of an adjoining region, with usually no sharp line of division. In fact, near the boundaries, or where the differences are due to drainage, there may be small areas of one kind surrounded by another. The following divisions may be recognized in the United States: (1) Arid or unleached soils—low in humus, (2) Dark-colored Prairie or semileached soils rich in humus, (3) Light-colored Timbered or leached soils low in humus, although containing considerable organic matter, (4) Dark-colored Swamp or leached soils high in organic matter, and (5) Organic or muck and

peat soils. Of these divisions the last two are of local development, and, therefore, of much less importance than the other three.[1]

While extremely important soil differences, as represented by these major divisions, have resulted from dissimilarity in the process of weathering or climatic origin, other differences due to variations in the character of the material or geological origin, occur within the above division (except peat and muck) so that further subdivisions of these can be made from this viewpoint.

In studying this phase of the subject it will be found that variations here are likewise due to differences in the agency of deposition and in the nature of the material deposited. The first is the basis of subdivision most commonly used in classifying soils, and while a difference in the agency of deposition does not necessarily imply an unlikeness of the material, or vice versa, such is usually the case. A knowledge, therefore, of the agency concerned in the formation of the soil material will aid in reaching a proper understanding of the true nature and properties of the soil. Where these agencies have had little appreciable effect upon the soil-forming material too much stress should not be laid upon them.

According to differences in the agencies or method of formation of the rocks, subdivisions of the major soil groups can be made. The following are suggested: (1) Soils from crystalline rocks formed through the agency of heat and metamorphism; (2) soils from sandstones and shales or consolidated material deposited by physical agencies; (3) soils from limestones formed by organic agencies or as chemical precipitates; (4) soils from ice-laid material (glacial); (5) soils from unconsolidated water-laid material (sedimentary); (6) soils from wind-laid material (æolian); (7) soils from gravity-laid material (colluvial); and (8) alluvial soils representing recent stream material deposited as actual soil.

Not all of the rocks formed by the same agencies or processes consist of identical material, and therefore variation in the soil derived from them is the result. In some cases the difference may be physical, in others mineralogical, and in still others chemical. We may thus have the same material overlying gravel or clay; may have alluvial soils washed from limestones or granite; may have glacial material composed of ground-up shale or limestone; or there may be sedimentary deposits rich in iron, or some other elements, while other deposits will contain these elements in only small amounts. For this reason further subdivision of the soils, even though derived from

[1] Two other divisions might possibly have been added, "alkali" soils, representing an excessive accumulation of soluble salts and semiarid soils or slightly leached surface soils containing considerable humus but having unleached subsoils. As the former can be so readily changed by leaching out the injurious salts it seems best to consider the "alkali" soils as a variation of the arid, while the semiarid constitute a transition from the Arid to the Dark-colored Prairie soils.

rock formed by the same agencies, becomes necessary. These differences are usually more easily detected by color than otherwise, and the division into series might be considered as based more upon this property than any other, although other factors are, in some cases, used also. The soils of a series are similar in all other characteristics except texture. Owing to the fact that very nearly similar soil material may be deposited by different agencies there may be a closer resemblance in two series formed from rocks of different origin than between two derived from rock of similar origin. For this and other reasons a classification based upon difference in the soil itself would be more desirable and some time will doubtless be made.

It has already been pointed out that texture is the most important physical property of the soil. According to differences in this property the series are divided into classes, or into sand, loam, clay, or some intermediate class. In order to bring out the importance of this property of the soil, the texture is made a part of the type name.

There are undoubtedly a large number of soil series, and it is possible in this paper to describe only some of the more representative. In some cases no division of the larger groups into series was attempted.

ARID SOILS.

The distinguishing characteristics of the Arid soils are (1) a large quantity of soluble mineral matter, (2) low content of organic matter, (3) generally gray or light color, (4) deep soils with little change in character with depth, (5) small quantity of clay, especially in the subsoil, unless formed from clay deposits, (6) less siliceous nature of the sand, and (7) marked productiveness when irrigated.

On page 15 is given a table showing that the average percentage of soluble salts in the soils of the arid regions, as determined by the electrolytic method and obtained by averaging the results secured in testing 155 samples, is one-third of 1 per cent (0.333 per cent), or slightly more than twenty-five times the average for the humid region. While the electrolytic method gives only approximate results, the above figures show conclusively and strikingly that the Arid soils have a much larger percentage of soluble salts than the humid. So large, indeed, is the quantity that a constant movement of water from below, and its evaporation at the surface, will result in the accumulation of these salts in sufficient quantity to injure or prevent plant growth, and the soil is then called "alkali."

A marked variation in the quantity of soluble material present is, however, shown by the determinations—five samples (sands) out of 155 falling as low as 0.01 per cent while nine samples were above 2 per cent, the highest containing 5.50 per cent. The lower percentages are probably due to the small amount contained in the

original material or to leaching by river action, while the higher ones represent areas where the salts have been concentrated by the movement of water and evaporation.

The presence of this large amount of readily soluble mineral matter is the result of the processes of formation. As was pointed out in another part of this paper, in an arid region mechanical processes predominate over chemical. The low precipitation precludes much leaching, and the soluble material is left in the soil instead of being carried off by drainage waters. The greatest contrast is in those elements or compounds which go into solution most readily and are therefore leached out in a region of heavy precipitation.

Lime is one of the most soluble as well as important compounds found in the soil. It is abundant in the Arid soils, as may be easily seen by testing with acid, there being very few of these soils which do not have a sufficient amount to effervesce freely with acid. The proportion between the lime content of the soil of the arid and humid regions has been estimated [1] at about 11 to 1, the average for the Arid soils being 1.43 per cent. As this average does not include soils derived from calcareous formations, it is probably too low rather than too high. When we consider the many important effects of lime carbonate, the significance of this large amount can not be easily overrated.

While lime is the most important soluble compound, almost as striking differences exist as regards others. It is not possible, however, in this paper to go into a detailed discussion of this matter, but a very good idea can be obtained from the table from Hilgard given on page 14. It is well to call attention to the much smaller percentage of "insoluble residue" in the Arid soils.

An examination of the sand simply with the eye is sufficient to show the relatively larger percentage of other minerals than quartz present, and from the mineralogical analysis given on page 87 it would seem that these seldom fall below 25 per cent, while the average for the three series (30 samples) is about 38 per cent, which doubtless accounts for the greater productiveness and more lasting quality of the sandy soils of the arid regions as compared with those of the humid.

While the Arid soils are high in soluble mineral matter, they are low in humus; although the nitrogen content of this is about three and a half times that of the humid.[2] The absence of much humus is indicated by the light color of the soils, which would not exist if a large amount were present. The dry, desert condition that usually occurs in the arid regions not only prevents the production of much

[1] Soils, E. W. Hilgard, pp. 377–381.

[2] Hilgard and Jaffa, on the nitrogen content of soil humus in the humid and arid regions. Rept. Cal. Expt. Sta., 1892–1894; Agr. Science, April, 1894; Wollny's Forsch. Geb. Agr. Phys., 1894.

organic matter but also furnishes conditions favorable to the rapid disappearance of that which is formed.

The light color of the Arid soils has just been referred to and is quite general except in cases where the soils are derived from highly colored formations. The characteristic colors are difficult to describe, but are usually some shade of gray. One familiar with the gray soils of the arid and timbered humid regions can usually distinguish between them simply from the appearance. The former show a more even distribution of color, with few or no streaks and mottlings, which are usually due to imperfect aeration. The marked change which usually takes place at a few inches below the surface in the latter is also almost or entirely absent.

Not only is there practically no change in the color with depth but also very little change in texture and other properties. In fact the true soil here extends to a great depth, often several feet. If the surface soil be removed in the humid regions it will be several years before plants will thrive upon the exposed subsoil. In the arid, however, such results do not follow, good crops being secured upon freshly exposed material from several feet below the surface. Recent investigations are showing that bacteria are abundant at depths of several feet in the latter case, while in the former their number rapidly decreases after the subsoil is encountered. In fact, the Arid soils can hardly be said to have true subsoils.

The marked productiveness of the Arid soils when irrigated is too well known to need comment here. It was recognized centuries ago, and some of our earliest and most highly organized civilizations were developed in arid regions. While these soils are rich in plant food their great productiveness is not to be attributed to this alone. Some of the physical and biological factors doubtless play an important rôle also.

Since the distinctive characteristics of these soils are due to the dry conditions under which they have been formed, they will necessarily be confined to regions of low precipitation. The line of division can not be drawn at any particular amount of precipitation, for while this is the most important factor the character and distribution of the rainfall, the evaporation, the topography as affecting the run-off, and the nature of the soil formations have an appreciable influence and may cause considerable variation. In southern Texas,[1] for example, almost typical arid soils were encountered where the mean precipitation is as much as 20 inches or even more, while in North Dakota Dark-colored Prairie soils, producing good crops without irrigation, are found with even less rainfall.

[1] Reconnoissance Soil Survey of South Texas, by George N. Coffey and party, Field Operations Bureau of Soils, 1909.

An examination of a precipitation map will show that the arid soils in the United States will nearly all be found west of the 103d meridian. Nearly all of New Mexico, Arizona, Utah, Nevada, southern Idaho, eastern Washington, and Oregon, eastern and southern California, and southwest Texas, as well as much of Colorado, Wyoming, and Montana have Arid soils.

SUBDIVISION OF THE ARID SOILS.

The soils of the arid region can be subdivided according to the agencies concerned in the origin of the soil material. It seems, however, that these factors do not necessarily produce as marked differences in the soils here as they do in the humid regions, and it is often difficult to see any very great difference between the soils of residual, colluvial, or even alluvial origin. As these soils are of little or no agricultural value until irrigated, and as most of the irrigation projects are situated in the valleys, most of the soils studied in this region are of sedimentary, colluvial, or alluvial origin. The area under irrigation is also comparatively small, so that no very definite knowledge of the soils of a large proportion of this part of the country has been secured. For this reason, and also because the writer has had little opportunity to make personal observations in this section, no further discussion of these soils will be attempted here, although many references to detailed studies are given in the bibliography.

DARK-COLORED PRAIRIE SOILS.

The most prominent characteristics of the Dark-colored Prairie soils are (1) a moderately high content of lime and other soluble mineral matter, (2) a high content of humus or organic matter in the condition which gives a dark color, (3) dark, or what is popularly called "black" color, except where this is masked by red iron oxide, (4) usually sharp and marked contrast, especially as regards color, between the soil and subsoil, and (5) generally high agricultural value.

As the rainfall in the prairie region may be two or three times as great as in the arid the amount of leaching that has taken place is correspondingly much greater and the soils therefore lower in soluble mineral matter. Very few samples were included in the determinations from which the table on page 15 was made up, but those given show an amount between that of the arid and humid. While the number of samples analyzed was insufficient to furnish more than an approximation, the true average undoubtedly lies between the other two. The amount is seldom sufficient to cause an accumulation of alkali. Naturally the percentage of soluble material increases as the border of the Arid soils is approached, while it decreases as the

precipitation becomes greater. In the former section the depth to which leaching has taken place or organic matter accumulated gradually decreases until it coincides with the surface and the Prairie soils[1] change into the Arid. This gradation or transitional condition exists over a considerable belt and might possibly be considered as another soil division.

The Prairie soils are usually well supplied with lime and give an alkaline or neutral reaction. Often, especially in the subsoil, the percentage of lime is sufficient to produce a free effervescence with acid, and is always enough to give the dark tint to the organic matter.[2]

The large amount of humus and the consequent dark color is one of the most striking characteristics of the Prairie soils. Field observations have conclusively shown that a relation exists between this accumulation of black humus and the presence of a considerable amount of lime and moisture. For example, the Selma chalk in Alabama and Missisippi gives a dark-gray to black clay and typical prairie conditions. Whenever there is wash from this chalk into the bottoms the alluvial soils are black also, while elsewhere they are lighter shades of color. East of Madill, in Oklahoma, an outcrop of a thin layer of limestone[3] around a hill can be traced by the darker color of the soil.

If a soil is low in lime, intermittent wet and dry conditions will cause it to turn white and markedly decrease in productiveness, while if lime is present it will become very much darker and an increase in productiveness will take place. Whenever a truly alkaline or calcareous condition exists and a sufficient amount of moisture for vegetative growth is present the soil is certain to have a dark color. Numerous examples could be cited, but a sufficient number have been given to show that the origin of the Dark Prairie soils is due to a relation between the lime, and possibly other soluble material, and moisture. The location of these soils between the unleached Arid soils on the one side and the leached Timbered Humid soils on the other is the very strongest evidence of such relation.

Whether this accumulation of humus is due to lime alone or to the lack of leaching, of which its presence is an indication, has not been definitely determined. Neither do we know whether it is due to chemical or bacteriological action; most probably the latter, an alkaline medium being necessary for the growth of those bacteria or other microorganism which cause this form of decomposition.

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[1] For brevity and facility in expression, the Dark-colored Prairie soils will often be referred to simply as Prairie soils and the Light-colored Timbered soils as Timbered soils.

[2] According to Hilgard the necessary amount varies from about 0.2 per cent in sandy soils to 1 per cent in clay soils. Soils, by E. W. Hilgard, p. 369.

[3] This is mapped in the Tishomingo Folio, U. S. Geol. Surv., as the Bennington limestone.

In order to throw some light upon this question jars were filled with a light-colored loess soil from Illinois. To one jar green pea vines were added; to another the same, with the addition of a large amount of lime; to a third, in addition to the lime and pea vines, some black soil, for the purpose of supplying the proper bacteria. The soil in all the jars was kept moist, or as near in the natural prairie condition as possible. In all of these the organic matter disappeared without any apparent change in the color of the soil. It would seem, therefore, that something more than mere chemical action of the lime is involved. The presence of forms of life inimical to the bacteria which bring about the decomposition of the organic matter may be possible, and a further test with sterilized soil later suggested itself, but there has been no opportunity for trying this.

That the organic matter, or at least part of it, is, however, in a different form from that either in the Timbered or the Black Swamp soils is very evident from field observations, although the exact nature and cause of the difference has not been satisfactorily worked out in the laboratory. In the Prairie soils the processes of decomposition have apparently gone much further, and the dark color is due to a product of this decomposition, while the black color of Swamp soils is due to partially decomposed organic material. The Prairie soils can be cultivated for years without causing any great change in color, while the swamp soils become lighter in color very rapidly, showing that the organic matter is disappearing.

The amount of humus varies considerably, depending upon conditions, the most favorable for its accumulation being plenty of lime and sufficient moisture. The former is found where the underlying formations are very calcareous, and have not been subjected to much leaching, and the latter where the soils are retentive of moisture and have a level topography so as to prevent too rapid surface drainage. Porous soils are usually well drained and aerated, and are not most favorable for a large accumulation, therefore sandy soils usually have less humus than loams and clays. In the transition toward the arid region the lower precipitation causes a decrease in the vegetation and a consequent lighter color of the soils. Since a high temperature accelerates decomposition, other conditions being the same the soils of higher latitudes have more humus than those of lower latitudes. A combination of practically all these favoring conditions is found in the Red River Valley in eastern North Dakota and western Minnesota, and a very large amount of humus is here present.

A high percentage of humus and the resulting dark color causes a marked contrast between soil and subsoil. The zone of darkening depends upon the depth to which the roots of the prairie grasses have extended, and is usually from 12 to 18 inches, being greatest in the more humid sections and poorest drained places.

A dark color is popularly considered as an indication of productiveness and, in general, this is true. Attention, however, must always be given to the cause of the dark color, although in most soils it may usually be taken as indicative of the presence of humus in considerable quantity and in the most beneficial form. As humus is one of the most beneficial soil constituents, the Prairie soils are in general of high productiveness.

The Prairie soils embrace a great stretch of country, extending northward from the Gulf coast of Texas into Canada. They cover a very large percentage of western and southern Minnesota, northern and central Illinois, northern and western Missouri, Iowa, North Dakota, South Dakota, Nebraska, Kansas, western Oklahoma, the northern, central, and Gulf coast regions of Texas, with smaller areas in Louisiana, Mississippi, Alabama, Arkansas, Indiana, Wisconsin, and some other States. Much of eastern New Mexico, Colorado, Wyoming, and Montana represent a transition from these soils to those of the arid region.

An examination of the precipitation map of the United States will show that most of this region has a precipitation of from 15 to 35 inches. The general eastern boundary of the Prairie soils does not follow very closely the line of 35 inches of precipitation, owing primarily to differences in the nature of the underlying formations, although topography has had much influence also. In Missouri and Illinois the line runs in a north-of-east direction, almost coinciding with the precipitation line of 40 inches. After reaching Indiana, however, it turns rather sharply to the northwest, leaves nearly all of Wisconsin to the right and passes near St. Paul in Minnesota, although Wisconsin has less rainfall than Illinois and northern Minnesota as little as eastern Nebraska. The less calcareous and more sandy nature of the glacial material, combined with a morainic topography, do not give as favorable conditions for humus accumulation as do the more level and heavier soils of Illinois and other sections where the line swings so far east.

One of the most interesting and instructive occurrences of Prairie soils is in Alabama and Mississippi. Here the soils are derived from the Selma chalk, and although the annual precipitation is between 50 and 55 inches, a sufficient percentage of lime is present to give them a dark color. The limiting of these prairies to this very calcareous formation is one of the most striking examples and strongest proofs of a relation between lime and the dark color.

The general location of the Prairie soils is shown upon the soil map, but there are many small areas, especially near the boundary of the Timbered soils, which could not be indicated. Sometimes small areas occur far within the timbered regions, the most striking example being that in Alabama and Mississippi just noted.

SOILS FROM CRYSTALLINE ROCKS.

So far as known, practically no areas of Dark Prairie soils derived from crystalline rocks occur in the United States. These rocks do not seem to be favorable to their formation. Near Tishomingo, Okla., a few small areas have been noted, but it is probable that the soil here has been derived in part from limestone, although the granite lies immediately underneath.

SOILS FROM SANDSTONES AND SHALES.

This group includes all Dark-colored Prairie soils formed from the weathering of sandstones and shales. The material composing these rocks was carried into the sea or other bodies of water and later consolidated, only to be again uplifted and converted into soil. The character of this material depends upon the kind of rock from which it came as well as the conditions under which the rock was broken down. In general it may be stated that the more arid the region from which the material came, the larger the amount of soluble matter and the greater the percentage of other minerals than quartz. The attrition during transportation tended to wear out the least refractory minerals, while the chemical action of the water dissolved those more easily soluble. The particles were also assorted, the finer ones being deposited in quiet waters and the coarser ones left where the currents were strongest. These different factors, combined with others which have been active during the transformation from rock to soil, give opportunity for a wide variation in the character of the soils derived from sandstones and shales.

Owing to the influence of these various factors, several different series of soils have been found. Among these the following are the most important in the United States: The Morton, Pierre, Oswego, Summit, Bates, Vernon, and Kirkland series. On the map the Oswego, Summit, Bates, and probably other series could not be shown separately, and these are included in the Kansas group, while the Vernon, Kirkland, and doubtless other series are shown as the Oklahoma group.

MORTON SERIES.

The Morton series includes the dark grayish-brown soils with light-gray to pale-yellow calcareous subsoils. In the more typically semi-arid portions the quantity of humus decreases and the color becomes more a yellowish brown, grading into the arid soils. The subsoils are usually very high in lime, sometimes almost white from its presence.

The soils of the Morton series very closely resemble the Williams soils of the glacial formation, and in the absence of glacial bowlders it is often difficult to distinguish between them. This is doubtless due to the nature of the material composing the sandstone and shales

from which the Morton soils have been derived. They have been formed principally from sandstone and shales of later Cretaceous age, chiefly the Laramie. The material composing these rocks was doubtless brought from the more arid regions to the west, where the original rocks were broken down largely through mechanical agencies, and therefore the material composing them resembles in character the glacial material which was ground up by the mechanical action of the ice. An examination of the sand shows it to contain a relatively large amount of minerals other than quartz. Being formed from disintegrated rather than decomposed rock material, the soils of both series have many similarities.

The most common class or texture in the Morton series is the silty loam to silt loam, while the fine sandy loam is next in extent. Only very small areas of stony loam, sand, clay loam, and clay have been encountered. A peculiar condition consisting of bare spots with a compact soil, locally called "gumbo flats," is a feature of the areas where the Morton soils occur.

The Morton soils are found chiefly in southwestern North Dakota, eastern Montana, and Wyoming, and northwestern South Dakota.

The topography is that of a gently rolling plain in which streams have carved out channels with considerable broken land along them. Buttes, sometimes rising as high as 500 feet above the surrounding plain, are a rather common feature of the landscape.

PIERRE SERIES.

Stretching along the west side of the Missouri River in South Dakota and extending westward to and around the Black Hills, like the prongs of a great Y, is an area of dark to slate-colored clayey shales which give rise to the Pierre series. This series consists of dark-brown to yellowish-brown surface soils underlain by gray to yellowish-brown subsoils. The heavier or clay member predominates, causing the section where this series occurs to stand out in marked contrast to the surrounding country of lighter textured soils. The Pierre clay is extremely sticky and is locally known as "gumbo." It occurs in quite large areas and constitutes one of the most extensive developments of heavy soils in the United States. Considerable areas of loam, silt loam, and silty clay loam also occur. The soils are derived from the Pierre and Graneros shales, principally the former, but some of those of lighter texture have probably been influenced by later deposits.

KANSAS GROUP.

In central and eastern Kansas, western Missouri, and northeastern Oklahoma the Carboniferous and Cretaceous shales form the surface rock and give rise to several series of soils different from either of

the two already described. These have been included in the Kansas group. They consist principally of silt loam and silty clay loams with compact "tight" silty clay or clay subsoils. Over the greater proportion of the area covered there is a very distinct line of demarcation between the surface soils and the subsoil, and this is one of the chief characteristics of this group. This is least in evidence in central Kansas, but very pronounced in the southeastern part of the State.

It so happens that the rocks to the southeast are not only older, thus subjecting them to leaching for a longer period, but are also in a region of greater rainfall. In addition, it seems that the material composing the rocks in the central part of the State has been brought from more arid regions and subjected to less attrition and leaching in the processes of deposition and degeneration. Some beds of shales are more calcareous than others, and where this is the case the soils are darker in color and more productive. In the extreme southeastern part of Kansas the Cherokee shales give a light-colored soil, which is really more like the Timbered than the Prairie soils, although originally prairie. It closely resembles the loess soil (Marion silt loam) of southern Illinois, while the dark-gray soil (Oswego silt loam) is very much like the loess soil (Putnam silt loam) in northern Missouri and southern Iowa, as well as the Crowley silt loam of Arkansas and Louisiana.

Three series have been recognized in the Kansas group: First, the Oswego, with gray to dark-gray, rather floury surface soils and very heavy impervious mottled-gray or yellowish subsoils; second, the Summit series, with dark-gray to black soils and heavy mottled subsoils, derived from calcareous shales; and third, the Bates series of dark grayish brown soils, with porous yellowish subsoils.

OKLAHOMA GROUP.

The rocks from which the soils of all the above series are derived are gray, light brown, yellowish, or sometimes black, with almost a total absence of red, and the soils are characterized by a general similarity in color, but in south-central Kansas, western Oklahoma, and north-central Texas occurs a large area of generally red sandstones and shales, commonly known geologically as the Red Beds, which give rise to a group of soils of strikingly different color. These rocks are known to underlie a large proportion of the Great Plains and in addition to the area mentioned have, through uplift and erosion, been exposed along the eastern front of the Rocky Mountains and in the Black Hills. They usually contain beds of gypsum and are sometimes called gypsiferous Red Beds.

In some cases the immediate surface soil is a decided red and it varies from this to almost black. Sometimes the subsoils are not very

red, but the deeper subsoils are practically always so. Upon this difference in color it is possible to separate the soils into at least two series, the Vernon and the Kirkland.

The Vernon series consists of reddish-brown to red soils with red subsoils. In texture they are principally fine sandy and silty loams with smaller areas of sand and clay. The structure in both soil and subsoil is loose and this makes them easily eroded, and deep gullies are a characteristic feature.

The Kirkland series has dark-brown soils with brown or yellowish-brown subsoils grading into red within a few feet of the surface. The texture is generally heavier than in the Vernon series, silt loams and silty clay loams predominating, and the structure of the subsoils is closer and less porous.

SOILS FROM LIMESTONES.

Limestones are not so extensive or important in the prairie as in the timbered region. The contrast between the soils of this and other formations is not so marked because practically all the Prairie soils are calcareous. The line of separation between the limestone soils and those derived from the unconsolidated calcareous deposits of the Gulf Coastal Plain is very arbitrary, as the material from which some of the latter soils is derived might be classed as a soft limestone.

The principal development occurs in the country west of Fort Worth, Waco, and San Antonio, Tex., but narrow bands are found in other sections, especially in central and eastern Kansas and west central Missouri, where thin beds of limestone alternate with the shales. The latter areas can only be shown in a detailed survey, but those in Texas are sufficiently extensive to be indicated on the accompanying map.

Not very much study has been made of these soils. The principal types so far observed are included in the Crawford series, which consist of dark or chocolate brown soils with reddish subsoils. Only the heavier classes of the series are present, the silty clay loam and clay being most common. The areas are generally characterized by frequent outcrop of the limestone and in the more broken areas stones are quite numerous on the surface, while the rock in many places is only a short distance below.

In central Kansas the limestone layers which occur in the Benton group give rise to the Benton series which has almost white and very calcareous subsoils. The areas are small, the surface rather broken, causing the white subsoils to be often exposed.

SOILS FROM ICE-LAID MATERIAL (GLACIAL).

One of the most important groups of Prairie soils includes those derived from deposits of drift laid down by the great continental ice

sheet. This material consists of a great variety of rocks ground up by the action of the ice and mingled in a very heterogeneous mass. The general movement of the ice was from the north and much of the material has therefore been transported far south of where the rocks are found in place. As the rocks have been broken down by mechanical action and have since undergone little alteration, the particles are usually sharp and angular and consist, especially in the sand, of a relatively large percentage of other minerals than quartz. There has also been little assorting of the particles by water action, so that a great variation in size, from large bowlders to the finest clay, is often represented. Owing to this commingling by the ice and the small amount of decomposition which has since taken place, no true clay soils are formed from the glacial drift. Little washing down and out of the finer particles has been effected and, therefore, little difference in texture of soil and subsoil exists, 75 samples giving an average of 15.9 per cent of clay in the soil and 19.2 per cent in the subsoil.

The glacial Prairie soils are high in humus, the amount being greatest in the more humid portions and in those of heaviest texture and in areas of level topography and poor drainage. In passing westward to the semiarid regions the percentage, as well as the depth to which the organic matter extends, decreases.

The color is dark grayish brown to black, depending upon the amount of organic matter present. The subsoils are much lighter in color and are usually a pale yellow, gray, or light brown.

In the more humid portions quite a little leaching has taken place, but generally the soils are fairly well supplied with lime, and many will effervesce freely with acid, especially in the subsoils. In western North Dakota and Montana the amount of lime is much larger, and the subsoils here are almost white from its presence. While this greater amount here is due in part to the less leaching under semiarid conditions, there was doubtless more in the original material also, as the rocks, which were ground up by ice in this section, had likewise been subjected to less lixiviation. This difference has been deemed sufficient to justify the separation of the soils into two series—the Carrington [1] and the Williams. The former includes the soils which have the least lime and other soluble material, but a rather larger amount of humus.

One other striking feature of the glacial Prairie soils is the relatively large percentage of loams and the absence of true clays. Nothing heavier than a clay loam has been encountered, while the percentage of sands and sandy loams is not very large. This is due, of course, to the method of formation. Where the drift has been modified by water action or was laid down largely by this agency,

[1] In nearly all the Soil Survey reports these soils were mapped as Marshall.

sandy and gravelly soils are usually formed, but the area where this has taken place is relatively small, much smaller than in the glaciated Timbered soils.

The surface features are those of a rolling prairie, with somewhat broken country along the streams and sometimes billowy ridges where the ice deposited its load in terminal moraines. In some sections, especially in areas of later glaciation, lakes form a pleasing feature of the landscape.

SOILS FROM WIND-LAID MATERIAL (ÆOLIAN).

IOWAN OR LOESSIAL GROUP.

Usually associated with and in many respects closely resembling the glacial Prairie soils are those formed from the loess. Mineralogically and chemically, the material is very much the same, consisting in both cases of ice-ground rock débris. In the case of the loess, however, there has been an assorting and redistributing of the material by the action of wind and water.

The origin of the loess has been a very puzzling problem, one which has provoked a great deal of discussion. Some attribute its formation to water action, others to wind, while still others believe both agencies were concerned. Most geologists now agree that the last is most probably true. From personal observations in practically all sections where it is found in this country, the writer believes that it represents rock material broken down by the ice, assorted by water and in most cases distributed by wind.

It is not intended to go into a discussion of this subject here, for this has been done by other writers, but there is one point which does not appear to have been sufficiently emphasized, to which attention might be directed, and that is the influence of the seasons. During the summer the streams flowing out of the ice-covered regions must have been greatly swollen and consequently flooded all the lower lands along them and deposited the silts washed out of the drift. As colder weather came these floods subsided, leaving the silt, without any vegetative covering, exposed to the wind, which swept it upon the adjoining uplands. This process was repeated each year and supplied a sufficient amount of material to cover large areas of the uplands. Evidence of this is seen in the widening of the belt of "bluff" loess along the Mississippi in Illinois opposite the larger bottoms.

The loessial Prairie soils are most extensively developed in central and western Illinois, eastern, southern, and western Iowa, northern Missouri, eastern and southern Nebraska, and northeastern and northwestern Kansas. Smaller areas are found in Indiana, Wisconsin, Minnesota, and the Dakotas.

Owing to the great uniformity in the size of the particles, the loessial Prairie soils are all silt loams. They are usually extremely

uniform in character over large areas, so that it is possible to show types even on a small-scaled map. Three main types have been recognized—the Marshall silt loam, the Putnam silt loam, and the Colby silt loam.

The Marshall silt loam is one of the most extensive, most uniform, and most productive soils in the United States. It consists of a dark grayish-brown to black rather heavy silt loam about 18 inches deep, underlain by a pale yellowish, often slightly mottled, porous silt loam subsoil. In northeast Kansas and eastern Nebraska the subsoil is slightly heavier than elsewhere, owing probably to longer weathering as the result of greater age. It is much more extensively developed than either of the other types, covering a very large percentage of central and northwestern Illinois, parts of Iowa, especially the western, northwestern Missouri, northeastern Kansas, eastern Nebraska, with a small development in some other sections.

In southern Iowa, northern Missouri, and to a much less extent in some parts of southern Illinois, a different kind of loessial Prairie soil occurs; in fact, it is so different that there is some doubt as to whether it should be classed as a loessial soil. This has been called the Putnam silt loam.[1] It consists of a dark-gray silt loam with stiff, impervious, brown to drab mottled silty clay subsoil. A white silt layer is often present between soil and subsoil. This type closely resembles the Oswego silt loam derived from shale and the Crowley silt loam of the Gulf group derived from unconsolidated marine deposits.

Being formed from a pebbleless layer over the glacial material, it is classed with the loess. The peculiar nature of this material is probably due in part to the character of the rock débris, which here constitutes the loess, and in part to weathering as a result of long exposure to these agencies. In Illinois it is clearly due to a thin deposit of later loess over the older loess giving rise to the Marion silt loam. Much of the country where it occurs has drainage well established and the streams have cut through into the underlying glacial drift, which here gives rise to the soils of the Shelby series.

In southwestern Nebraska, northwestern Kansas, and eastern Colorado the loess extends westward into the semiarid region, and the difference in climatic conditions has produced sufficient difference in the soil to necessitate its separation here into the Colby silt loam. The surface soil resembles the Marshall silt loam, but is not so deep, nor so dark in color, is lower in humus but higher in lime. The chief distinction, however, is in the subsoil, the Colby silt loam being very calcareous and mealy because the material has undergone practically no weathering. This type really represents a transition toward the Arid soils.

[1] Mapped in earlier soil surveys as Shelby silt loam.

SOILS FROM WATER-LAID MATERIAL (SEDIMENTARY).

Over a considerable proportion of the prairie region the surface formations consist of unconsolidated deposits formed through the action of water. While the material has been deposited by water, the soils differ from those found in the river bottoms in that they have been derived from the underlying material through the processes of weathering instead of being laid down as actual soils.

In the northern portion of the prairie region these deposits consist principally of lacustrine sediments, in the Great Plains section of old alluvial fans or débris aprons, and in the Coastal Plain of marine sediments. Because of the difference in the character of the material, the soils have been divided into three groups, the Red River Valley group, the Plains group, and the Gulf group.

RED RIVER VALLEY GROUP (LACUSTRINE).

Lakes are of very frequent occurrence in the glacial region, especially in sections where drainage is still immature. During the melting and retreat of the ice these lakes were not only much more numerous but covered much larger areas. Glacial material was carried into them and deposited as lacustrine sediments. Many have since become drained and from these deposits have been formed the Red River group of glacial-lacustrine soils.

These soils are closely related to the glacial Prairie soils, the difference being due largely to the assorting of the sediments by water rather than to any marked dissimilarity in the character of material. There is usually much less heterogeneity in the size of the particles and some very heavy clays occur in this formation, while they are entirely absent in the glacial. The topography is generally much more level; drainage is therefore poorer and the amount of humus greater.

The soils contain a large amount of organic matter, have a decided black color, and are very calcareous, especially in the subsoils. Except where incoming streams have formed sandy deltas, the greater proportion of the valley soils are of heavy texture, consisting of silt loam, silty clay, and clay. Most of the soils have been included in the Fargo series. Around the border of the valley very little material was deposited and the principal action of the lake consisted in smoothing the surface, and here are somewhat different soils. It is often possible here to bore through the lacustrine deposits into the underlying drift.

While the Red River Valley in eastern North Dakota and western Minnesota contains the most extensive development of these soils, they are found in smaller areas scattered throughout the glacial prairie region from Indiana westward.

PLAINS GROUP (AGGRADATION).

Throughout a large proportion of the Great Plains region south of the Black Hills the surface material consists of slightly consolidated deposits of Tertiary and Quarternary age. These deposits are characterized by a light almost white color and usually by a very large amount of lime. In the northern extension they are distinctly stratified, as may be seen in the "Big Bad Lands" of South Dakota, but farther south they are made up of irregular beds of gravel, sand, silt, and clay. The stratification in the older, more northern extension gives undoubted evidence of deposition in water, probably lakes, but the central and southern portion represents a great débris apron which has been spread over the plains through the action of streams. As a result of tilting or a change in climate, these eastward flowing streams were unable to carry their load of sediments and therefore filled up their channels and sought new ones. The coarser material was dropped where the currents were strongest, while the finer particles were deposited in more quiet interstream areas. In this manner a great series of aggradation deposits was built up, from which the plains group of soils has been derived.

Owing to the subhumid to semiarid conditions under which the soils have been formed from these deposits, little leaching has taken place. The zone of weathering has not extended much below 2 feet, being deeper toward the more humid eastern portion and shallower toward the drier western portion. The amount of humus is also greatest toward the east and the soils therefore darker.

Several different series can be recognized, among which the Rosebud, Richfield, Greensburg, Pratt, and Amarillo are the most important.

The Rosebud series consists of dark-gray to brown surface soils, with light-colored, almost white, very calcareous subsoils. One of the most characteristic features of this series is the almost white or pale flesh color of the deeper subsoil. Because of the ease with which this material erodes, the more hilly areas especially are dotted with bare white spots, and in extreme cases large areas of "Bad Lands" have been formed.

This series is formed chiefly from the White River and Arikaree formations of the Tertiary and occurs principally in southwestern South Dakota and western Nebraska. The former is generally silty and gives rise to the silt loam, which is the most important member of the series, or to occasional areas of silty clay loam and clay. The fine sandy loam covers considerable areas, especially where the Arikaree formation constitutes the surface.

The surface soils of the Richfield series are very much like those of the Rosebud, but the subsoils are more of a pale yellow or gray color. They occur principally in southwest Kansas and adjoining

portions of other States. The principal type is the silt loam, which covers large uniform stretches, but considerable areas of sandy loams and silty clay loam are also found. The silty clay loam covers nearly all of Morton County, Kans., extending southward into the Panhandle of Texas.

As the formations which give rise to the Richfield series extend eastward into Kansas they become less calcareous, and have been more deeply weathered. Where this condition exists the soils contain more humus and are included in the Greensburg series, of which the silt loam is the only member of any importance. The most eastward extension and the oldest formations of the Tertiary in Kansas are only slightly calcareous and have a reddish tinge or color. These deposits have given rise to the Pratt series, which is characterized by dark or chocolate brown soils with reddish subsoils. Considerable areas of the sand; coarse sandy and gravelly loam; loam, and silt loam are found. The cause of the reddish color in this section is not entirely clear, but since the Red Beds underlie a large proportion, it seems probable that they have contributed a sufficient amount of material to produce this effect.

Principally on the High Plains in northwest Texas and the adjoining portions of Oklahoma and New Mexico occur the soils of the Amarillo series. This series consists of chocolate-brown to reddish-brown soils with reddish-brown to red subsoils, grading usually at less than 3 feet into an almost white or pinkish white very calcareous substratum. This calcareous substratum constitutes the most obvious difference between the Pratt and Amarillo series. The former, however, is hardly as red as the latter, especially in the sandy members. The series consists of sands, sandy loams, loam, and silty clay loam. The last is by far the most extensive, covering practically all of the Llano Estacado, or Staked Plains, as well as large areas of the High Plains north of the Canadian River. The sandy soils are found principally in the latter locality and are well developed around Dalhart, Tex.

In the case of the Amarillo soils the red color has apparently been developed in weathering. The occurrence of these reddish soils in this section is probably due to a reworking and admixture in the Tertiary deposits of material from the Red Beds. An examination of a geological map will show that these beds form the surface over a considerable area to the west, through which the Canadian River flows, but similar conditions are not found northward in the Cimarron and Arkansas drainage. It seems very probable, therefore, that material was washed from these Red Beds and transported eastward by the Canadian River to form a part of the deposits from which the Amarillo soils have been derived and that the reddish color is due to this cause.

GULF GROUP (MARINE).

In the Gulf Coastal Plain, particularly in Texas, occurs a series of unconsolidated or slightly consolidated calcareous clays, marls, and chalks, ranging in age from Upper Cretaceous to Pleistocene. These deposits give rise to another very important group of soils to which the name Gulf is applied.

The group may be divided into several series, the two most extensive and characteristic being the Houston and the Victoria. Where the calcareous deposits, from which these have been derived, grade into the Timbered soils some transitional series occur but these are of limited extent.

The soils of the Houston and Victoria series are very similar in character, and the separation is based largely upon topography, the former being rolling, while the latter is almost a dead level. The Houston series is situated in the inner portion of the Coastal Plain and the Victoria in the level coast country.

The most characteristic member of both series is the black clay or "black waxy land," so called because of its very sticky nature. The Houston black clay covers quite a large stretch of country, extending almost continuously from east of Paris, Tex., to beyond San Antonio. The Victoria clay occupies large disconnected areas in the coast country between Houston and Kingsville, Tex.

These black clays are very much like the Fargo clay of the Red River Valley group. One interesting feature of these clays, especially in the less humid southwestern extension, is the pitted surface on account of which they are often called "hog-wallow land." These depressions are seldom more than a foot deep and 3 or 4 feet across and are due to deep intersecting cracks, which allow the surface material to drop in, causing the formation of saucer-shaped hollows.

In some places the texture becomes lighter and areas of loam occur. The Houston fine sandy loam is of very limited extent, but the Victoria covers rather large areas.

In Alabama and Mississippi occur two belts of calcareous deposits which give rise to the Houston clay. While this soil is very dark in color compared to those with which it is associated, it is not so black as the Houston black clay. The difference is in part due to greater erosion under the heavy rainfall in the more eastern States.

Coming eastward from Texas into Louisiana, the coastal deposits become less calcareous, and although some prairies occur the soils are not so dark in color and the subsoils are more impervious. They represent a transition toward the Light-colored Timbered soils and in fact, the areas on the may really include a considerable percentage of Timbered soils. The texture here is also more silty, owing probably

to an admixture of loessial material brought down by the Mississippi River when these deposits were laid down. One of the most important soils is the Crowley silt loam, areas of which occur in southern Louisiana and in Prairie and Lonoke Counties, Ark. Others have been mapped as Edna and Lake Charles fine sandy loam and loam. A characteristic of these last soils is the presence of sand mounds.

ALLUVIAL SOILS.

Along all the streams in the prairie regions, and also along those which have come from these regions, occur strips of alluvial soils which have been deposited during periods of overflow. The alluvial soils include what are popularly known as bottom lands. While they are very widely distributed, they usually occur in such narrow strips that only a few of the largest can be shown on the map. The most extensive development is found along the Mississippi River from the mouth of the Ohio to the Gulf.

Although part of the soils in this area have a light color and contain a relatively small percentage of humus, in general the color of the soils is dark gray to black, depending a good deal upon the texture. Where this is sandy, the color is usually not so dark as in the heavier soils, owing to the more favorable condition for the accumulation of humus in the latter. There is usually very little change in color with depth because the material was laid down as actual soil and therefore contains much humus several feet below the surface.

An exception to the almost black color of the alluvial soils of the prairie regions is found along those streams which run through the Permian Red Beds, and have reddish-brown to red soils along them. The principal streams are the Canadian, Red, Brazos, and Colorado. So pronounced has been the influence of these Red Beds that the Miller soils, as these red soils are called, follow these streams all the way to their mouth. The Miller soils are very calcareous, contain a considerable quantity of humus and are exceedingly productive.

The texture of the alluvial soils depends primarily upon the velocity of the current at the time of deposition, but is also influenced by that of the surrounding uplands. For example, all the streams where the Houston black clay constitutes the uplands, have a heavy black clay (Trinity clay) along them, but where the upland is covered by the Marshall silt loam, as in much of Illinois, the bottoms also consist very largely of silt loam, although the streams have about the same fall in both cases. In general, however, it may be stated that the swifter the streams, the coarser and more variable the texture. The coarsest particles are always deposited nearest the banks of the stream, while the finer ones are carried into the quiet back waters. Clay being the only particles which will remain suspended

in quiet water for any length of time, the heavy soils are usually found next to the uplands, while those along the immediate banks are nearly always sandy. Large streams like the Mississippi River never deposit soils of coarse texture because the velocity is not sufficient to carry particles much larger than fine sand. Such streams, however, are practically the only ones which deposit very fine sandy loams, the velocity being just about the rate to carry particles of this size (0.1 to 0.05 mm.)

Usually these bottom lands are timbered, but since the soil has come from the prairies and as most of that shown on the map has the characteristics of the Prairie soils, they are included with them.

LIGHT-COLORED TIMBERED SOILS.

The light-colored soils of the timbered region have certain characteristics which distinguish them from those of the two regions already described. The most striking of these are (1) a lower amount of readily soluble mineral matter, including the important constituent lime, and a consequent large percentage of silica; (2) a moderate amount of organic matter, but a low percentage of black humus; (3) generally light color; (4) shallow surface soil with rather marked line of separation, especially as regards texture, between this and the subsoil; (5) native vegetation generally timber; and (6) lower average productiveness.

The heavy precipitation that occurs in this region leaches out a large percentage of the soluble salts, so that the soils are comparatively low in these substances and generally nonalkaline or "acid" in character. So great is the amount of leaching which has taken place that even the soils derived from limestones are deficient in lime or at least give a nonalkaline reaction. Brown[1] shrowed this to be true of the limestone soils on the experiment farm at State College, Pa., and the failure of the soils in other sections to give the dark tint to the humus is, in view of the relation which has been shown to exist between lime and this color, very strong evidence of the nonalkaline nature of even the limestone soils throughout the timbered regions. This is especially true as regards the surface material where the decay of the organic matter by the formation of carbon dioxide greatly aids in the leaching out of the lime. This process has not gone on so rapidly in the subsoil which sometimes has sufficient lime to effervesce quite freely with acid.

Since quartz is the most refractory toward purely chemical agencies of all ordinary mineral constituents, and since decomposition processes are relatively much more pronounced in humid than in arid regions, the soils of the former are relatively high in silica. In

[1] Annual Report Pennsylvania State College 1907–8, Part II, p. 45.

the case of the sands this may be readily seen from an examination with the aid of the eye alone, the grains consisting very largely or almost entirely of quartz. This is especially true where the sands have undergone much abrasion as in the South Atlantic Coastal Plain and least so where crystalline rocks have been ground up by ice. In the former case the quartz may constitute as much as 99 per cent, as may be seen by reference to the table on page 90.

In the table on page 15 the amount of "soluble salts" in the humid soils, according to the electrolytic method, was 0.013 per cent as compared with 0.333 per cent in the arid region. This shows that a large amount of material has been carried away. According to Merrill[1] "among siliceous crystalline rocks, this loss, so far as shown by available analyses and calculations, rarely amounts to more than 50 per cent of the entire rock mass. Among calcareous rocks, on the other hand, it may in extreme cases, amount to even 99 per cent." The amount of "insoluble residue," as shown by Hilgard in the table quoted upon page 14, is for the humid soils 84.17 per cent while for the arid soils it is 69.16 per cent.

Not only are these soils relatively low in soluble material, including the very important constituent lime, but this fact has had a very profound influence upon the amount and character of the organic matter they contain, as has already been pointed out in connection with the Dark Prairie soils. The failure, however, of soil investigators to recognize the importance of this matter justifies further emphasis here. In fact, the subject is one which needs to be studied very carefully and furnishes a very fertile field for further investigations. Probably new methods will have to be devised before very great progress is made. A statement of some field observations may be of assistance in pointing out lines along which these studies should be undertaken.

A determination[2] of the amount of organic matter in the Light-colored Timbered soils and the Dark-colored Prairie soils does not always show as marked a difference as one would expect from the great dissimilarity in color. An average of 150 samples from each section showed 1.64 per cent in the former and 3.56 per cent in the latter, the average being 2.60 per cent. Forty-five of the Prairie soils fell below the average and 24 of the Timbered soils above. In some instances, the percentage in a light-colored soil[3] is greater than in a dark-colored one, and it is not always possible to get a definite idea

[1] Rocks, Rock-weathering, and Soils, by George P. Merrill, p. 234.

[2] "The 'organic matter' * * * was determined by a wet combustion of a sample of soil with chromic acid and multiplying the carbon dioxide obtained by the conventional factor 0.471, proposed by Wolfe, van Bemmelin, and others." Field Operations of the Bureau of Soils, 1902, p. 130.

[3] An examination of a few of the most striking examples showed the presence of small pieces of charcoal in the light-colored soils, while others had a large amount of roots, bark, etc., which in these instances accounted for the high percentage of organic matter.

of the color of the two soils from an analysis by the "wet combustion method."[1] If, however, Prairie soils are compared with Prairie soils and Timbered soils with Timbered soils, it is nearly always possible, from the color, to arrange them according to the content of organic matter. This would strongly indicate that the organic matter in the soils of the two regions is in a different form, although the exact nature of the difference has not yet been shown. That this difference has a very pronounced influence upon productivity is reflected in the popular association of a dark color with a fertile soil.

Where the soils are closely associated, especially where derived from identical material, the difference in color seems to correspond more nearly with difference in organic matter than when derived from different formations. The Marshall and Knox silt loams in Illinois[2] are both formed from loess, the former being prairie and dark colored and the latter timbered and very light colored. An average of 12 samples of the Marshall silt loam showed 3.14 per cent of organic matter, while 10 samples of the Knox silt loam gave only 1.34 per cent. In all cases, however, there is a very marked difference in the character of the organic matter, the Timbered soils apparently containing a much smaller percentage of humus.

The moderate amount and nature of the organic matter gives to the soils of the timbered region a light color, except where mineral coloring matter predominates or where a surface mold has been formed. The most common colors are gray and light brown, with red coming in prominently in the South. In some cases, however, they become almost white, and when associated with almost black soils, as in the country near the boundary between the timbered and the prairie regions, stand out in striking contrast. The difference in color is of very great importance, because it not only indicates a difference in the amount and character of the organic matter, but the lighter color is associated with a leached condition.

While there are some exceptions, it is, nevertheless, generally true that the lighter colored, nonalkaline soils are favorable for timber growth, while the conditions which cause the accumulation of humus are unfavorable. Therefore, these light-colored soils were practically all originally timbered. This contrast between the native vegetation on these two great groups of soils is very characteristic and striking. In the border regions it has been noted that certain species of trees are seldom if ever found except upon the light-colored soils, while

[1] Grandeau proposed a method for differentiating the matiere noire or humus from other forms of organic matter and while this method is not entirely satisfactory, it is much better than the wet combustion, which simply shows the total amount of organic matter with no indication of the condition in which it exists in the soil.

[2] Soil surveys of Sangamon, Knox, Winnebago, and McLean Counties, Ill., by George N. Coffey and others, Field Operations, Bureau of Soils, 1903. Knox silt loam was mapped as Miami silt loam.

others may grow upon the dark soils. Among the former may be mentioned the oaks and among the latter the walnut and elm.

Probably the most conspicuous example of original prairie upon the light-colored soils is in southern Illinois on the type mapped [1] as the Marion silt loam. Most of this type consists of very level prairies with almost white, "acid" soils. The subsoil is very hard and impervious, making root penetration difficult, and this is probably one of the principal reasons why timber is not found upon a large percentage of it. Along the border zone other exceptions may be found and transition soils must be expected.

While some of the Timbered soils are very productive, they are in general of lower agricultural value for general farm crops than those of the prairie region, although much better adapted to early truck crops. This is due largely to the fact that the lower amount of humus decreases their moisture-holding capacity and therefore causes them to warm up much more rapidly in the spring.

From certain observations that have been made and from a comparison of the results of some experiments it seems very probable, if not indeed proved, that the varieties of some of our leading crops which do best on the Dark Prairie soils will not prove best suited to the Lighter-colored Timbered soils. It is possible here to give only one illustration.

The Turkey Red wheat is a standard variety in almost all the black prairie region. On these soils in Illinois it was found to stand first, or among the first, while on the light-colored loess soil in the southern part of the same State, on soils from crystalline rocks in North Carolina, on limestone soils in Pennsylvania, and on glaciated shales soils in Ohio it proved one of the poorest yielders.

SOILS FROM CRYSTALLINE ROCKS.

Under this heading are included all Timbered soils derived directly from crystalline rocks except the limestones and marbles. The principal area in the eastern United States begins in eastern Alabama and extends in a northeasterly direction slightly beyond Philadelphia. The same rocks continue into New England, but glaciation here gives rise to transported rather than residual soils. The eastward and seaward boundary is marked by the "fall line" which passes through or near the cities of Baltimore, Washington, Richmond, Raleigh, Columbia, Augusta, and Columbus. In its southern extension the western boundary practically coincides with the North Carolina-Tennessee line, while northward it follows the westward side of the Blue Ridge. This area practically includes all of the Piedmont Plateau, except the Triassic basins and bottom lands, as well as the eastern portion of the Appalachian Mountains.

[1] Soil surveys of Clinton, St. Clair, and Clay Counties, Ill., Field Operations, Bureau of Soils, 1902.

A few small areas occur in Missouri, Oklahoma, and the Black Hills. The Rocky Mountains consist very largely of crystalline rocks, although not all are timbered, while other areas are found throughout the West, although very little study of the soils in these localities has been made.

The rocks belong to the two great groups, igneous and metamorphic. From the soil standpoint, however, these may be combined under the more general term of crystalline. These rocks were formed through the agency of heat and metamorphism, and the conditions to which they are now exposed are very dissimilar to those under which they had their origin. In general, therefore, it may be said that they are out of harmony with their surroundings and rather easily attacked by the agencies of weathering. They represent the oldest part of the continent and have been subjected to degenerating influences for a great length of time. In the ages that have elapsed since these rocks were exposed, doubtless many hundred feet of soil have been formed and washed away only to be renewed by further weathering of the rocks below, and this process will continue until the regions where they occur are reduced to base level.

One of the characteristics of soils derived from crystalline rocks is the angular shape of the particles, especially the sand, due, of course, to the absence of rounding by water action. As there is a great variety of crystalline rocks, many kinds of soil will be formed through their degeneration. It is not possible to give all the different varieties that occur, and only the most important will be considered. These distinctions are based more upon differences in the soils than in the rocks, for, although the former are largely dependent upon the latter, weathering has often extended to such depths that fresh specimens of the rocks are difficult to obtain, and the determination of their exact nature therefore impracticable, although differences in the soils are plainly evident.

In the northern Piedmont the rocks are largely granites, gneisses, and mica schists which have given rise to light-brown or yellowish-brown surface soils, with yellow or slightly reddish yellow porous, friable subsoils. They usually show a large percentage of mica, principally biotite. They have a granular, rather "loamy" structure, with little difference in texture between soil and subsoil. They apparently have more humus and lack the gray appearance of the nonred soils further south. A much greater proportion of loams and silt loams is also present. The percentage of silt is greater, and the contrast between soil and subsoil is much less, as may be seen from the table following.

Average amount of silt and clay in Northern and Southern Piedmont soils.

Region.	No types.	No samples.	Silt.		Clay.	
			Soil.	Subsoil.	Soil.	Subsoil.
Northern	5	39	48	43	22	21
Southern	10	141	33	28	17	40

The principal soils are included in the Chester series, of which the Chester loam is the most extensive. Large areas of this type have been mapped in the Albemarle and Leesburg areas of Virginia, Cecil and Harford Counties, Md., and Montgomery and Chester Counties, Pa.[1]

From central Virginia southward occurs a series of hydro-mica schists or slates, which give soils quite different from those of the Chester series. The surface soils are light gray to almost white and very siliceous. They run together and become more compact than the Chester soils, and organic matter disappears very rapidly and almost entirely. This seems to be characteristic of many soils derived from magnesian rocks. The subsoils are heavy, plastic clays with a distinct greasy feel, due to the sericite mica present. The color of the subsoil varies from yellow to red, and upon this difference they are separated into two series, the Louisa series being characterized by red and the York series by yellow subsoils.[2]

Throughout the central and southern Piedmont the greater proportion of the country is covered by soils of the Cecil series, consisting of grayish-brown to red soils, with moderately friable and porous, though rather heavy red clay subsoils. One of the characteristic features of this red clay is the large content of sharp sand and the small percentage of silt. An average of 80 samples showed 35 per cent of sand, 20 per cent of silt, and 45 per cent of clay.

The Cecil series is derived from granite, gneisses, and schists, and from gabbro diabase and other basic igneous rocks. The granites and gneisses include those in which the more basic ferruginous minerals are relatively most abundant. The dominant types in the series are the sandy loam, clay loam, and clay. The small amount of silt precludes the formation of loam and silt loam members. The sandy loam is formed exclusively from the granites, gneisses, and schists. The clay is also formed from these rocks, but in addition is derived from basic igneous rocks, such as gabbro and diabase, which never give the sandy loam. The formation of the clay from the more

[1] See Reports of Bureau of Soils for these areas. Except in Pennsylvania it was mapped as Cecil loam.

[2] These soils have been mapped as Cecil fine sandy loam and Cecil silt loam in nearly all the soil survey reports of the Bureau of Soils, but are now placed in separate series, because of these differences which are inherited from the parent rock.

acidic rocks has been due to the washing off of the sandy surface layer and the exposure of the red clay which constitutes the subsoil. In some cases it may be due to an increase of the basic minerals in the granitoid rocks. The deep weathering makes the determination of this point very difficult.

The very acidic or binary granites weather into soils with yellow rather than red subsoils, and these are included in the Durham series, the coarse sandy loam and sandy loam being the principal members. The surface soils are light gray and very siliceous, being composed very largely of crystalline quartz. They are very much less extensive and considerably less productive than the Cecil soils.

One of the most distinctive groups of soils in the Piedmont Plateau consists of types with rather dark gray or brown surface soils, containing a very large percentage of iron concretions, underlain by very impervious, plastic, waxy, dingy yellow clay subsoils. This subsoil is the most characteristic feature and has given rise to the local name of "beeswax land." The native growth of blackjack oak causes the term "blackjack land" to be applied also. These soils are included in the Iredell series. The subsoil swells and shrinks in wetting and drying, causing the formation of many cracks. This marked change in volume is possibly due to the presence of large amounts of "colloidal" clay. A sample shaken in water for several hours and placed in a long tube gave a gelatinous deposit upon the sides as well as the bottom of the tube, while the Cecil clay did not. This subsoil is so extremely impervious that sufficient water can hardly pass through it to cause the decomposition of the underlying rock, which is usually found within less than 3 feet of the surface.

The rocks are principally diorite and diabase and appear as intrusions through the granites, gneisses, etc. An aplite granite is often associated with the basic rock, and the change from one to the other is very frequent. In Alamance County, N. C., alternating bands of these rocks, sometimes only a few inches in thickness, are very common.

Although very much the same kinds of rocks occur in the Blue Ridge Mountains as in the Piedmont Plateau, the marked difference in topography has caused considerable variation in the processes of soil formation, and therefore the soils are somewhat dissimilar. Here erosion has much more nearly kept pace with degeneration, the rock is nearer the surface, the subsoils not so deeply weathered, and the color generally a less pronounced red. In other words, the regolith in the mountains is thinner and not so thoroughly decomposed.[1] In some of the intermountain plateaus, like that around Hendersonville, N. C., the zone of weathering is deeper and the soils are really more

[1] Compare the mineralogical composition of the Cecil and Porters soils in table on p. 88.

like those of the Piedmont Plateau than those of the surrounding mountains.

Owing to the mountainous and nonagricultural character of so large a proportion of the country, the soils have not been studied in as much detail as in the more thickly settled Piedmont Plateau.

Most of the soils are included in the Porters series, but further and closer study will doubtless show the necessity of recognizing others. So far as observed they are most nearly like the Cecil soils of the Piedmont Plateau.

While practically no true loams are found in the Piedmont, a loam and a black loam occur in the mountains. The latter is the result of the accumulation of organic matter in the coves of the mountains and has no counterpart in the Piedmont. The loam seems to be due to a less thorough decomposition of the rock in the mountainous region.

SOILS FROM SANDSTONES AND SHALES.

The soils formed from sandstones and shales constitute one of the most extensively developed formations in the timbered region. They occur in two principal areas. The first and largest one begins in north-central Alabama and extends northward to New York, its northern boundary being formed by the southern limit of glaciation. It includes nearly all of the Allegheny Plateau and in shape is almost exactly the reverse of the adjoining eastern area formed from crystalline rocks, being widest in the north with a panhandle to the south. Along the eastern border, especially to the south, it is cut by numerous limestone valleys.

Another rather large area occurs in central and western Arkansas and eastern Oklahoma. In the latter State, especially near the central and northeastern part, the Light-colored Timbered soils and the Prairie soils are rather badly mixed and could be separated only by a detailed survey. Similarly small areas are found in Missouri, especially along the contact of the limestone with the sandstone and shale soils of the prairies, the more broken sections having light-colored soils, although the more level areas are darker.

A considerable area occurs in west-central Kentucky and a duplicate of this is found across the Ohio in southern Indiana, although much of the latter is covered by the loess.

Others are found in the Triassic basins of the Piedmont Plateau from North Carolina northward, the largest development being in Pennsylvania.

The rocks consist of mechanical deposits which were eroded from the older rocks, carried into the sea, consolidated through heat and pressure, uplifted to form the land, and through the agencies of weathering converted into soil. The various processes which this material has undergone have removed the more easily abraded and

readily soluble parts and combined with the leaching, which is taking place at the present time, makes these soils generally very siliceous in character, much more so than those from the same kind of rocks in the prairie region. The sandstones, especially, are very resistant to weathering and have often given rise to rocky ridges or mountains with really little soil upon them. These are very prominent along the west side of the Appalachian Mountains and in parts of Arkansas and eastern Oklahoma.

In texture, the soils are principally fine sandy loams and silt loams, the latter being the more common. The fine sandy loams are derived from the sandstones, while the silt loams come from the shales. In some cases, however, as in the Panhandle of West Virginia, a silt loam is formed from fine-grained sandstone. A shale, however, never gives a fine sandy loam, although a sandy shale may give a loam. Silt loams derived from sandstones are generally poorer soils than those from shales. In many cases, principally in the older rocks, fragments of sandstone or shale constitute a large percentage of the soil mass, and here stony or shale loams are formed. Over much of the country the rock is only a few feet below the surface, and outcrops are not infrequent. While some of these soils are very productive and many areas of good farming land are found, in general, they are rather low in agricultural value.

Not all sandstones and shales are alike in lithological and chemical composition, and this variation causes differences in the character of the soils. The most extensively developed soils in the Allegheny Plateau are gray to yellow brown in color, while the subsoils are usually some shade of yellow. Most of these soils are included in the Dekalb series. In general, they are a little more granular in structure and not quite so gray in color in northern areas as farther south, but the difference is not so great as in the soils in the Piedmont Plateau, Coastal Plain or the limestone valleys, where the variation is too great to permit correlation as the same types. In general, the relative percentage of sandy loams is larger in the southern portion. The Dekalb soils most closely resemble in character the Norfolk soils of the Coastal Plain.

Interbedded with the lighter-colored rocks, which give the Dekalb soils, are purplish-red sandstones and shales which weather into brown and red soils with red subsoils, constituting the Upshur series. The color is not a bright red like the Cecil soils, but more of a purplish or Indian red, very similar to the Penn soils of the Triassic basins. In general, there is a larger percentage of clay in the Upshur than in the Dekalb series, the Upshur clay being the most characteristic member of the series. The Upshur soils are very limited in area, especially in the southern extension of the Allegheny Plateau.

In the Triassic basins included in the Northern Piedmont, red rocks predominate, and these have given rise to the soils of the Penn series. These soils have the same Indian-red color as the Upshur, to which they are very closely related. The surface here is much less broken, the rocks have weathered more deeply, and the country is much better adapted to agriculture. The soils are characteristically silty, the texture being principally a loam, with a large percentage of silt, or a true silt loam.

Associated with the red soils are those derived from gray and yellowish rather than red rocks These give light-brown or yellowish-brown soils with pale-yellow or yellowish-gray subsoils and are included in the Lansdale series, of which the silt loam is the principal member.

The Penn and Lansdale soils are practically confined to the northern Piedmont Plateau. A considerable development of the former may be seen as far south as Orange, Va., and small areas even farther, but, in general, the Triassic soils in the southern Piedmont are quite different from those in the northern. This may be due in part to differences in weathering under somewhat different climatic conditions, but is much more largely the result of a change in the character of the rock. In the northern Piedmont the Triassic basins are surrounded largely by limestones and shales, and the formations in them are made up principally of wash from these rocks. In the southern Piedmont, however, the material came almost entirely from the crystalline rocks and is somewhat different. In the Richmond basin, for example, the Triassic rocks are arkose in character and give gray sandy soils with yellow subsoils, very much like the Durham soils derived directly from granite.

In the Triassic basin in North Carolina, the soils are not very dissimilar, except the deeper subsoils are heavier and more plastic and show more of the purplish red color. In the deeper cuts still more red is seen, while in some cases the red comes to the surface.

In texture the soils of the northern and southern Triassic areas show quite marked contrasts, the former being very largely loams and silt loams while the latter are predominately sandy loams. It is probable that the more sandy texture has aided in leaching out the red color of the more southern soils through the action of organic matter. They are of considerably lower agricultural value than those in the northern section.

SOILS FROM LIMESTONES.

Limestones are composed essentially of calcium carbonate, with which occur various impurities. Through solution, which readily takes place in water containing carbonic acid, the carbonate is removed leaving behind the more resistant materials, occurring in

connection with it, to form the soil. In some cases limestones contain as much as 98 per cent calcium carbonate, and it would therefore require many feet of rock to form one foot of soil.

While the original rocks contain a very large percentage of lime, it does not necessarily follow that the soils derived from them are calcareous. A limestone soil and a calcareous soil are not synonymous terms. The former refers to soils derived from limestones; the latter to soil in which there is actually a considerable content of lime. There are many calcareous soils not derived from limestones and many soils derived from limestones that are not calcareous, the lime in the latter case having been leached out. While the amount of lime in soils derived from limestones is usually greater than in those from other kinds of rocks, it is seldom sufficient in humid regions to give the dark color to the humus. In fact, most of these soils require the addition of lime in order to give an alkaline reaction. In limestone regions it is not an uncommon sight to see farmers burning the limestone, which is found a few feet below the surface, and applying the lime to the fields.

The reason for the low lime content of these soils is found in the excessive leaching which has taken place. The rocks are usually rather hard and a long period of time is necessary to weather them into soil. They are all of pre-Cretaceous age and have been subjected to leaching for many thousands of years. Therefore not enough lime is left to make the surface soils truly alkaline and organic matter has not accumulated in sufficient amount and in the proper form to give them a dark color.

One rather striking fact in regard to limestone soils is the almost total absence of sandy soils. The texture is practically always as fine or finer than a loam and usually there is very little sand present, silt and clay constituting almost the entire mass. This is the result of the method of formation of the stone, clear water being essential to the life of the organisms to which most limestones owe their origin.

The limestone soils may be divided into two general groups; (1) those formed from the purer, noncherty limestones or Shenandoah group, and (2) those derived from the cherty or siliceous limestones or Ozark group. The former usually occur as valleys or basins, and are generally of high agricultural value, while the latter form plateaus or ridges and are held in much lower esteem. The general location of the two groups is shown on the map, but it was impossible in some cases to separate them on so small a scale. In fact, many small bands or areas of the limestone soils could not be indicated, especially throughout the series of valleys lying along the eastern boundary of the Allegheny Plateau.

While the above groups and series include the principal limestone soils, smaller areas differing very distinctly from any of these, are occasionally encountered. The Bangor limestone in northern Alabama, eastern Tennessee, and Kentucky, for example, gives rise to a yellowish-brown to yellow clay loam or clay overlying a sticky yellow clay.

SHENANDOAH GROUP.

The soils from the purer limestones may be divided into the yellow-brown soils with yellowish to reddish-yellow subsoils and the deep red soils with intense red subsoils.

The majority of the yellow-brown limestone soils are included in the Hagerstown series. The soils are light brown or yellowish brown in color and of a rather granular, loamy structure. There is a considerable amount of humus present, apparently much more than in the soils formed from the more siliceous limestones. The immediate subsoil is usually yellow, but becomes redder with depth, and at 3 feet is often a reddish yellow or sometimes even a red with only a slightly yellowish tinge. In general, the heavier the texture, the redder the subsoil. The texture is predominantly silty, although some small areas of clay occur. The Hagerstown soils are among the most productive in the country.

The principal areas of the Hagerstown soils occur in the limestone valleys of Virginia and Pennsylvania and in the interior basins of Kentucky and Tennessee. Very small areas have also been seen in West Virginia, Alabama, Missouri, and Arkansas. Going southward from Pennsylvania the character of the limestone changes, becoming more dolomitic and cherty until in southwest Virginia the Shenandoah limestone grades into the Knox dolomite. A gradual change can also be noticed in the soils, the color becoming less brown and more gray southward, the structure less granular, the percentage of chert noticeably greater, the topography more hilly.

In the Allegheny plateau thin strata of limestone are often interbedded with the shales and these give rise to narrow bands of limestone soils which resemble in many characteristics those of the Hagerstown series. In some cases the materials from the shale and from the limestone have been mixed. This is usually true where the latter occurs on hillsides, but often the limestone caps the hills, and here true limestone soils are formed. Owing to differences in topography the agricultural value is not as high as in the case of the Hagerstown soils. These soils are placed in the Brooke series.

In northern Alabama, northwestern Georgia, and to a less extent in Tennessee, the pure limestones and dolomites give rise to intensely red soils which are included in the Decatur series. Typical developments may be seen around Decatur, Tuscumbia, and Talladega, Ala.

The Maryville limestone in eastern Tennessee has, so far as seen, always given rise to these blood-red soils. The red color is probably due to an accumulation of iron in the weathering of the relatively pure limestones. The texture is principally silt loam and clay loam with some small areas of clay. These soils are very strong, fertile, and highly esteemed.

OZARK GROUP.

In striking contrast to the above soils are those formed from the cherty and siliceous limestones. The surface soils of the latter are gray in color, much more siliceous and stony in character, contain a less amount of lime and humus, are less granular in structure, generally much more hilly in topography, and of decidedly lower agricultural value. The subsoils are yellowish to reddish yellow, often changing to yellowish red or red in the lower portions. Most of these soils are included in the Clarksville series.

There are two principal areas of these soils, one occupying the Highland Rim region of Kentucky and Tennessee, the other the Ozark region of Missouri and northern Arkansas. Smaller areas occur in eastern Tennessee and northern Alabama.

In the latter areas the soils, which are formed principally from the Knox dolomite and Fort Payne chert, usually have a little more sand than in the other areas and in texture are loams, although the percentage of silt is rather high. The percentage of chert here is not so great, especially where derived from the Knox dolomite, as in the two larger areas.

In the Highland Rim and the Ozarks the surface soil is all very silty, but there is a great variation in the amount of chert present. In some places fragments of chert literally cover the surface, while in others very few or none are found. In general, the more level areas are the least stony.

The reason for the great variation in stone content is not entirely clear. The stoneless areas may represent places where there was very little chert in the limestones or where the silt has been left from the shales which formerly overlaid the limestones in many sections. In the former case its occurrence upon the more level areas could be accounted for by the more rapid wearing down of the surface where no chert was present, just as a layer of shale overlying a hard stratum of sandstone tends to form a table-land. The irregular distribution of the chert would explain the failure to form distinct table-lands, as is the case in sandstone and shale formations. On the other hand, if the silt represents a residue from former overlying shales, it would naturally be found more upon the level areas where erosion had been least. The similarity of the soil in the cherty and noncherty areas, the doubtful occurrence of a previous covering of

shales in some areas, at least, where the stones are not present, the almost total absence of sand (an average of 35 samples shows only 16 per cent of sand of all grades), which would be more likely to remain than silt, and the irregular elevation at which these silty areas are found, all seem to indicate that their presence is due to the variation in the character of the original rock and not to a residue of silt left from a former overlying deposit of shale.

SOILS FROM WATER-LAID MATERIAL.

The unconsolidated formations, which have been laid down through the action of water, cover extensive areas in the timbered portion of the United States. In the glaciated section they consist of lacustrine deposits composed largely of reworked glacial material, but in the Coastal Plains they represent marine or aggradation deposits, principally the former. Accordingly, the soils are divided into two principal groups—the Atlantic Group and the Ontario Group.

ATLANTIC GROUP.

In the Atlantic and Gulf Coastal Plains and in a few detached areas farther inland occurs a great series of unconsolidated formations which give rise to one of the most extensive soils divisions of the United States. The material composing these formations was eroded from the older land areas to the north and northwest, transported by streams and deposited in the sea, in estuaries and bays, or as aggradation deposits upon older formations which had previously been elevated above sea level. Doubtless the rocks from which this material came had been subjected to leaching for a great length of time and much of the soluble material had been removed. This fact, combined with the decomposition and attrition which took place during the transportation and final deposition of the material and the further leaching since the elevation of the Coastal Plains above sea level, has resulted in the removal of many of the easily abraded and more soluble minerals and has given to the soils in general a very siliceous nature.

Differences in the character of the material which has been brought down by the streams and in the amount of reworking or wave action to which this material has been subjected have produced considerable variation in different sections. In the Chesapeake Bay region and northward the streams came either from a glacial section farther north or from limestone valleys, and in general the deposits are less siliceous than farther south. The sand here consists of a larger proportion of other minerals than quartz and is not so clean, i. e., more fine material adheres to it, seeming to indicate less reworking by wave action. In some places, however, especially on the lower eleva-

tions near the coast and the larger streams and estuaries, the material has apparently been reworked and resembles that found farther south. From Virginia southward to Florida, especially in the level country covered by the Columbia formation, the deposits are most siliceous, some of the sands containing as high as 99 per cent of silica.[1] Wave action has apparently had much influence here and it is also probable that much of the material came from the older formations of the Coastal Plain and had previously been subjected to much attrition. In some cases the material has been so abraded by wave action that very little is left except pure white quartz, and the soil might then be truly designated as "worn out."

Going westward in Alabama, Mississippi, and Louisiana deposits are in general somewhat less siliceous, owing probably to the fact that part of the material came from the limestone valleys while other portions were brought from the north by the Mississippi. Some of the younger formations show a mingling of loessial material. The change becomes very evident in Texas. Going southwestward the streams come from progressively more arid regions and the material brought down by them therefore contains more and more soluble material and a larger percentage of feldspar and other minerals than quartz.

As a whole, the soils of this group are predominantly sandy, although some very heavy clays are found. These heavier areas most often occur in the Cretaceous formations near the inner border of the Coastal Plain or associated with calcareous formations like the Selma chalk. The Potomac clays of Maryland, the lignitic clay of Alabama and Mississippi, and the Yegua clays of Texas give the largest areas of heavy soils, while the Columbia formation has the largest proportion of deep sands.

In general, the sandiest soils occur along the streams and in the country nearest the coast. The sounds, bays, and estuaries, which indent the Atlantic coast, principally south of the Chesapeake Bay, and the streams which enter them are nearly always bordered by deep sands. In eastern North Carolina, especially along the Cape Fear, Neuse, and Tar Rivers, the sands often cover practically all the country lying at an elevation of less than 20 to 25 feet above tide level, while the higher areas are sandy loams. Rather similar conditions exist in South Carolina and Georgia and to a less extent in Florida, Alabama, and Mississippi. In the last two States, the deep sands do not extend so far inland, while in Louisiana and Texas no such conditions exist, although a fringe of sand islands follows the coast from New England to the Rio Grande.

Not all of the deep sands occur near the coast and at low elevations, but some are located in the very opposite positions. In fact, a sandhill region is found near the inner border of the Coastal Plain. This

[1] See Norfolk series in table of mineralogical analysis, p. 90.

region begins in North Carolina and extends through South Carolina and Georgia into Alabama. A similar belt has been observed just north of Crockett, Tex., which extends southwestward and may be seen about 15 or 20 miles southeast of San Antonio. These narrow bands of deep sands very much resemble old shore lines.

A very large proportion of these formations consists of sandy clays which give rise to sandy surface soils, most often from 8 to 24 inches in depth, overlying sandy clay subsoils. Although this condition occurs practically throughout this division of the Coastal Plains, it is more prevalent in the section between Virginia and Florida. In Alabama, Mississippi, Louisiana, and Texas the subsoils often consist of heavy, plastic, impervious clays, but these are almost entirely absent in Virginia, North and South Carolina, Georgia, and Florida, while northward they are practically confined to a narrow strip near the inner border.

One of the most striking features of the Atlantic group of soils is the very small percentage of silt, causing the almost total absence of loams and silt loams. In the Chesapeake Bay region and northward silty soils are not uncommon, but from Virginia southward very few areas are encountered until the Mississippi drainage is reached and usually not in this section except where the soils are derived from formations younger than the loess, especially those formed from the Port Hudson and Grand Gulf. In other words, the silty soils in this group are practically confined to the northern portion of the Coastal Plain and to the Mississippi embayment.

There is a greater variety of colors in this division than in any other group in the United States. The surface soils range from white, gray, light, or yellowish brown to brown, reddish brown, and deep blood red. In some places the amount of organic matter increases and the color becomes darker and these soils grade into the Black Swamp or Prairie soils. The subsoils show even a greater variety of colors than the surface soils. This is due in part to the leaching out of the coloring matter in the surface material, but poor aeration has often caused mottlings, especially in the heavy clays.

In the northern Coastal Plains the majority of the surface soils are of a light or yellowish-brown color, while the subsoils are yellow to reddish yellow and are included in the Sassafras series. Usually beds of sand or gravel occur within a few feet of the surface and often outcrop as rather narrow bands along the stream slopes. The gravel is more common near the border of the Piedmont Plateau. The texture varies from beds of gravel through sands and sandy loams to loams and silt loams, the last closely resembling the loess of the Mississippi Valley. The sands are very restricted in extent and in fact hardly any true sand is found, most of that which occurs really being a loamy sand. The sandy loams are quite extensively developed as are

also the loams and silt loams, the latter more widely than in almost any other section of the Coastal Plains. The explanation is probably found in the source of the material, this having come from the silty limestone and shale soils and from glacial deposits.

A very striking example of differences in soils formed from exactly the same material, but under different moisture conditions, occurs in this section. Where the surface is rolling or undulating the yellow-brown soils of the Sassafras series just described are found; where identically the same material has been subjected to intermittent wet and dry conditions, the soils have turned almost white, and where water stands practically all the year organic matter has accumulated in sufficient quantity to give the Black Swamp soils. The white soils are included in the Elkton series. They have a very small amount of humus, are close and compact in structure rather than granular, have mottled gray subsoils showing lack of aeration, and are apparently low in iron and lime, and on the whole of rather low productiveness.

Most soils when heated turn red as a result of the dehydration or higher oxidation of the iron, but a sample of the Elkton silt loam remained almost white even after heating to a red heat. A qualitative examination showed only a very small percentage of iron, this element having probably been leached out by the action of organic matter in solution. Where a considerable amount of lime is present, similar drainage conditions will not give the white soils.

The Elkton soils are not so extensive as the Sassafras and occur principally on the level divides between water courses. As sandy soils are usually too porous to hold water, the loams and silt loams are the principal types in the Elkton series.

Associated with the formations which give rise to the Sassafras and Elkton soils are deposits of greensand marl which weather into a yellow-brown sandy loam (Collington) underlain by a yellow or greenish-yellow sticky sandy loam or sandy clay at 30 to 40 inches. This grades into the greensand. Deposits of greensand are reported from many other sections of the Coastal Plains, but with the exception of small areas in some parts of Texas, they do not outcrop sufficiently to be mapped even in a detailed soil survey. Near Lufkin, Tex., and in Lee County in the same State a deep red clay has been formed from a greensand marl.

Throughout almost the entire timbered portion of the Coastal Plain occur extensive areas of gray soils with yellow subsoils, resembling in many characteristics the Sassafras soils which are confined to the region around and north of Chesapeake Bay. The majority of these are included in the Norfolk series.

From Virginia southward to Florida the Norfolk soils have their most extensive and most typical development. In the inner portion of the Coastal Plain in North Carolina they cover almost the entire

country, but going seaward the surface becomes more level and Black Swamp soils alternate with them. This latter condition exists southward to Florida and to a less extent in southern Alabama and Mississippi. Beginning in South Carolina and extending through central and southwest Georgia into northwest Florida and thence westward to Texas, the Norfolk series occupies relatively a much smaller proportion of the country than in the section just referred to. In these latter sections, especially in Louisiana and Texas, the soils are not exactly similar to those in the Atlantic Coastal Plains, while the surface features are also much more rolling.

The Norfolk soils consist very largely of sands and sandy loams, the latter usually having very sandy surface soils with yellow sandy clay subsoils. Practically no loams or silt loams are found, the only areas seen being formed from the "yellow loam" in Alabama and Mississippi, which closely resembles the loess and probably represents an eastern extension of this formation mixed to some extent with other material. The Norfolk sands represent the most extensive occurrence of very sandy soils in the United States. They are found as a border around the sounds and along the streams, especially in the central and south Atlantic sections and to a less extent on the divides between the streams. The latter, however, are more often occupied by the sandy loams. In general the texture of this sand is finer nearer the coast. In some inner sections, particularly in Georgia and Alabama, deposits of coarse sand and even gravel are found. The sands are practically confined to the Post Tertiary formations, but the sandy loams are derived from both Tertiary and Quarternary deposits.

Some reference has already been made to differences in the soils of the northern and southern Coastal Plains, but it seems best to bring these out more clearly and to show reasons for this variation. As the Sassafras series is the dominant series in the former and the Norfolk in the latter (as well as the most nearly equivalent), this can probably be best done by contrasting these two series.

In the Sassafras series a larger amount of silt is present, the sand grains have more fine particles adhering to them, a relatively higher percentage of other minerals than quartz are found, the deeper subsoils are usually sandy or gravelly, the surface soil has a yellow-brown rather than a dead-gray color, is more granular in structure, apparently contains a greater amount of humus and lime, and is in general more productive.

Several factors have combined to cause these differences. In the first place some of the material comprising the Sassafras came from the glacial region, where the rocks were ground up by the ice, as is proven by the presence of striated bowlders on the eastern shore of Maryland. In the second place, most of the larger streams, like the

Potomac and the Susquehanna, drain extensive areas of limestone, sandstone, and shale formations, while all the streams southward to Alabama, except the James, flow from areas of crystalline rocks. Only a few small headwater tributaries of the latter stream come from limestone and shale formations. Coming from the limestone valleys the northern streams have brought down more lime and also more silt than those of the south. In the third place, the soils from the Piedmont Plateau, as already pointed out, are different in its northern extension. And in the last place, the climate of the two sections is not entirely similar and this has doubtless had an effect upon the character of the soil. The last condition has probably had less influence than any of the others.

The division between the northern and southern Coastal Plains soils is just south of the Potomac River and Chesapeake Bay. There is really no well-defined boundary, but rather a grading one into the other. The southern soils extend farther northward along the inner border than along the outer. In fact, some of the soils in northeastern North Carolina show the influence of a mixing of the northern material, although very little effect is seen even north of Richmond, which is situated on the edge of the Piedmont. In some sections near the coast where the Sassafras material has evidently been reworked by wave action there are small areas, even as far north as New Jersey, which have soils very much like those farther south.

In southern Georgia and Alabama and possibly elsewhere occur gray soils with yellow subsoils, which closely resemble the Norfolk but have some characteristic differences. They are locally called "pimply land" from the iron concretions or cementations which are a constant and characteristic feature. These are really not true concretions, but are rather cementations of the sand in concretionary form. While yellow, the subsoils are of a slightly different color from the Norfolk, resembling somewhat cottonseed meal. The agricultural value of these soils, which are included in the Tifton series, is higher than of the Norfolk.

In northwest Alabama and northeast Mississippi the Coastal Plains deposits lap up over the sandstones and shales of the southern Allegheny Plateau, and both the topography and the soil material have been influenced thereby. The country has a hilly and broken surface and the soils are rather gravelly, have many iron crusts in them, and are of low agricultural value. The surface soil is gray, while the subsoil is yellow to reddish yellow. These are included in the Guin series, the principal type being the Guin fine sandy loam.

Beginning in South Carolina and extending southwestward into Florida and westward into Texas, a large proportion of the timbered Coastal Plains is covered by deposits of red to orange or yellow sandy clays, most of which have been included geologically in the Lafayette

formation. Some geologists have held that this formation was of marine origin, but it is now believed to be a fluvial or aggradation deposit. The character of the material itself, its occurrence as a mantle over nearly all of the older deposits of the Coastal Plains, the variation in elevation even within short distances, the irregular stratification or lack of stratification, the almost total absence of fossils, all seem to support the theory of an aggradation deposit.

The soils from this formation usually have a gray surface, but in some places it is red. Where the gray soils have a yellow subsoil they are included in the Norfolk series, but where the subsoil is red they are called Orangeburg. In case the red color comes to the surface and is of a darker, deeper, or more of a blood-red shade, the soils are included in the Greenville series.

The cause of the difference in color between the red and the yellow has been investigated by several workers who have not reached an agreement or offered an entirely satisfactory explanation. The writer selected 22 samples of red and yellow soils from different parts of the United States and a study of the cause of the difference was made by Robinson.[1] He found that in every case except one the red soils showed a larger percentage of iron than the yellow, provided soils of similar texture were compared. This would seem to show that the difference is usually due to a variation in the thickness of the film of iron oxide coating the soil grains.

The deposition of these red sandy clays probably followed a period of long stability or gradual sinking of the land surface during which the rocks were deeply weathered, forming a thick regolith of red material. Comparatively rapid changes of level, especially an uplifting movement, greatly accelerated erosion. The deep-red regolith was carried down the hillsides into the streams and spread out by them farther seaward. The material looks very much as if the Cecil soils of the Piedmont Plateau had been simply transported and redeposited without much change in character. The material does not seem to have been subjected to much, if any, wave action. In almost all instances where it has been reworked into later formations, especially those of undoubted marine origin, the red has been washed out or changed to yellow. Few or no red soils are found in sections of the Coastal Plain covered by post-Tertiary formations. For some reason, not clearly understood, the Lafayette formation north of South Carolina is seldom, if ever, red.

As the Orangeburg soils resemble so closely the Cecil, it is easy to account for their origin in the section of the Coastal Plain adjoining the Piedmont Plateau, but it is more difficult elsewhere, especially west of the Mississippi River. In northern Louisiana the Orange-

[1] The Color of Soils, by W. O. Robinson, Bul. 79, Bureau of Soils, 1911. This bulletin contains a summary and discussion of the results of various investigations.

burg soils are quite similar to those farther east, but west of the Red River some change is noted, probably due to the fact that the streams come from a region of less rainfall as well as different geological formations. The surface soils are hardly as gray, not quite as siliceous, and contain more iron concretions, while the subsoils are not so typical red sandy clays, but are rather heavier and contain slightly more silt.

The Greenville soils are closely associated with the Orangeburg. They differ from them in having reddish brown to red instead of gray surface soils and deep blood-red subsoils. The color is very similar to the red (Decatur) limestone soils, but the texture is not so silty. They are, however, somewhat more loamy than the Orangeburg, have a less rolling topography, and are also more productive.

The cause of the intense red color and its persistence, especially in the surface soil is not understood. It is possible that this material is more calcareous and that the lime neutralizes to some extent the organic acids and prevents the leaching out of the iron. The presence of limestone only a few feet below the surface in some places and of greensand marl in others would lend color to this theory.

The Orangeburg and Greenville soils are very largely sandy loams. The surface soils, however, are very light sandy loams or sands with a very sharp change in texture when the subsoils are reached, particularly in case of the Orangeburg. The depth of the sandy covering varies from a few inches to nearly 3 feet, depending upon the favorableness of conditions for the removal of the finer particles.

In general, the older geological formations of the timbered portions of the Coastal Plains consist of heavier clays than the younger ones. These formations, and to a much less extent the later ones, have given rise to soils characterized by heavy, impervious, and plastic, rather than porous and sandy-clay, subsoils. The surface soils are usually gray in color and sandy in texture, the fine sandy loams predominating, while the subsoils are nearly always mottled, owing to imperfect aeration. According to differences in the coloring of these clays, the soils have been divided into several series. Of these, the Susquehanna and the Lufkin are most extensively developed, the former including gray soils with mottled red plastic clay subsoils and the latter gray soils with mottled yellow and gray subsoils.

The Susquehanna soils are very extensively developed in Georgia, Alabama, Mississippi, Louisiana, and Texas. Practically none are found in Virginia and North and South Carolina, although a band occurs along the border of the Piedmont in Maryland. In other words, they are found in those sections which are not covered by the Lafayette or later formations.

One of the striking features of these soils is the marked difference and abrupt change in texture between the soil and subsoil in the sandy

loams. For example, an average of 20 samples of the fine sandy loam, which is the most extensive type, showed 8 per cent of clay in the soil and 44 per cent in the subsoil. It seems that this is probably due in part, at least, to the former presence of a more sandy formation, possibly the Lafayette, overlying the heavier clays.

In the "flatwoods," or Lignitic clay, section of Alabama and Mississippi and in portions of Texas, especially where the Yegua clays constitute the underlying formation, occur the gray or mottled gray and yellow clays which form the subsoil of the Lufkin series. As regards plasticity and imperviousness, the Lufkin subsoils closely resemble the Susquehanna, the principal obvious difference being in the coloring. In general, however, the topography of the Lufkin soils is much more nearly level than the Susquehanna, which is often quite hilly.

Associated with the Selma chalk formation, which gives the black prairie belt in Alabama and Mississippi, are the gray to yellowish-brown soils and yellowish-brown to dingy-yellow subsoils constituting the Oktibbeha series. These are locally known as "post-oak prairies." The formation from which they are derived immediately overlies the Selma chalk and in the lower portion is quite calcareous. It probably represents a transition from the deep or quiet water conditions under which the Selma chalk was deposited to that of more agitated and turbid waters. Some of the lighter textured soils doubtless contain an admixture of material from later deposits.

Along the streams in many portions of the Coastal Plain, but more particularly in Alabama, occur a series of terraces or "second bottoms" upon which the soils differ in some respects from those of the adjacent uplands and might be considered as another group, although their extent is too limited to indicate on the map. These terraces were formed during Pleistocene time and in age are probably synchronous with the deposits in the level country bordering the coast, which is usually included in the Columbia. The material was deposited by the streams and was not subjected to the action of the waves. While this material was laid down by streams, the soils are distinctly different from those of the present flood plains, being much more like those of the uplands proper. This is due to their exposure to the agencies of weathering for many centuries. They should, therefore, be considered as soils derived from water-laid material rather than true alluvial soils. The principal series so far encountered are the Cahaba and Kalmia, the former consisting of brownish-gray soils with reddish-yellow to reddish-brown subsoils, and the latter of gray soils with mottled gray and yellow subsoils.

A number of other series are included in the Atlantic group of soils, but they are of much less importance and present no especial features of interest, so they will not be described in this paper.

ONTARIO OR LACUSTRINE GROUP.

During the melting and retreat of the ice from the northern part of the United States there were formed numerous lakes, many of which remain until the present time, although less extensive than formerly. Into these lakes material was carried by streams and a series of lacustrine deposits formed, from which soils have since been derived through the action of certain agencies and processes. The chief development of these deposits occurs around the Great Lakes, but smaller areas are scattered throughout the timbered glacial region.

Differences in the character of the material brought in by the stream have given rise to several series of light-colored soils, the most important being the Vergennes, Dunkirk, and the Superior.

The Vergennes series occurs on the terraces surrounding Lake Champlain, and is derived from the Champlain clays. The surface soils are gray to light brown, while the subsoils are drab to light gray, appearing almost white when turned up by the plow. The chief type is the clay, which covers about three times as great an area as all the other members of the series combined.

Where the material carried into the lakes consisted largely of wash from shales, with standstones and limestones, the Dunkirk series occurs. This series has light-gray to brown soils, with drab, gray, and mottled yellow subsoils. The Dunkirk series occurs principally around Lake Ontario, Lake Erie, and smaller lakes in New York and Ohio.

Around the southwestern end of Lake Superior and on the western side of Lake Michigan the lacustrine deposits are red instead of gray or yellowish, as is the case farther east. These red deposits give rise to the Superior series, of which the clay is most extensive.

SOILS FROM ICE-LAID MATERIAL (GLACIAL).

During Pleistocene time almost the entire northern portion of the United States was covered by a great continental ice sheet which, upon melting, left a mantle of heterogeneous material over the underlying formations. The line of the southern extension of this ice sheet touches the Atlantic coast about New York City, passes through northern New Jersey, northeastern Pennsylvania, and southern New York; thence turns southwestward through northwestern Pennsylvania and Ohio to Cincinnati, crosses the Mississippi River at St. Louis, follows along the west side of the Missouri River into Montana, runs just south of the Canadian boundary line across northern Idaho into Washington, extending farthest south in the Puget Sound region.

While practically all of the country north of this line is covered by glacial deposits, only small areas of the Light-colored Timbered

soils occur south of a line drawn from about Lafayette, Ind., to St. Paul, Minn. Such developments as are found to the south generally occupy narrow strips near stream channels, while the more level divides have Dark-colored Prairie soils. West of the Rocky Mountains only a few small prairies occur, and most of the glacial soils here are forested.

As compared with the Prairie soils from ice-laid deposits, these timbered soils are much lighter in color, and lower in humus and lime, while the percentage of stony, gravelly, and sandy soils is very much greater. Large areas of these coarser textured soils occur, especially in Michigan, Wisconsin, and Minnesota, where the drift has been more or less assorted by water and the finer particles washed out, probably contributing to the formation of the loess. With the exception of western Ohio and central and northern Indiana, the topography is more hilly and morainic, kettle holes and billowy ridges being a rather constant feature. The drift is also thinner and its rock content consists of a much larger percentage of the underlying formation, so much so in places that some writers are inclined to treat the soils as residual rather than transported. This is especially true in New York and New England and in the extreme northwest. In the mountainous portion of these sections particularly the soil is very stony and areas where the ice swept off all the loose material, leaving the bare striated rock to form the surface, are not of infrequent occurrence.

As compared with the soils outside the glaciated region these soils consist of a more heterogeneous mixture of rock material, the size of the particles varying from that of bowlders to clay. The sand is composed of a larger percentage of other minerals than quartz and is not so clean.

The texture is practically never heavier than a clay loam, and except where water has assorted the material to some extent at least is not lighter than a heavy sandy loam. There is also very little difference between the texture of the surface soils and subsoils, an average of 120 samples of each showing 39 per cent of silt and 17 of clay in the soil and 41 per cent of silt and 21 per cent of clay in the subsoil, or a difference of only 6 per cent in the silt and clay combined, hardly enough to be perceptible were the quantity of organic matter and the structure the same. It is thus seen that the clay subsoils, which are so common in the warmer, more southern, latitudes, are usually wanting, doubtless owing to the less decomposition which has taken place in the glacial soils.

The color of the soils is usually some shade of gray or light brown, while that of the subsoils is most often gray to yellowish. A striking feature of these soils is the almost total absence of red or other brilliant colorings, which is the result of the predominance of me-

chanical disintegration over chemical decomposition in the breaking down of the rocks. The only examples of red glacial soils are where the coloring existed in the rocks which were ground up by the ice. Considerable areas exist in northeastern Pennsylvania and the adjoining portion of New York. In western Wisconsin and eastern Minnesota the till is slightly reddish, sufficiently so to be called the "red till." Some reddish soils have also been found in the Puget Sound region, but there is very little development in other sections than those mentioned.

Over much of the country covered by this group of soils it is possible to subdivide them according to the character of the rocks which predominate in the drift. In much of New England and the Adirondack region of New York, as well as in parts of Wisconsin and Minnesota and the extreme Northwest, the glacial material is composed largely of crystalline rocks. In the first areas these rocks really represent the northward extension of the crystalline rocks of the Piedmont Plateau and eastern Appalachian Mountains and the soils are therefore related to those found in these sections.

Variation in the character of these crystalline rocks has given rise to several series, the most extensive being the Gloucester and the Bangor. The Gloucester series consists largely of granitic material and is usually decidedly micaceous, principally biotite. In the Bangor series the mica is largely sericitic and the subsoils are grayer than in the Gloucester. In both series the stony sandy loams, stony loams, and loams are the principal types.

In northeastern Pennsylvania, southeastern New York, western Massachusetts and Vermont, and possibly in some other portions of New England occurs a series of slates and slaty shales, which have very largely determined the character of the drift and given rise to the Dutchess soils, among which the slate loam is the principal type.

In southern New York, northern and northwestern Pennsylvania, and northeastern Ohio the underlying rocks are largely shales, with some sandstones, which were ground up by the ice and give rise to the important Volusia series of soils. The texture is chiefly a silty loam to silt loam, although westward toward Cleveland, Ohio, it might be classed as a silty clay loam. The percentage of shale fragments is usually high, but decreases toward the west where the shales are softer. In parts of Michigan, Wisconsin, and Minnesota the deeper glacial deposits consist largely of sandstone and these soils have been included in the Coloma series.

In western Ohio, eastern, central, and northern Indiana, parts of Michigan, Wisconsin, and Minnesota, and to a less extent in other sections, the drift contains a large percentage of ground-up limestone. In Ohio and westward the drift is rather thick and many bowlders of igneous and metamorphic rocks are scattered over the

surface. These soils are included in the Miami series, which is one of the most important series of glacial soils. In Ohio and Indiana the clay loam covers almost the entire section occupied by the Miami series, but elsewhere it is found in only small areas, the stony, gravelly, and sandy loams constituting the principal types. In eastern New York and New England the drift on the limestone is very thin and other series of soils are found, among which the Dover and the Nunda are the more important.

SOILS FROM WIND-LAID MATERIAL (ÆOLIAN).

In general it may be stated that in a humid region the æolian deposits are of less importance than in an arid, because the vegetative covering and the moist condition of the ground in the latter are not conducive to the movement of the material by the wind. Practically the only deposits of any depth being formed at the present time are those consisting of dune sand along the coast or around the border of lakes. During the glacial time, however, it seems that conditions were more favorable for the deposition of finer material and large stretches of country were covered with a mantle of silt, known as loess, largely through the action of the wind. The æolian soils of the timbered region may then be divided into the light-colored loess soils included in the Mississippi group, and Dunesand or Sandhill. The latter group is of practically no agricultural value and will not be discussed further.

MISSISSIPPI OR LOESSIAL GROUP.

As the loess is all very silty, no true series of loess soils exists, and the subdivision is really into types instead of series. Three principal types of light-colored loess soils have been encountered. These are the Knox silt loam,[1] the Memphis silt loam, and the Marion silt loam. The first two grade into each other and the difference is not marked, but the Marion is strikingly different. The Knox silt loam is a light-gray, sometimes almost white, or light-brown silt loam, while the Memphis silt loam is often of a pale-yellow color, does not contain quite as much clay, but more silt, and the deposit is usually much deeper. The Knox is confined to the upper Mississippi Valley, usually as strips of timbered lands bordering the streams; the Memphis to the middle and lower portions, principally on the east side of the river, although some outliers are found on the west side, as in Crowleys Ridge, Ark. In the country bordering the Ohio it is rather difficult to say with which type the loess soil should be correlated, although it is probably nearer the Memphis.

The Marion silt loam covers the greater part of 30 counties in southern Illinois, while some areas occur in southern Indiana and

[1] Mapped in most reports of the Bureau of Soils as Miami silt loam.

Ohio. This type has a very light gray ashy surface soil, with generally a white subsurface layer changing abruptly at about 15 inches into a hard silty clay, locally called hardpan. It possesses the characteristics of the Russian podzol (under-ash). It is low in lime, and tests by the Vietch method show that an addition of 2,000 pounds of lime per acre is often necessary in order that the soil may give an alkaline reaction.

The reason for the low amount of lime is probably about as follows: The greater part of the underlying rocks in central Illinois are shales and sandstones, which had been subjected to leaching for a great length of time, when the ice moved southward over them, and therefore the lime, never very abundant, was carried away. The ice picked up this leached material which went into the composition of the loess, causing it to be low in lime. The level character of the surface allowed water to remain for some time after rains, causing an intermittent wet and dry condition. In the absence of sufficient lime to neutralize the acids formed, they attacked the iron and other compounds and caused them to be leached out or downward into the subsoil. Had lime been present, the soil would have been black.

In St. Clair, Ill., the Marion silt loam is undoubtedly derived from an older loess than the Memphis, many sections being seen where the latter material occurs as a distinct overlying layer.

BLACK SWAMP SOILS.

The Black Swamp soils are characterized by (1) a small amount of soluble mineral matter, (2) a large amount of organic matter, (3) a dark or black color, and (4) usually marked contrast between soil and subsoil. It is thus seen that they resemble the Prairie soils in some respects and the Light-colored Timbered soils in others. They might be regarded as forming a transition from the latter to muck and peat.

As these soils are confined to the humid region, they have been largely leached of the soluble mineral matter. They are low in lime and are therefore in an "acid" or nonalkaline condition. The organic matter in them is "sour" and apparently in a different form from the humus in the Dark-colored Prairie soils. In the latter case it seems to be an alteration product due to very thorough decomposition, while in these soils it is largely undecomposed. As soon as the soil is drained and aerated, the organic matter begins to decay more rapidly and in a comparatively few years almost entirely disappears. As the dark color is due to the presence of organic matter, the shade becomes lighter as the amount of this decreases.

The formation of these soils is due to the accumulation of organic matter under a superhumid soil condition. They are therefore formed in those sections where the precipitation is abundant and the

surface is level or depressed, so that the water does not readily run off. It is also evident that an impervious subsoil will be favorable to their formation. The largest areas in the United States where these conditions exist are in the southeastern part, especially in the coastal section of the Carolinas, Georgia, and Florida. They occur, however, in smaller areas throughout the humid region.

Owing to the small areas in which these soils are found it is not practicable to make a separate group of them on the map. They occur almost entirely in that portion of the humid regions where the underlying formations consist of unconsolidated water-laid deposits, principally in the sections shown as the Atlantic and Ontario groups on the map. The principal soils are included in two series, the Portsmouth and the Clyde. The former occurs in the Atlantic group, principally in the level country from Virginia southward to Florida, while the latter occurs in the Ontario group, principally from Michigan eastward into New York. The Portsmouth has been formed from very much the same material as the Norfolk, the difference being due to poor drainage, which has resulted in the accumulation of organic matter and also chemical changes in the material, as is evidenced by the gray or mottled subsoil. The Clyde is derived from the same material as the Dunkirk, to which it bears the same relation that the Portsmouth does to the Norfolk.

ORGANIC SOILS.

This division includes soils composed very largely or almost entirely of organic matter. Owing, however, to the great influence of this material in determining the character of the soil the line of division between Organic and other soils can not be placed at 50 per cent as has been done by some investigators.[1] Although no study has been made to determine the exact percentage, it seems probable that it should be not more than 20 per cent and, in fact, if a soil contains more than 10 per cent it appears rather "mucky."

According to differences in the quantity and stage of decomposition of the vegetable matter, organic soils may be divided into muck and peat. The latter consists almost entirely of organic matter in a partially decomposed condition, the fibrous nature and vegetable origin of the material being usually quite evident. Muck has a larger percentage of mineral matter present, while decomposition has progressed so far that the fibrous structure is no longer discernible.

These Organic soils have been formed by the accumulation of the remains of various plants, spagnum moss being especially abundant in northern latitudes. They occur only where a superhumid condition retards the decay of the vegetable matter.

[1] See the classification of soils given in "Terres Arables du Pas-de-Calais," by A. Pagnoul, 1894.

While deposits of peat and muck are found in many parts of the United States, the areas are usually small, so that they could not be indicated on the map. These areas are, however, very numerous in the northern portion of the United States where the topography left by the ice is especially favorable to their formation. A considerable development also occurs in the Atlantic and Gulf Coastal Plains where the surface is so level that water does not run off. Some areas occur even in the arid regions, where local drainage conditions are particularly favorable. An example may be seen near Stockton, Cal., and in other places in the Interior Valley.

Although all these areas are classed as muck or peat, there is undoubtedly a difference in the character of the material, which is sometimes expressed by the terms "sour" and "sweet." Where the associated soils are calcareous the Organic soils usually have considerable lime, but when this is not the case they are generally much benefited by liming. Coffee-colored water or material is indicative of a "sour" condition. In Illinois peat soils have shown marked response to potash fertilizer, but this may not prove true in all other sections.

MINERALOGICAL COMPOSITION OF SOME IMPORTANT SOIL SERIES.

In order to find out something in regard to the mineralogical composition of the soils which have been described in preceding pages, 25 important series were selected for mineralogical analysis.[1] Ten individual samples of the surface soils of each series were taken and a composite sample made from these. A separation of the sand, silt, and clay in each composite sample was then made by mechanical analysis, and the mineralogical composition of the sand and silt determined, the clay particles being too fine for a study of this character. The analysis included the determination of the percentage of all other minerals than quartz; the more abundant or characteristic minerals, and those less abundant or less characteristic. The results are given in the table on pages 87 to 91. Some of the most striking facts in the table have already been alluded to,[2] but it seems best to add further emphasis to some of them in this connection and to make other brief comments.

One will note at once the large percentage of other minerals than quartz in the arid soils as compared with the humid. It is true that some of the series from the crystalline rocks—particularly the Iredell, Chester, and Porters—have almost or quite as large a proportion, but there is a marked contrast in the minerals present. In the arid series the feldspars, including practically all the principal varieties, are abundant, while in the humid series, with the possible exception of orthoclase and microcline, they are rather accessory than characteristic, the chief minerals being hornblende, mica, pyroxene, and other basic varieties.

Of the major divisions of humid soils those from crystalline rocks show much the wider variation in the proportion of quartz, as well as in the character of the minerals present, which is to be expected. In some of the series orthoclase feldspar occurs in considerable quantity, indicating a good supply of potash. In others this mineral does not appear at all; in some (Iredell) the percentage of femic minerals is very high; in others calcic varieties predominate. Apatite is found in only one of the five series, suggesting a low phosphorus content. The Louisa series is mineralogically and agriculturally among the poorest series of the country.

[1] The analytical work was done by Mr. W. J. McCaughey, formerly connected with the laboratories of this bureau, but now with the Ohio State University. These examinations were made by oil-immersion methods and the details of the examination will be found in a forthcoming bulletin of this bureau on the Microscopic Determination of Soil-Forming Minerals. It has not been found possible to examine the clay separate for mineral determination, as these particles are too small to lend themselves to this method. These examinations therefore indicate the composition of the soil, disregarding the clay separate.

[2] These analyses were not received until the other part of this paper was written, and so it was not possible to make much use of them there without entirely recasting the material, which it did not seem desirable to do.

Mineralogical analyses of important soils.

ARID SOILS.

Soil series.	Minerals other than quartz in—		Abundant and characteristic minerals in—		Less abundant or accessory minerals in—		Remarks.
	Sand.	Silt.	Sand.	Silt.	Sand.	Silt.	
	Per cent.	*Per cent.*					
Fresno	30–50	50–70	Hornblende, feldspars; orthoclase, plagioclase,[1] albite to andesine.	Biotite, hornblende...	Epidote, biotite, zircon..	Plagioclase, muscovite, pyroxene, epidote, tourmaline, orthoclase, apatite, zircon.	Distinctly angular. Characterized by high content of feldspars, mostly alkalic type, generally unaltered. Plagioclase weathered. Traces of diatoms in silt.
Yakima	50	50 est.	Augite, volcanic glass, plagioclase mostly andesine and labradorite, oligoclase.	Biotite, hornblende, pyroxene, muscovite, diatoms.	Epidote, biotite, phlogopite, apatite, serpentine (iddingsite), hypersthene orthoclase.	Plagioclase, orthoclase, apatite, epidote, Iddingsite (serpentine).	Grains fairly well rounded to angular. Volcanic glass has inclusion of microlites and trichites. Some feldspars zonally developed. Much devitrified glass.
San Joaquin	20–25	15–20	Hornblende, plagioclase, albite, oligoclase, and andesine, orthoclase.	Biotite, epidote.....	Epidote, zircon, titanite, microcline, biotite, basaltic hornblende, muscovite.	Muscovite, orthoclase, hornblende, chlorite, tourmaline, zircon, rutile.	Characterized by large amount of hornblende and presence of acid plagioclase. Also quartz grains well rounded.

[1] Plagioclase is so listed when the variety could not be determined and in some cases the feldspars could only be listed as such or simply as feldspar residues. The same is true of some other minerals.

Mineralogical analyses of important soils—Continued.

SOILS FROM CRYSTALLINE ROCKS.

Soil series.	Minerals other than quartz in—		Abundant and characteristic minerals in—		Less abundant or accessory minerals in—		Remarks.
	Sand.	Silt.	Sand.	Silt.	Sand.	Silt.	
	Per cent.	*Per cent.*					
Cecil	3–5	10	Zircon, sillimanite, rutile, microcline, plagioclase, biotite.	Sillimanite, chlorite, muscovite, orthoclase.	Epidote, muscovite	Garnet, hornblende, epidote, tourmaline.	Stretched and undulatory quartzes. Grains mostly angular but not prominently so.
Chester	25	30	Hornblende, biotite	Hornblende, biotite, muscovite.	Microcline, andesine, tourmaline, magnetite, garnet, chlorite, actinolite, rutile, epidote, muscovite, sillimanite.	Epidote, tourmaline, sillimanite.	Magnetite inclosing rutile needles.
Louisa	1–2	5–8		Muscovite (sericite), epidote, sillimanite.	Epidote, zircon, tourmaline, biotite, hornblende, rutile.	Biotite, tourmaline, zircon, rutile.	Grains mostly angular, some rounded; zircons well rounded. Mostly carries inclusions showing secondary origin.
Iredell	30+	40 (est.)	Pyroxene, augite, hornblende, epidote.	Pyroxene, biotite, epidote, hornblende	Feldspar: Orthoclase, microcline, plagioclase, andesine, labradorite, apatite, ilmenite, biotite, magnetite.	Hornblende, chlorite, magnetite.	Quartz mostly angular, sharply so. Characterized by high percentage of femics.
Porters	13	25–30	Hornblende, orthoclase, microcline (unaltered).	Biotite, hornblende, muscovite.	Muscovite, biotite, garnet, epidote.	Pyroxene, epidote, zircon, chlorite. plagioclase, microcline, rutile.	Angular, a few well rounded. Minerals show but slight alteration.

SOILS FROM SANDSTONES AND SHALES.

Light-colored Timbered soils: Penn	5	20	Orthoclase, much altered, hematite.	Decomposed feldspar, epidote.	Epidote, microcline, muscovite, chlorite.	Plagioclase, pyroxene, zircon, biotite, sillimanite, tourmaline, muscovite, magnetite, chlorite.	Many secondary quartz grains, inclosing iron oxide. Hematite as inclusions and as covering of grains in silt.
Dekalb	2–3	8	Orthoclase, very much altered.	Tourmaline	Microcline, zircon, chlorite.	Chlorite, hornblende, muscovite, biotite, epidote, rutile, zircon.	Grains fairly well rounded. Quartz crystals. In silt quartz crystals carrying calcite.
Dark-colored Prairie soils: Morton	25+	30+	Calcite, orthoclase, feldspars abundant and altered.	Epidote, hornblende, calcite, orthoclase, altered and fresh.	Microcline, plagioclase, oligoclase, epidote, chlorite, hornblende, tourmaline, apatite, zircon.	Tourmaline, muscovite, apatite, zircon, biotite, chlorite.	Feldspar altered and much rounded and also angular and fresh, suggesting admixture of material.
Summit	50–60	60 est.	Feldspar, plagioclase, oligoclase, labradorite, microcline, orthoclase.	Epidote, hornblende, feldspars, orthoclase.	Apatite, epidote, garnet, pyroxene, zircon, fluorite.	Rutile, chlorite, muscovite, tourmaline, biotite, zircon, sillimanite.	Quartz grains not much worn. Primary and secondary about equal. High feldspar content. Much organic matter in silt.

SOILS FROM LIMESTONES

Hagerstown	5–8	8–10	Secondary quartz crystals, microcline, weathered orthoclase.	Altered feldspar	Tourmaline, zircon, chlorite, muscovite, rutile, fluorite.	Hornblende muscovite, epidote, tourmaline, chlorite, rutile, zircon, microcline.	Angular grains predominate over rounded grains 3:2. Quartz grains mostly secondary. Rather unusual amount of feldspar.
Clarksville	2–3	3–5	Secondary quartz crystals, feldspar highly altered.	.....	Tourmaline, rutile, zircon, hornblende garnet, chlorite, biotite, partly altered to chlorite.	Tourmaline, muscovite, epidote, chlorite, zircon, hornblende, microcline.	Many grains fairly well rounded, others angular. Many primary quartz.
Decatur	4 est.	5–7	Many secondary quartz crystals carrying inclusions of calcite.	.....	Tourmaline, zircon, rutile.	Tourmaline, muscovite, biotite, rutile, hornblende, zircon.	Angular, fairly well rounded to well-rounded grains, 2:1:1, characterized by abundant quartz crystals. Quartz grains in the silt carry calcite.

Mineralogical analyses of important soils—Continued.

SOILS FROM WATER-LAID MATERIAL.

Soil series.	Minerals other than quartz in—		Abundant and characteristic minerals in—		Less abundant or accessory minerals in—		Remarks.
	Sand.	Silt.	Sand.	Silt.	Sand.	Silt.	
	Per cent.	*Per cent.*					
Sassafras	12	18–20	.....	Biotite, hornblende..	Hornblende, biotite, muscovite, apatite, chlorite, microcline, epidote, rutile, tourmaline, hypersthene, weathered orthoclase.	Muscovite, orthoclase, epidote, acid plagioclase, microcline, staurolite, zircon, tourmaline.	Angular grains predominate 2:1, complex mixture of varied mineralogical composition.
Norfolk	1 or less.	3–5	.....	.....	Microcline, apatite, zircon, tourmaline.	Microcline, orthoclase (altered), biotite, chlorite, hornblende, zircon, tourmaline, rutile, sillimanite, epidote.	Well-rounded quartz grains and zircons. Many quartz grains secondary carrying inclusions of iron oxide.
Greenville	3–5	5–8	.....	Feldspar residues.....	Magnetite, apatite, zircon, rutile, sillimanite, weathered feldspar.	Biotite, epidote, chlorite, rutile, zircon, blue magnetite, sillimanite, tourmaline.	Quartz and zircons well rounded. Many secondary quartz grains other than crystals inclosing iron oxide.
Elkton	3	3	.....	.....	Rutile, tourmaline, chlorite, microcline, zircon, magnetite.	Muscovite, orthoclase, microcline, hornblende, rutile, epidote.	Angular and rounded, 1:1 admixture of grains. Less secondary quartz grains than primary.

SOIL FROM ICE-LAID MATERIAL.							
Light-colored Timbered soils: Volusia	10–12	8–10	Microcline, orthoclase, very much altered and fresh.	Feldspar residues	Garnet, zircon, chlorite, biotite, hornblende, tourmaline, epidote, albite.	Chlorite, biotite, hornblende, epidote, muscovite, tourmaline.	Grains well rounded. Many secondary quartz grains. Orthoclase altered to epidote, also fresh orthoclase. Silt shows extensive chemical alteration.
Miami	10	10–15	Hornblende, garnet, microcline.		Orthoclase, zircon, epidote, plagioclase, oligoclase, apatite, garnet.	Tourmaline, hornblende, epidote, chlorite, orthoclase, microcline, zircon.	Well rounded. Most quartz grains show evidence of great wear.
Dark-colored Prairie soils: Carrington	15	20	Hornblende, epidote, garnet, magnetite, ilmenite, microcline, in some quantity, feldspars.	Hornblende, chlorite	Hornblende, chlorite, zircon, plagioclase, albite, oligoclase.	Epidote, biotite, calcite, rutile, muscovite, plagioclase, orthoclase.	Rounded to angular. Characterized by high-content feldspar and other minerals than quartz.
SOILS FROM WIND-LAID MATERIAL (LOESS).							
Dark-colored Prairie soils: Marshall	12	15–20	Feldspars, including orthoclase, microcline, plagioclase, oligoclase, andesine.	Epidote, muscovite	Apatite, muscovite, hornblende, rutile, garnet, zircon, sillimanite.	Hornblende, biotite, chlorite, tourmaline, orthoclase, zircon, microcline, sillimanite.	Grains mostly angular, some fairly well rounded. Contains few quartz crystals. Orthoclase much altered, also fresh orthoclase.
Light-colored Timbered soils: Memphis	15	15	Feldspars, orthoclase, altered; microcline.		Biotite, albite, oligoclase, zircon, fluorite, rutile, tourmaline, apatite, hornblende.	Biotite, hornblende, epidote, muscovite, orthoclase, microcline, epidote, sillimanite, rutile, zircon.	Grains mostly well rounded, few angular; orthoclase in general highly altered.
White Prairie soils: Marion	10–12	12	Microcline, hornblende, orthoclase.	Orthoclase, hornblende.	Fluorite, zircon, garnet, tourmaline, plagioclase, oligoclase, epidote.	Tourmaline, microcline, epidote, titanite, chlorite.	Admixture of angular and well-rounded grains. Admixture of fresh and weathered orthoclase. Some minerals highly altered, others entirely fresh.

A very interesting case of the influence of topography upon the character of the soil is presented in the Cecil and Porters series. These two series are derived from the same kind of rocks and have very much the same minerals present, although the percentage of other minerals than quartz is about three times as great in the latter as in the former. The Porter series has a mountainous topography, and erosion has permitted only a thin mantle of soil to accumulate. The minerals show very slight alteration, indicating that they have not been long subjected to weathering. The Cecil series, on the other hand, occurs in the Piedmont Plateau, where the surface is not so broken, giving rise to less rapid erosion and more advanced decomposition.

Probably no more striking contrast between soils formed from the same group of rocks can be found than that exhibited by the Penn and Dekalb soils, representing the timbered humid region, and the Morton and Summit series of the black prairie region. The former two are very silicious, the average percentage of quartz in the sand and silt approximating 85 to 90 per cent, while in the last two it is sometimes less than 50 per cent. The feldspars, which, if present at all in the two humid series, are very much altered, occur in abundance in the prairie soils. In the latter, however, especially the Morton, there is a mingling of fresh and altered feldspar, indicating an admixture of materials. Apatite is also present in the latter, although absent from the former. Calcite is reported as abundant in the Morton series, something of unusual occurrence, the black glacial soils of the Carrington series being the only other series in which this mineral was found, except as inclusions in quartz crystals.

The reason for such marked contrast in these soils formed from the same group of rocks has already been discussed (see pp. 13 to 23), but may be briefly stated as being due not only to differences in the amount of leaching which has taken place, but also to differences in the history of the material composing them.

The limestone soils show hardly as great a contrast as one might expect, where so decided a difference in productiveness exists, as that between the Hagerstown and Clarksville. The percentage of other mineral than quartz is not very high, although nearly three times as great in the former as in the latter. Since these soils are composed almost entirely of fine silt and clay, there is reason to suppose that the minerals present in the limestones are there in very small particles.

The Hagerstown shows a rather unusual amount of feldspar, since limestones are considered to be free from feldspar, although it has been reported in exceptional cases; but in the Decatur, which is almost as productive as the Hagerstown, no feldspar at all is found. The only other series in which this is the case is the Louisa. The presence of the feldspar in the limestone soils is the result of admix-

ture of material from other rocks. Secondary quartz crystals, often containing inclusions of calcite indicative of other origin, are abundant and characteristic in all the series. With the exception of fluorite none of the less common minerals appear in any of the limestone soils.

Four of the series analyzed represents soils derived from unconsolidated water-laid deposits. All of these are from the Atlantic Coastal Plain. With the exception of the Sassafras these series all show a high percentage of quartz, the sands ranging from 95 to 99 per cent or more of this mineral.

The Sassafras series is confined to the northern Coastal Plain, and the reasons for its less siliceous nature have been already discussed (see p. 74). It represents an admixture of rock material from many sources. The angular shape of the grains, as compared with the well-rounded forms of the Norfolk, show that the material composing it has not been subjected to as great a degree of wearing as the latter series.

The Sassafras and Elkton series furnish an excellent example of the change which may be brought about in soils from identically the same material through the processes of weathering (see p. 73). These two series are intimately associated, but the intermittent wet and dry conditions, which have existed where the latter occurs, has caused the disappearance of three-fourths of the minerals other than quartz that must have been present in the material originally. A comparison of the minerals present in the two series shows that biotite, apatite, hypersthene, plagioclase, and staurolite—a mineral peculiar to metamorphic clay slates and schists—are lacking in the Elkton, while magnetite is the only mineral present in this series which is not found in the Sassafras. A chemical analysis to see whether the percentage of silica in the entire soil mass has increased, with a corresponding decrease in the iron, phosphorus, etc., would be of much interest and might throw light upon the chemical changes which have taken place and possibly give an indication at least of the cause of the decidedly lower productiveness of the white Elkton soils. Such study, however, could not be made at this time.

The soils formed from glacial material are characterized by a relatively large percentage of other minerals than quartz, especially in the sands. This is undoubtedly due in the main to the grinding up of the rocks through the mechanical action of ice. Of the three series analyzed the Volusia and the Miami represent the Light-colored Timbered soils and the Carrington the Dark-colored Prairie soils. It should be noted that the last is characterized by a high content of feldspar and almost 50 per cent more of other minerals than quartz than is found in the humid series. The grains are less rounded, and calcite is also present. There is hardly as great a

contrast between the Volusia and Miami soils as one would have expected, since the former consist largely of shale material while the latter are composed principally of ground-up limestones and crystalline rocks. This may be due, in part at least, to the inclusion of sandy soils in the composite sample of the Miami series, which was not done in the Volusia series.

Three types of loessial soil were selected for analysis—Marshall, Memphis, and Marion. The first is a Dark-colored Prairie soil, found in the northern Mississippi Valley, the second a Light-colored Timbered soil, occurring in the southern part of this valley, while the last is a white Prairie soil, confined almost entirely to southern Illinois. They represent types of decided difference in productiveness—the Marshall being one of the richest and the Marion one of the poorest soils in the country. The Memphis holds an intermediate position, though more like the latter than the former. They are all silt loams, and therefore quite comparable from a textural standpoint, which is not true of most of the series here included.

As about 75 per cent of the soil mass consists of silt, this grade should be given most weight in comparing these soils. The Marshall shows the largest and the Marion the smallest percentage of other mineral than quartz, although the difference is not very great. The feldspars are rather more abundant and of greater variety in the Marshall, especially in the sand. Andesine, muscovite and biotite micas, apatite, and sillimanite appear in the Marshall and not in the Marion, while the opposite is true of titanite and fluorite. It is very interesting to note that the Marion soil, which is low in phosphorus, does not contain any apatite, a mineral consisting of calcium phosphate.

A very interesting fact is brought out in the remarks relative to the shape of the grains and the weathering of the orthoclase in these soils. In the Marshall the grains are mostly angular, with some fairly well rounded, and there is an admixture of fresh and much altered orthoclase, while in the Memphis the grains are mostly well rounded, with a few angular, and the orthoclase is generally highly altered. The latter represents loessial material which was transported much farther southward and has therefore been subjected to more abrasion and decomposition. The Marion seems to represent an admixture of the two classes of material.

In order to show more clearly just what minerals are present in each series and whether they are abundant or in small quantity, the following table has been arranged:

Minerals present in important soil series.

Name of minerals.	Number in which found.	Fresno.	Yakima.	San Joaquin.	Cecil.	Porters.	Chester.	Louisa.	Iredell	Penn.	Dekalb.	Morton.	Summit.	Hagerstown.	Clarksville.	Decatur.	Elkton.	Sassafras.	Norfolk.	Greenville.	Volusia.	Miami.	Carrington.	Marshall.	Memphis.	Marion.
Quartz	25	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hornblende	23	A	A	A	S	A	A	S	A	.....	S	A	A	S	S	S	S	A	S	.....	S	A	A	A	S	A
Orthoclase	20	A	A	A	A	A	.....	.....	S	A	A	A	A	A	.....	.....	.....	S	S	.....	A	.....	A	A	A	A	A
Microcline	20	.....	.....	S	A	A	S	.....	S	S	S	A	A	A	S	.....	S	S	S	.....	S	A	A	A	S	A	S
Epidote	24	S	S	A	S	S	S	A	A	A	S	A	A	S	S	.....	S	S	S	S	S	S	S	S	S	S	.....
Biotite	21	A	A	A	A	A	A	S	A	S	S	S	S	.....	S	S	.....	A	S	S	S	.....	S	S	S	.....	.....
Muscovite	20	S	A	A	A	A	A	A	.....	S	S	S	S	S	S	S	S	S	.....	.....	S	.....	S	S	S	S	S
Zircon	22	S	.....	S	A	S	.....	.....	.....	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	.....	S
Chlorite	20	.....	.....	S	A	S	S	.....	S	S	S	S	S	.....	S	.....	.....	S	S	S	S	.....	S	A	S	S	S
Tourmaline	21	S	.....	S	S	.....	S	S	.....	S	A	S	S	S	S	S	S	S	S	S	S	.....	S	S	S	S	S
Rutile	17	.....	.....	S	.....	S	S	S	.....	.....	S	.....	S	S	S	S	S	S	S	S	.....	.....	S	S	S	S	S
Plagioclase	13	A	A	A	.....	S	.....	.....	S	S	.....	S	A	.....	.....	.....	.....	.....	.....	.....	.....	S	S	S	S	S	S
Apatite	12	S	S	.....	.....	.....	.....	.....	S	.....	.....	S	S	.....	.....	.....	.....	.....	S	S	.....	A	.....	.....	S	.....	.....
Garnet	10	.....	.....	.....	S	S	S	.....	.....	.....	.....	.....	S	S	.....	.....	.....	.....	.....	S	S	.....	A	.....	A	.....	.....
Sillimanite	10	.....	.....	.....	A	.....	S	A	.....	S	.....	.....	S	.....	.....	.....	.....	.....	S	S	.....	.....	.....	.....	S	S	S
Oligoclase	7	.....	.....	A	.....	.....	.....	.....	.....	.....	.....	S	A	.....	.....	.....	.....	.....	.....	.....	.....	S	S	.....	S	S	.....
Andesine	6	A	A	A	S	.....	.....	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	A	.....	.....
Albite	5	A	.....	A	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	S	.....	S	.....	.....	S	.....
Pyroxene	6	S	A	.....	.....	S	.....	.....	A	S	.....	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Magnetite	6	.....	.....	.....	.....	.....	S	.....	S	S	.....	.....	.....	.....	.....	.....	S	.....	.....	S	.....	.....	A	.....	.....	.....	.....
Labradorite	3	.....	A	.....	.....	.....	.....	.....	S	.....	.....	.....	A	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Titanite	2	.....	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	S
Fluorite	4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	S	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	S	.....	S
Augite	2	.....	A	.....	.....	.....	.....	.....	A	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Ilmenite	2	.....	.....	.....	.....	.....	.....	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	A	.....	.....	.....	.....
Calcite	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	A	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	S	.....	.....	.....	.....
Hypersthene	2	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sericite	1	.....	.....	.....	.....	.....	.....	A	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Phlogopite	1	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Hematite	1	.....	.....	.....	.....	.....	.....	.....	.....	A	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Serpentine	1	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Actinolite	1	.....	.....	.....	.....	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Iddingsite	1	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Staurolite	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	S	.....	.....	.....	.....	.....	.....	.....	.....	.....
No. of minerals	.....	13	16	16	13	13	13	10	15	14	11	14	19	12	10	7	11	15	12	11	12	12	17	17	15	14

A=Abundant. S=Accessory or less abundant.

The total number of minerals reported from all the series is only 34[1]—a smaller number than one might expect when the many different species which have been identified by mineralogists are considered. The number present in any one series varies from 7 to 19, the average being a fraction more than 13. Of the 34 minerals present only 1—quartz—is reported in all the series, although several others occur in nearly all of them and if it had been possible to determine the minerals in the fine as well as the coarser particles it is very probable that not only other minerals besides quartz would have been found in all the series, but also a greater number. One-fourth of the 34 appear in only 1 series, while only 12 are found in as many as one-half. Taking the 12 most common minerals it will be seen that only 4 series have them all present; 4 have 1 of the 12 missing; 11 have 2 missing; 2 have 3 missing; 2 have 4 missing, and 2 as many as 5 missing. It would thus seem that there is considerable variation in the mineralogical composition of the different series, even when only the most common minerals are considered, and that this variation becomes greater when those of less frequent occurrence are included. Soils usually have a greater variety of minerals than rocks, since they are often the result of the degeneration and transportation of many different rocks.

As regards the relation between the variety or number of minerals present and the productiveness of the soils, no very definite statements can be made or conclusions drawn. However, if the different series be arranged in the order of their productiveness it will be found that only four in the most productive half fall below the average for all the series, while in the least productive half 10, or all except three—two of which are loessial soils—are less than this figure. This would indicate that soils having a variety of minerals are on the average likely to be more productive than those having a less varied mineralogical composition.

In the Coastal Plain the Sassafras has a greater variety of minerals than either the Norfolk or the Elkton and is also more productive, but the Greenville, which is more fertile than the Norfolk, has fewer minerals. In the Piedmont Plateau the Iredell has a larger percentage than either the Chester or the Cecil, although less productive, but the Louisa has fewer than either and is decidedly less desirable. In the case of the sandstone and shale soils, as well as those of glacial and loessial origin, the more productive have in nearly every case a larger number of minerals present. The limestone soils are all rather poor in minerals, the Decatur, although an excellent soil, shows less than any other series, including the Clarksville. The

[1] Some of the minerals included are really varieties of other minerals; thus, labradorite, andesine, oligoclase, and albite are all plagioclase feldspars and when not identifiable were so classed. Other examples also occur particularly among the iron minerals.

Hagerstown, however, has a higher percentage than the Clarksville and is much more productive.

Of the minerals found quartz is, of course, by far the most abundant. It is the only one of which any quantitative determination was attempted, except to state whether they were abundant or not. According to the determination the percentage in the different series varies from less than 50 per cent to more than 95 per cent, the average being about 83 per cent. Quartz constitutes about 40 per cent less of the silt than of the sand, indicating that a still smaller percentage would be found in the clay, and this is undoubtedly true. In general it may be stated that the amount of quartz is highest in soils derived from acidic rocks and in those where the material has undergone most attrition and decomposition; geographically the soils in the southeastern part of the United States.

While there are some exceptions it may be stated that, in general, the soils having the lowest percentage of quartz are the most productive. Much depends, of course, upon the nature of the other minerals present, but it is nearly always true when comparing soils derived from the same general group of rocks. It is probably least often the case in soils formed from igneous and metamorphic rocks, especially the former. In the soils from crystalline rocks the lowest percentage of quartz occurs in the Iredell series, although these soils are not as desirable as those of either the Chester or Cecil. The last two are decidedly more productive than the Louisa, which is more silicious. In the case of soils derived from sandstone and shales, from limestones, from water-laid, ice-laid, and wind-laid material, an arrangement under each division, according to the percentage of quartz, will correspond without a single exception to their productiveness. This is very strong evidence that there is an inverse relation between the amount of quartz and the productiveness of the soil when the comparison is made between soils derived from material formed by the same general agencies or processes. It would seem, therefore, that a determination of the percentage of quartz in all samples, which are analyzed mechanically and published in the soil survey reports, would be of considerable value.

Next to quartz the most common mineral is apparently epidote, although both hornblende and the two potash feldspars—orthoclase and microcline—may be considered as more abundant, since they occur as such in a larger number of series. Epidote is found as abundant in both good and poor soils and no apparent relation exists between its presence and the fertility of the soil.

Next to epidote, hornblende appears to be the most common mineral, although the potash feldspars both occur as abundant in a larger number of series. It is absent from only two, both of which represent decidedly red soils. Out of 12 series in which it is abun-

dant 8 are above the average in productiveness, while 4 are below; in the 11 series in which it is least abundant 3 are above and 8 below. This would seem to indicate that the chances for a soil being productive are greater when this mineral is abundant. The two soils, however, from which it is absent are of at least average productiveness.

Taken as a whole the feldspars are, next to quartz, the most abundant mineral in the series examined, orthoclase and microcline being the most common varieties. There is apparently seldom any relation between the presence or abundance of these two potash feldspars and the productiveness of the soil. It should be noted, however, that the Hagerstown, in which they are abundant, is much more productive than the Clarksville. Of the 16 series in which the plagioclase feldspars occur, 10 are above the average in productiveness and 6 below; in the 9 series in which none appear 2 are above and 7 below, while every series in which any of them are abundant is of very high productiveness; all of which seems to indicate a direct relation between their presence and the fertility of the soil. It is interesting to note that every series in which the plagioclases do not appear are situated in the timbered humid regions of the eastern or southeastern United States, where the soils have been subjected to the greatest amount of leaching and attrition.

The micas—biotite and muscovite—chlorite, zircon, tourmaline, and rutile, are all common minerals, but with the exception of the micas are seldom abundant. The last three are all rather hard minerals, which resist wearing and weathering, and this doubtless accounts in part at least for their wide distribution.

Apatite is of much more importance than some of the minerals already mentioned, because it is the principal mineral carrying the agriculturally important element, phosphorus, in which some think our soils are most likely to be deficient. It is reported in 11 series, in none of which is it abundant. Of the 11, 7 are above the average in productiveness and 4 below. Taking the 14 series in which it is absent, 5 are above and 9 below the average. Its absence in nearly all of the series which are of very low agricultural value, taken in connection with the above facts, is rather significant.

An interesting and suggestive point in regard to the presence or absence of this mineral in "crawfishy" or "mascerated" soils should be brought out in this connection. Two such series—the Elkton and the Marion—are fortunately included. The former is derived from identically the same material as the Sassafras, but while apatite is present in the latter it is absent from the former. Likewise this mineral is found in two of the loess soils—Marshall and Memphis—but not in the Marion. It appears that the apatite has been attacked under stagnant water conditions, the phosphorus probably leached

out or locked up in inert iron concretions which are characteristic of both soils.

One of the most peculiar things about the mineralogical analysis of the various soils is the almost total absence of the iron minerals—magnetite and hematite—which are so commonly found in rocks. This can probably be explained by the fact that all the soils examined were surface soils and that these minerals are easily attacked when organic matter is present.

The presence of magnetite may depend on slight differences in chemical composition, since some magnetites are found bright and unaltered and others have a thick coating of iron oxide, thus indicating differences in ability to resist chemical decomposition. These two types sometimes occur in the same soil.

While it has not been possible to draw as definite conclusions from these mineralogical analyses as one could wish, it is believed that enough data have been presented to show the value of such studies as another possible way of throwing light upon the complex problem of soil fertility and the changes which may be brought about by various processes. It should be borne in mind that the samples included only surface soils and that an analysis of the subsoils might give additional suggestions of value. It would certainly be interesting to know whether any marked differences exist between the surface soils and the underlying subsoils. As some of the surface soils, especially in the southeastern United States, are decidedly more sandy than the subsoils, one would naturally expect them to show a larger percentage of quartz. It is probable also that the larger percentage of organic matter in the surface soils would cause more leaching to take place and that the subsoils would not only show a smaller percentage of quartz but also a greater variety of minerals.

The samples analyzed were, as already stated, a composite of 10 samples taken in widely separated localities. They were selected to represent the series, which may include soils varying in texture from sand to clay, rather than the type. It would probably have been much better to have confined the samples to the same type. In fact, it would be well to have a number of analyses of the same type to see if there is much variation from place to place. It is hoped that further studies can be undertaken in order to determine more definitely the meaning and value of this line of soil investigation.

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PRELIMINARY
SOIL MAP
OF THE
UNITED STATES
BY
GEORGE N. COFFEY
1911

NOTE.—With our present knowledge it is not possible to show the same amount of detail in all parts of the country, and therefore the colors do not represent divisions of the same relative rank. Many of the boundaries are necessarily approximate and arbitrary.

The first letter in the symbol represents the larger division: A=Arid; P=Dark-colored prairie; T=Light-colored timbered; B=Black swamp, and O=Organic soils. The last letters occurring in smaller areas to be shown by separate colors, but symbols are used on the map where they constitute a considerable proportion of country shown as some other group.

The second letter stands for the subdivision based upon difference in the rocks, while the last letters represent the group or series. Where all the soils in a section covered by one color belong to practically only one series the series name is used, but where two or more series could not be differentiated the term group is applied.

BASE MAP FROM U. S. GEOLOGICAL SURVEY

ENGRAVED BY U.S.C.S.

Scale 1:10,000,000

100 50 0 100 200 300 400 500 STAT. MILES

A. HOEN & CO.

LEGEND

ARID SOILS
(Includes much semi-arid. Eastern boundary very arbitrary)

A — Undifferentiated

DARK-COLORED PRAIRIE SOILS
(Many small areas near eastern boundaries not shown)

SOILS FROM SANDSTONES AND SHALES

PFMo — Morton Series *(Mostly semi-arid)*

PFPr — Pierre Series *(Mostly semi-arid)*

PFKn — Kansas Group *(Boundaries in Oklahoma very arbitrary and include much timbered)*

PFOk — Oklahoma Group *(Much timbered in eastern and semi-arid in western part)*

SOILS FROM LIMESTONES
(Many small areas especially in Kansas and Missouri, not shown. Some semi-arid)

PL — Undifferentiated

SOILS FROM ICE-LAID DEPOSITS (GLACIAL)
(Boundary between these and Aeolian soils very arbitrary. Some semi-arid)

PG — Undifferentiated

SOILS FROM WIND-LAID DEPOSITS (AEOLIAN)
(Includes chiefly loessial soils with some glacial, especially in northeastern Missouri and southeastern Iowa. Some semi-arid)

PW — Undifferentiated

SOILS FROM WATER-LAID DEPOSITS (SEDIMENTARY)

PSRd — Red River Valley Group (Lacustrine) *(Numerous small areas in glacial region not shown,*

PSPl — Plains Group (Aggradation) *(Includes much semi-arid)*

PSGu — Gulf Group (Marine) *(Includes some timbered, especially in Louisiana)*

ALLUVIAL SOILS
(Only larger bottoms shown. Mostly timbered but soils have characteristics of dark-colored Prairie Soils)

PA — Undifferentiated

LIGHT-COLORED TIMBERED SOILS

SOILS FROM CRYSTALLINE ROCKS
(Excludes crystalline limestones and part of Western Mountains)

TC — Undifferentiated

SOILS FROM SANDSTONES AND SHALES
(Includes some limestone not separable)

TF — Undifferentiated

SOILS FROM LIMESTONES

TLSh — Shenandoah Group *(Purer limestone and dolomite)*

TLOz — Ozark Group *(Cherty or siliceous limestones)*

SOILS FROM WATER-LAID MATERIALS (SEDIMENTARY)

TSAc — Atlantic Group *(Includes many series and also many areas of Black Swamp soils (B))*

TSOn — Ontario or Lacustrine Group *(Includes some Black Swamp soils)*

SOILS FROM ICE-LAID MATERIALS (GLACIAL)
(Includes modified drift and some Aeolian)

TG — Undifferentiated

SOILS FROM WIND-LAID MATERIALS (AEOLIAN)

TWMi — Mississippi or Loessial Group *(Boundaries rather arbitrary and many small strips not shown, especially in Illinois, Iowa and Wisconsin)*

TWDs — Dunesand and Sandhills *(Includes much semi-arid. Many small areas not shown, especially in Michigan and Wisconsin)*

TU — Undifferentiated *(Includes all western timbered soils except glacial)*