THE BLACK ROCK FOREST

BULLETIN NO. 2

HENRY H. TRYON, *Director*

PHYSICAL PROPERTIES OF THE COVE SOILS ON THE BLACK ROCK FOREST

BY

HAROLD F. SCHOLZ

CORNWALL-ON-THE-HUDSON, NEW YORK

1931

PRINTED AT THE CORNWALL PRESS, INC.
CORNWALL, NEW YORK, U. S. A.

TABLE OF CONTENTS

FOREWORD

THIS survey presents the results of a coöperative study by the Harvard Forest and the Black Rock Forest.

Acknowledgment is made to Professor P. R. Gast of the Harvard Forest for supervision of both field and laboratory technique and the preparation of the manuscript for this report. Credit is also due Robert M. Borg, who assisted in collecting the field data.

THE BLACK ROCK FOREST

Purpose of the Study

One of the objects of the management of the Black Rock Forest is the development and demonstration of the measures necessary to improve mismanaged stands. Obviously the improvement of both growing stock and soil will contribute to this end. The purpose of this study is to identify and analyze the soils found in the coves and on the slopes.

Location of the Black Rock Forest

The Black Rock Forest (Tryon, 1930) is just west of the Hudson River at the southern edge of the village of Cornwall-on-Hudson. Scarcely more than fifty miles above New York City, pioneers following up the river had settled the locality by 1694.

Forest History

Two hundred and more years of unregulated cutting, fires, and repeated coppicing have found their final expression in the present degenerate growing stock of the Black Rock Forest. At the beginning of the period the widespread use of hardwoods for charcoal made heavy inroads on the existing forests. These clear cuttings for charcoal were followed by others for fuelwood, ties, etc. About the middle of the nineteenth century heavy cuttings on this area began to fall off.

The character of the original forest from which the present one evolved is not definitely known. Certainly, however, it differed from its present degenerate offspring in the following particulars. The virgin forest was of seedling origin as contrasted with the present coppice; the distribution of tree species was more in accord with soil and moisture requirements and temperature adaptabilities rather than accidental factors; and the chestnut now eliminated by the blight was abundant.

Climate

Eastern New York is in the portion of the temperate zone characterized by hot summers (Bowman, 1911). Due to its greater altitude the summer temperatures in the Hudson Highlands probably do not run as high as elsewhere in eastern New York. The records at West Point, which adjoins the Forest, show a mean annual temperature of 50.7 degrees Fahrenheit (10.4° C.) for the period 1880 to 1909 (Crabb and Morrison, 1914). The absolute minimum for the same period is minus 15 degrees Fahrenheit (–26.1° C.) and the absolute maximum 103.0 degrees Fahrenheit (39.4° C.). The growing season starts in May and ends in September.

Fifty to sixty per cent of the annual precipitation falls during the six warmer months (April to September inclusive). Precipitation like temperature shows considerable variation between extremes. A total of 63.56 inches (161.4 cm.) of rain fell during the wettest year of the twenty-nine year period above, and less than half that amount, 30.64 inches (77.8 cm.), during the driest year for the same period. The mean precipitation was 46.37 inches (118.6 cm.) with approximately 13.0 (33.0 cm.) falling during the summer months.

The average annual humidity for the region is somewhere between seventy-five and eighty per cent as interpreted from Bowman's map (page 119, Figure 21).

GEOLOGIC HISTORY

Structural and Historical Geology

The Highlands in which the Black Rock Forest lies is an area of varied and complex geologic history. In spite of the complicated geology of the region, certain facts seem to have been well established. Evidence is at hand, for example, to show that the entire Highlands belt is the result of a great thrust fault. The displacement of this fault, probably belonging to the Appalachian deformation (Taconic) epoch, averaged at least 2,000 feet (Berkey and Rice, 1919). A later folding which resulted in a further uplifting is believed to have taken place during the Triassic Period. This folding seems to have marked the end of major deformations. During more recent geologic times, glacial ice sheets moved across the region. The glacial action has been described as "slight," and the drift left behind as "thin and broken" (Crabb and Morrison, 1914).

Before the first disturbance spoken of above, this region was a part of the great Hudson marine gulf. Submarine deposits were laid down which became the Hudson shales. The two successive upheavals which resulted in the formation of this rough terrain exposed the limestone and shales to weathering and glacial erosion and left the Pre-Cambrian granites as the superficial rock.

Petrology

Thus the rocky substratum of the Black Rock Forest is composed almost entirely of Precambrian gneiss, schists, and limestones and their associated intrusives (Berkey and Rice, 1919). Granite, limestone, hornblende, serpentine, augite, gneiss, hornblendic gneiss, and trappean rocks characterize the region. In most cases the strata do not lie in a horizontal plane but dip at an angle of 50 to 90 degrees toward the southeast. The original character of many of these strata has been altered by dynamic metamorphism, although the most common formation of the Black Rock Forest, the Storm King granite, is freer from it than is usually the case. A detailed description of Storm King granite is given in the Appendix.

It is upon this granite bedrock that the glacial till has been deposited. In those places where the glacial drift is not more than a foot or two deep, the bedrock undoubtedly influences the development of the soil. This possibility was appreciated by Crabb and Morrison (1914), who in discussing the soils of the Highlands said, "The glacial-residual group includes all the soils formed by glacial action or by combined glacial and residual forces, as in the case where the country rock is covered only by a shallow mantle of glacial drift or, as in some extreme cases, it is practically bare of glacial deposit and the soil is affected markedly by materials from underlying rock. This group is represented by the Gloucester, Dover, Dutchess, and Culvers soils."

As might be expected in a region characterized by hard, slowly-weathering, crystalline rocks, the topography of the Black Rock Forest is extremely rough and broken. The mere statement of the fact that the elevation ranges from 450 feet at the north end of the tract to 1,461 feet in the south central portion is not significant unless it carries with it a picture of numerous V-shaped valleys having slopes often as great as 50 to 65 per cent, long narrow ridges, decided exposure categories, and rapid surface run-off. The entire area is drained by a series of brooks which eventually empty into the Hudson. Artificially formed storage reservoirs, made by damming some of the larger brooks, serve to regulate their flow in several instances.

SOIL DESCRIPTIONS

Early Soil Work

The soils of the Black Rock Forest have been mapped by the U. S. Department of Agriculture. Because the broken topography of the Highlands region makes it unfavorable for agriculture, the tract was passed over in the first survey (Crabb and Morrison, 1914) as "rock outcrop" and "rough stony land" with the exception of two small areas in the southern part of the Forest mapped as Gloucester stony loam. The early description of this soil series as well as the Clyde series, which also occurs on the Black Rock Forest area, appears in the Appendix.

In accordance with the accepted classification scheme of the period, all soils were separated upon the basis of their geologic origin, texture, and other physical properties. The importance of the rôle played by climate and vegetation in the development of the soil profile apparently was not fully understood or appreciated at the time (1914). Consequently we find the emphasis on the geologic source of the soil by the use of such terms as "water material," "mixed derivation," "ice-laid material," "crystalline rocks," etc. Also in the earlier work the soil was divided into only two strata, an upper zone, the soil, and a lower, the subsoil.

In more recent work, several zones or horizons are recognized. The physico-chemical properties of the horizons distinguish several types of soils formed in regions of different temperature and humidity. Classification of these soils considers the regional climate and vegetation of first importance, but also weights topography, chemical reaction, and moisture relations. Of the various soil types that have been distinguished, the two of interest to the student of Black Rock Forest soils are the podsols and brown earths.

The Podsols and Brown Earths

Typical podsolic soils are characterized by white leached upper horizons, especially well developed under stands of coniferous tree species. The brown forest soils, to the contrary, do not exhibit any color differences due to leaching. Podsolic soils are the product of a cool moist climate; brown soils are developed under conditions of higher temperature and somewhat greater rainfall. In the podsol region, under forest conditions, humus shows a tendency to accumulate faster than it decomposes, especially when the vegetation is predominantly conifers. In the brown soil belt there is less humus accumulation, and decomposition takes place more rapidly. Podsolic soils exhibit an "area of accumulation" in the lower part of the soil profile. The material leached out of the upper white layer is redeposited in this area. In the brown soil profile there is no well-defined area of this character. The clay content of podsolic soils is lower in the leached layer than in the area of accumulation (Kellogg, 1930), while in the brown soils the clay content is about the same throughout the entire profile. The podsol profile reaches its maximum development in a region of pure coniferous or coniferous-hardwood forests, while the brown forest soils are most characteristic in a region of mixed hardwoods and conifers or pure hardwood stands.

Field observations show that the larger portion of the area of soils covered by this study agree with the general characteristics of the brown soils, and upon that basis they are assigned to that group distinguished by Marbut (1927) as Group I ("Humid" soils), subgroup Ib (Brown Soil Group). The principal features of this group of soils as found in their undisturbed state are:

1. A layer of deciduous leaf litter one to three inches thick underlain by well decomposed, black, granular leaf mold slightly mixed with mineral soil and rarely more than one inch thick.

2. Upper mineral horizons which grade in color from dark grayish brown above to light brown or yellowish brown below and have an aggregate thickness of five to eighteen inches, being deepest in sandy profiles and shallowest in clay soils.

3. Brown, yellow-brown, and occasionally pale reddish brown horizons, characteristically heavier in texture than the superior layers. Unlike the typical podsol profile, there are no coffee-brown organic accumulations in this horizon.

4. The more or less unweathered condition of the parent material.

5. An absence of free carbonates throughout the entire profile; relatively low organic and relatively high silica content of the upper horizons, lower layers strong in alumina and iron oxides.

6. Smaller contents of nitrogen and phosphorus in lower portions of profile.

To anticipate the detailed descriptions, it may be remarked that for those soil characteristics on which data are available, the profiles studied agree with this general description. Particularly is this true of such physical properties as texture and color. The absence of free carbonates was also demonstrated by field tests. Not one of the 137 profiles dug gave a positive carbonate test with HCl.

Determination of the chemical peculiarities of the Black Rock Forest soils was not possible during this study. However, there seems to be very good evidence at hand to show that chemically they are in agreement with points 5 and 6. Bizzell (1930) recently analyzed 101 soils and subsoils representing 85 per cent of the total area of New York covered by soil surveys and found that most of the soils of the state are "medium to high in total nitrogen, phosphorus, sulphur, potassium, and magnesium" and that "a majority of the most extensive soil types are low in calcium". He also found that excepting calcium all these elements "show a tendency to increase with an increase of fineness of the soil", calcium exhibiting no definite relationship to texture.

Podsols and brown soils are developed under different climatic conditions. Yet podsol may occur in a region predominantly of brown soils and contrariwise. On examination it is often found that the exceptional soil, podsol in this case, is formed by a local climate differing from that of the region as a whole.

An example of this kind was observed on the Black Rock Forest where a slightly podsolized profile had developed under hemlock stands in moist cove bottoms. The cooler local climate of these coves results in the slow decomposition of organic debris and the formation of organic acids which leach the upper soil layers and produce a podsol in a glacial drift, which in other parts of the Forest is weathered to a brown soil.

Because these modifications of a somewhat homogeneous glacial drift sheet have been apparently a result of the local differences in moisture and temperature, topography becomes a major influence on the soil. Other examples than the one just cited of the affect of topography upon local climate and soil development are to be found on the Black Rock Forest. The occurrence of peat deposits in some of the poorly drained basins and of compacted, wet, clayey lower horizons containing rust-red, blue-green, and white flakes—common indicators of improper aeration and drainage—on flat slopes are specific illustrations.

Glinka (1927) cites several cases of the extreme importance of vertical zonation (climatic effect of elevation) in mountainous regions upon the development of soil types. As a concrete example he gives the "Pouszta" region of Hungary where, as elevation increases, chestnut colored soils give place successively to tschernosem and podsol. In this instance the chestnut colored soils are developed under semi-arid climatic conditions in a locality of insufficient moisture. The tschernosems, to the contrary, are formed in a belt having lower temperatures and greater precipitation. A further decrease in temperatures and increase in moisture furnishes the necessary climatic conditions for leaching and the development of podsol. This example is, of course, extreme and would not be likely to find a parallel in the Highlands of the Hudson where differences in elevation are not, strictly speaking, great.

It is difficult to estimate the intensity and duration of climatic influences in the soils of the Black Rock Forest. This apparent immaturity, as it is called by soils workers, is ascribed by Morgan (1930) to the comparatively recent glacial origin of the soil material. He was speaking of Connecticut soils, but the Highlands soils exhibit somewhat the same characteristics as those which Morgan was studying. However, Morgan's explanation is not sufficient because fully developed podsol profiles are found in glaciated areas in the Lake States region, and the soil material is no older than that of Connecticut. In the author's opinion a better explanation has been advanced by Romell (1930), who believes that New York state lies in a climatic transition belt between the raw humus-podsol zone of the northern Appalachians and the mull-brown soil region of the southern Appalachians. This opinion seems to be very well corroborated by both the climatological data presented and by field observations, and in it can be found a very plausible explanation of how the disturbance of general climatic conditions by topography can result in the development of podsols in the midst of brown soils.

THE FIELD DATA

During the course of the present investigation, the physical characteristics of forty-six "sets" of profiles were studied. A set consisted of three separate soil wells or holes separated by distances varying from 42 to

306 feet, the average being 103 feet. They were thus included within a triangular-shaped area varying in size from 0.04 acre for two of the smallest groups to 0.58 acre for one of the largest. For any set, the stand of trees was essentially homogeneous in composition and age class. No attempt was made to obtain uniform densities. In this way the local variations of the soil profile under the same stand were demonstrated. The descriptions appearing in this report show the range of these variations.

After each profile excavation had been completed, the following data were taken: (1) depth and physical condition of litter, duff, and humus; (2) depth, structure, color, texture, and consistency of mineral horizons (these physical properties furnished the basis for separating the horizons); (3) moisture conditions of the soil; (4) altitude, slope, and exposure; (5) soil samples for subsequent texture and humus analyses from depths of 2 to 3, 4 to 6, 8 to 10, and 18 to 20 inches; (6) the average and greatest depth of the plane of three root concentration.

BIOLOGICAL ASPECT OF SOIL TEXTURE

If any correlation is to be made between soils and the vegetation growing upon them, the portion of the profile chosen for characterizing its texture should have a biological significance. Thus, agricultural lands are classified texturally upon the basis of the amount of sand, silt, and clay in the upper four to six inches of the soil. Clearly this results from the fact that it is the upper five to eight inches which are plowed, planted, and cultivated. This is the zone of maximum feeding root development in most soils, and would indicate the importance of this part of the profile for judging the agricultural value of the soil.

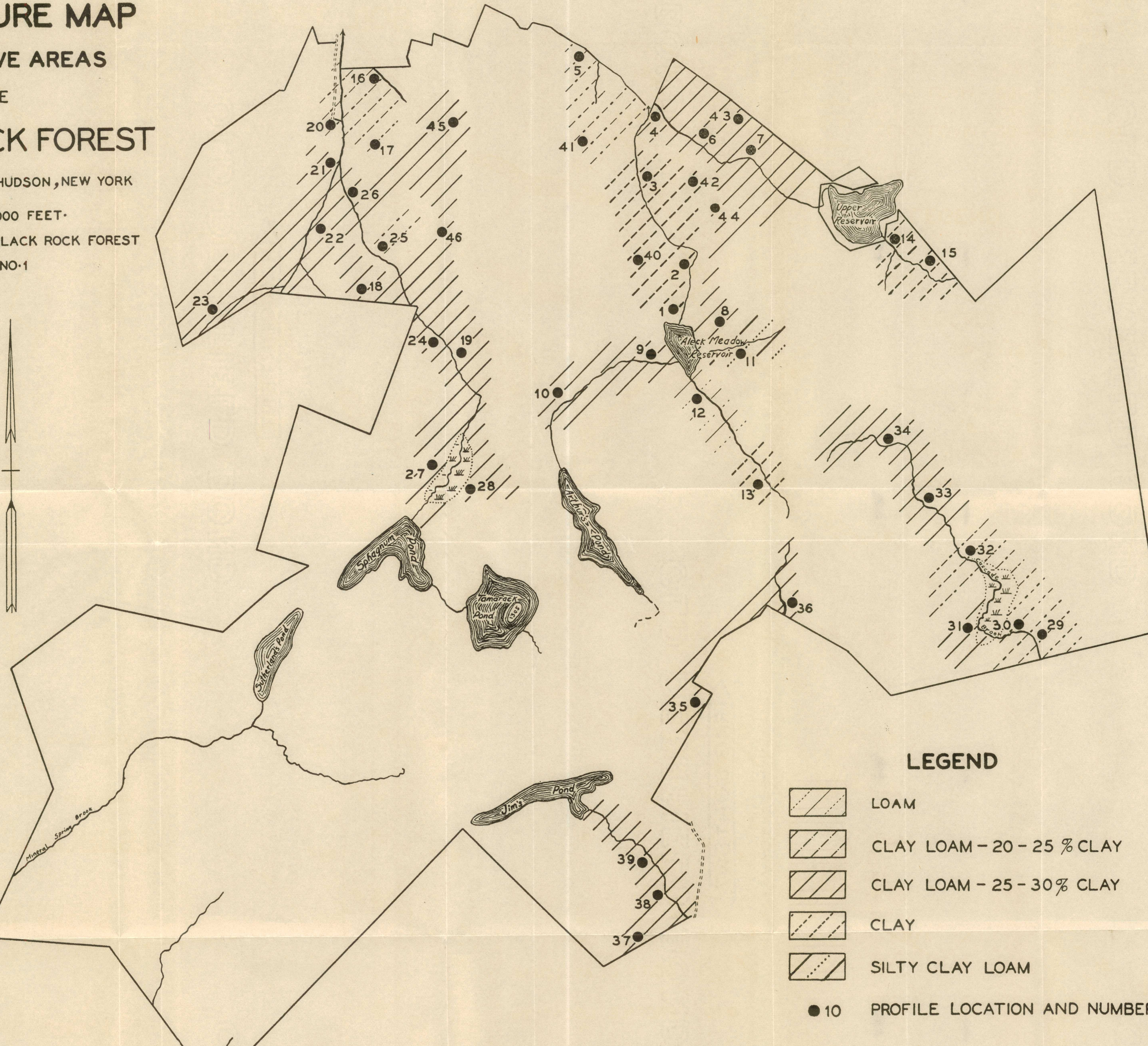
Trees, like field crops, are vitally concerned with the

SOIL TEXTURE MAP
FOR THE COVE AREAS
OF THE
BLACK ROCK FOREST

CORNWALL-ON-THE-HUDSON, NEW YORK

SCALE: 1 INCH = 1000 FEET.

BASE MAP TAKEN FROM BLACK ROCK FOREST BULLETIN NO. 1



upper layers of the soil. The feeding roots of the trees, especially conifers, are confined to the organic horizons and the upper soil layers rich in organic matter. Investigations (Büsgen and Münch, 1929; Edgington and Adams, 1925) show that these horizons are the chief source of nitrogen and, we may assume, of the other nutrients also, with the possible exception of calcium. How much water is supplied to the tree by the anchorage roots is unknown. So we will assume that it is important to know the texture characteristic of that part of the profile included within the plane of tree root concentration.

In order to determine the depth of this plane, measurements were taken for each of the 137 profile holes used for the study. These measurements show that the greatest number of tree roots are found in the upper eleven inches of the profile and that the number decreases in the eleven to eighteen inch zone, while only an occasional root is found in the Black Rock Forest soils below eighteen inches.

From these measurements it appears that the study of soil texture should include the upper eighteen inches of the profile and that the results of mechanical analyses should be expressed as an average of this depth. It should be understood, however, that eighteen inches is not a constant value that can be used for any locality but applies only to the areas studied. There the soil deposits are characteristically thin and the forest vegetation predominantly hardwoods.

In order to obtain the "average" texture of the upper eighteen inches of the soil profile, the mean percentage values for sand, silt, clay and colloid contents of the four zones (2 to 3, 4 to 6, 8 to 10, and 18 to 20 inches) were calculated. The "average" percentage of sand for the profile was obtained by dividing the sum of the percentage values for these four horizons by four. Silt, clay and colloid were calculated in the same manner. The sums of the "average" sand, silt and clay equaled approximately 100 per cent.

For some profiles it was expedient to use only one horizon for characterizing texture. The 4 to 6 inch depth was chosen for this purpose. This choice seemed to be justified upon two grounds: (1) the plane of maximum tree root concentration includes the upper eleven inches of the soil, and the 4 to 6 inch layer is the central portion of this zone; and (2) there is a marked similarity between the percentage of sand, silt and clay in the 4 to 6 inch stratum and the average for the entire profile.

The use of the 4 to 6 inch depth for characterizing the texture of the entire profile will depend upon how much variation there is between the percentage values for the average sand, silt and clay contents of the profile and the percentage values for any specific zone, as 4 to 6 inches. Such a comparison of the average values with the sand, silt and clay percentages for the 4 to 6 inch depth shows that the total variation may be as much as 12.4 per cent, or as little as 0.3 per cent, with an average of 5.2 per cent. (See Table 8, pp. 52-54.) Distributed among the four fractions—*viz.,* (1) fine gravel and coarse sand; (2) medium, fine and very fine sand; (3) silt; and (4) clay—this average of 5.2 per cent is apportioned in the order above as 0.7 per cent, 1.8 per cent, 1.1 per cent, and 1.6 per cent.

Inasmuch as these percentage variations are not, strictly speaking, large, one would naturally suppose that there would also be a reasonable agreement in respect to the texture class name. That this is actually the case is shown by the fact that in 72 per cent of the total analyses, the texture class—loam, clay loam, clay, etc.—of the 4 to 6 inch depth agrees with the classification of the soil profile as a whole.

For these soils the sand, silt, and clay contents of the upper 18 to 20 inches are fairly constant and either average percentage values or those for the 4 to 6 inch zone may be used with a fair assurance of accuracy.

There remains, of course, an open question as to whether the arithmetic mean of the sand, silt, and clay in the four depth zones is the best index to the texture of the soil from the viewpoint of forest management. Regardless of what the final decision may be with respect to this point, the fact still remains that since the 4 to 6 inch and average percentage values for the sand, silt, and clay are practically identical in 72 per cent of the cases, the 4 to 6 inch horizon may well be the only measure taken when economy of time and work is an object.

SOIL TEXTURE

Texturally the cove and slope soils of the Black Rock Forest are not entirely homogeneous. The total sand content of this group of soils varies from 20.4 to 44.2 per cent; the total silt content from 29.8 to 50.8; the total clay content from 17.5 to 42.7; and the total colloid from 10.9 to 28.8 per cent. Upon the basis of a strict classification there are four distinct classes, *viz.,* loams, clay loams, clays and silty clay loams. (See the technical discussion of the methods and results of mechanical analyses starting on page 32, especially Table 8, pp. 52-54.)

However, in many cases the differences between them are border line distinctions. For example, the average clay content of four out of a total of five profiles analyzed for texture and classified as clay varied from 30.7 to 33.1 per cent. Though a clay content of 30 per cent is the maximum in clay loam by arbitrary definition (Davis and Bennett, 1927), there is a strong temptation not to make fine distinctions and to place those soils having no more than 33 per cent clay in the clay loam class. In a like manner some of the clay loams closely approach the realm of loams in regard to their clay content, three of the total of twenty clay loam profiles analyzed having no greater clay content than 21.8 per cent, and an additional five, 25.2 per cent clay or less. Before a texture map could be made of the cove and slope areas covered by this study, it was necessary to decide just how these soils should be grouped. Should loams with their border line clay loams be grouped into one class, and clays with their border line clay loams into another; or should the usual classification in which the absolute limits of sand, silt and clay are defined be used instead? The latter possibility seemed to offer fewer difficulties and had the advantage in that the element of empiricalism was eliminated.

The soils studied may be separated into five texture categories, *viz.*, (1) loam; (2) clay loam having a clay content of 25 per cent or less; (3) clay loam having a clay content of 25 to 30 per cent; (4) clay; and (5) silty clay loam. The limits of the various areas of differing classes on the soil map are not precise, and the breaks in the cross hatching indicates the probable separation of the various areas. Their distribution is shown on the map (Figure 1).

From the standpoint of the frequency of their occurrence, (2) and (3) are by far the most important texture groups. Quantitatively clay loam constitutes 74 per cent of the total number of 27 typical profiles analyzed for texture; clays, 18.5 per cent; and loams and silty clay loams, each 3.75 per cent. It follows that the areas of loam and silty clay loam are the most infrequent. The clay soils cover the next larger area, being about four times as common as the combined loam and silty clay loam soils. Clay loams are distributed over the largest area—almost five times that of the other three texture classes combined. Of the clay loams, those having a clay content of more than 25 per cent are by far more important than the division of clay loams having less than 25 per cent clay.

Typical Profiles

A photograph of a typical brown soil developed on the prevalent heavy clay loam texture class is shown in Figure 2. That this profile is located on a slope rather than in a strictly cove area does not in the opinion of the writer render it any the less typical of the brown soils of the Forest.

The profiles developed on all the five classes of soils with varying textures described above are brown soils. These brown soil profiles, although essentially similar, differ in their physical properties with the varying quantities of sand, silt and clay which comprise the mineral soil and may be grouped on this basis. In order to demonstrate these variations, Figure 3 has been prepared. The five profiles shown by the figure were chosen as being typical of their respective texture classes. In a comparison of these profiles first to be noted are the distinct differences in the color of similar horizons. Next, in spite of textural differences, they show an important similarity in that the lower part of the soil profile is characteristically compacted. That this compactness is not always a result of heavier texture is suggested by the mechanical analysis data which accompany the five profiles. This is discussed more fully on page 25. These analyses show that the clay content of the compacted part of the profile does not exceed that of the non-compacted zone by more than four per cent, and that in two cases (profiles 11 and 40) there is less clay in the compacted lower layers than in the friable upper horizons.

It will also be observed that regardless of texture, color and physical properties there are no striking quantitative differences in the humus content of the

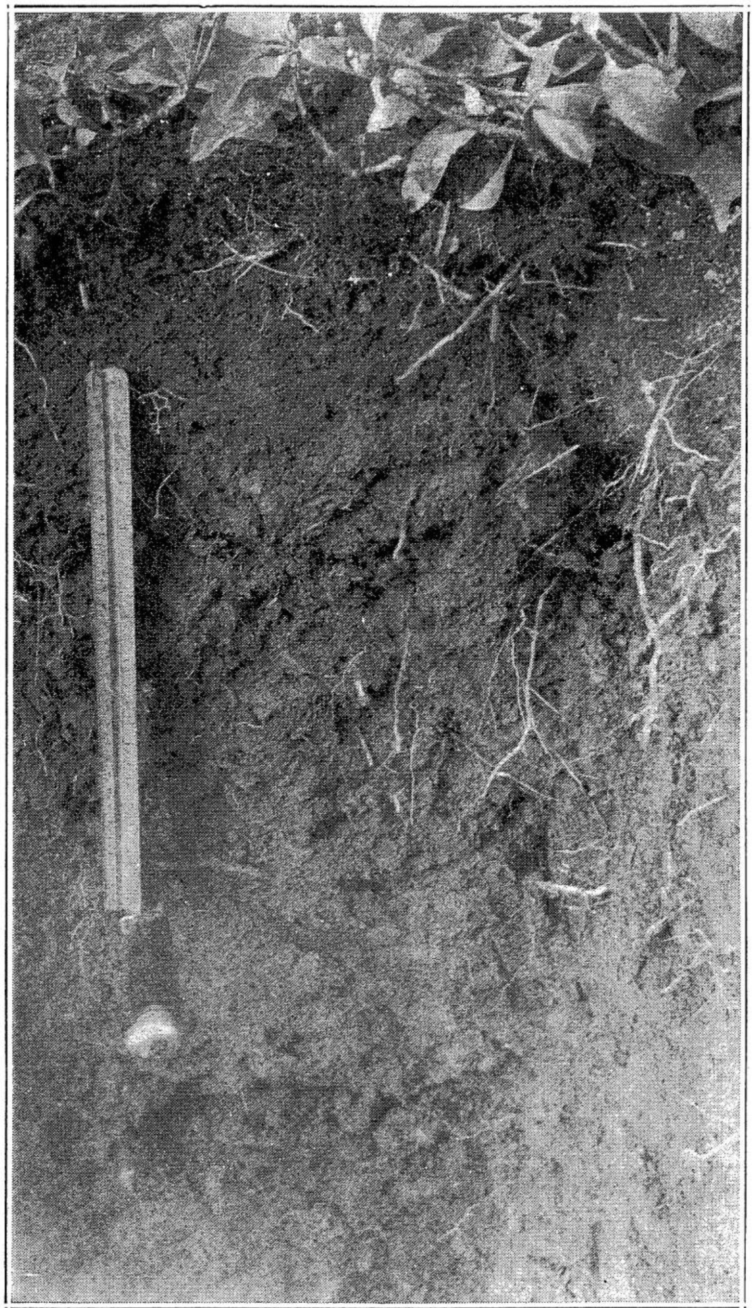


FIGURE 2. PROFILE 44. BROWN SOIL.

This soil has developed under hardwoods, chiefly chestnut oak and red oak. Recently the hardwoods were cut and red pine and spruce planted in their place. The important features of this profile are: (1) a superficial dead organic layer 0.6 to 1.0 inch thick; (2) underlain by a mineral layer (1.0 to 1.6 inches) of a dark blackish brown color, granular structure, and excellent tilth; (3) a second horizon (1.3 to 2.3 inches) having the same physical properties as the first excepting the color which is a grayish brown; (4) a third horizon, 10.1 to 11.7 inches in depth, having a medium yellowish brown color, granular structure, and excellent tilth; (5) a fourth layer (6.1 to 11.2 inches) with a light yellowish brown color, columnar structure, and a slightly compacted physical condition; and (6) a zone 7.0 to 10.0 inches in depth having a light brownish yellow color with a decided grayish cast, columnar structure, and a very compact physical condition. This last horizon contains some tongues of reddish brown clay. The average clay content of the profile as determined by laboratory analysis is 27.5 per cent. It will be noted that there is a concentration of tree roots in the upper 15 inches of the profile. Toothpicks (above the end of the 12-inch engineer's scale) mark the upper two mineral horizons, the scale the third, and an ordinary match (below the knife handle) the fourth. The last horizon is only partially shown. The total depth of the section of the profile photographed is about 25 inches.

brown soils of the Black Rock Forest; although it must be remarked that on the whole there appears to be slightly more humus in those profiles (11, 26, and 40) having the highest clay content. See also Table 1, page 32. Whether the difference is great enough to be of practical significance in forest management is questionable.

The most active root development is in the non-compacted upper layers of the soil, as shown in Figure 3. Profile 11 furnishes the exception, the roots penetrating the upper part of the very much compacted horizon. The depth at which the apparent maximum cross-sectional area of roots occur is shown by the convergence of the diagrammatic root systems on the left hand side of the profile. Above and below the point of convergence, the apparent cross-sectional area of the roots diminishes.

Tilth

The preceding discussion of the physical properties of five typical profiles opens the way for a more detailed treatment of the factors of tilth.

Unquestionably the improvement of the physical properties of the soil by silvicultural measures should be one of the ultimate aims of forest management. When the soil is loose and crummy, as in a well cultivated garden, it is said to have good tilth. Excellent tilth in forest soils is usually associated with a rapid decomposition of the superficial dead organic layer, good flocculation, a crumb structure, and a loose consistency.

By structure is meant the manner in which the clay, silt and sand particles are associated. A soil may have a grainy structure, as is the case with sand low in organic content; or the structure may be granular, as when the particles are bound into small units by the cohesive force of small quantities of organic matter. Again, the structure may be crummy, when bound by comparatively large amounts of organic matter to form a larger unit, a "crumb." The essential feature of a columnar structure is a high colloidal clay content marked by a cleavage into angular lumps when the soil is broken. With the same amount of organic matter, structure is altered by the degree of flocculation, possibly the result of differences in the nature of the organic matter. Such are at present inadequately distinguished. The content of calcium greatly affects the flocculation as do also physical changes —wetting and drying, freezing and thawing. The changes in structure determine the consistency or firmness of the soil and also its porosity.

The profiles studied show little structural variation. The average soil profile may be divided into four structural zones:

1. A superficial organic layer.
2. A zone (of varying depth but rarely exceeding fifteen inches) of mineral soil, usually granular, but sometimes columnar in structure.
3. A third zone ordinarily having a compact physical condition and a columnar structure. Less commonly this zone exhibits a granular structure and fair tilth.
4. A fourth horizon of more or less unweathered parent formations, usually of glacial till, but not uncommonly solid granite bedrock.

The duff horizons are characteristically slightly felted, and the humus horizons loosely bound together with small rootlets and mycelial threads. In exceptional cases the duff is unfelted, or both it and the humus layer may be missing—a condition often attending a crumb structure of the upper soil layers. (See Figure 3 showing the depth and physical properties of these profile elements as described in this and the preceding paragraph.)

The consistency of the soil profile varies from top to bottom. The upper ten inches is generally loose. From ten to twenty inches the soil is strongly compacted into what is locally known as "bastard hardpan" in about 50 per cent of the profiles examined. This compacted part of the profile can only be excavated easily with a mattock, and in some cases (profile 11) the compactness becomes so great that even mattock excavation is done with difficulty.

The compactness of the lower soil layers is one of the common features of the brown soils and is ascribed to the heavier texture of this part of the profile by Marbut. (See page 13 of this report.) Although this may be the usual case, it is not altogether true for the soils of the Black Rock Forest. Mechanical analysis data for 27 typical profiles show that the clay content of the upper 8 inches of the soil is slightly greater than that of the 8 to 20 inch depth in somewhat more than 50 per cent of the total number of analyses made. Neither does the absolute percentage of clay present seem to bear a definite relationship to compactness, for a comparison of the soils having a clay content of 25 per cent or less with those having more than 25 per cent clay does not show any definite trend.

Rock Content of the Soil

The soils of the Forest are characterized by an extremely high rock content. Most of this rocky skeleton material has been brought in as a part of the last glacial sheet, and is derived largely from the hard, crystalline granite of the immediate vicinity. Rock outcrops occur over the entire forest and not uncommonly the glacial drift sheet is only a few inches deep. Field observations indicate that the soil mantle is deepest on upper slopes and hilltops and shallowest in the deep, V-shaped valleys and along the lower slope areas.

A measure of the quantity of rock in the soil was obtained in this study only for the material of gravel size. The mechanical analysis of soil included only the fraction smaller than 2.0 millimeter; material larger than this was removed by sieving. By weighing the skeleton gravel material with a diameter range of 2.0 to 114.5 millimeter (4.5 inches) and comparing this weight with the weight of the unsieved sample, percentage values were obtained for the coarsest fraction. The gravel content of the 27 profiles analyzed for texture was from 17 to 52 per cent of the weight of the unsieved soil on an oven dry basis, the average value for the weight of the gravel being 31 per cent.

In addition to this rather high content of gravel, the soils of the Forest also contain a considerable quantity of rock fragments larger than 4½ inches in diameter. As previously stated, no exact measure of the amount of these coarse fragments was attempted in this study. However, general field observations led to the conclusion that the weight of large rocks and stones equals or exceeds the weight of the gravel in many profiles; and that the combined weight and volume of the two render the soil unfit for agriculture and place it in the category of absolute forest land. Also from these data it is easy to understand why the Black Rock Forest was classified mainly as rough stony land and rock outcrop in 1914 by Crabb and Morrison.

SOIL MOISTURE

The relationship between annual precipitation and the development of the distinguishing horizons of the profile led Glinka (1927) to classify the soils of the world according to the moisture conditions under which the soil genesis took place. Recently, the same classification scheme has been accepted in the United States. In accordance with this classification, podsol soils are recognized as those which are developed in the cool humid region of the northern part of the United States; the brown soils, those developed under the influence of the warmer, humid climate of the eastern and southeastern states, etc.

This climatic classification of soil upon the basis of moisture is of value chiefly as a means of orientation; for soil moisture in its direct influence upon plant growth must be studied from profile to profile within a given locality.

It has been shown (Wilde and Scholz, 1930) that within a specific area the distribution of soil moisture will depend mostly upon the nature of the topography. Black Rock Forest furnishes a concrete example of the interrelation of soil moisture and relief complexes. An examination of the brown soils of the Forest reveals that the profile is ideally moist and well drained in the cove bottoms and on lower and middle slope areas. Contrarily, on the steeper upper slopes and high ridge tops a less favorable moisture condition prevails and the soil is drier, this in spite of the fact that the glacial till is ordinarily deepest in these situations. As an opposite extreme there are a few undrained or poorly drained swampy areas formed in basin-like depressions or along the overflow zone of streams. Such profiles are wet.

In the opinion of the writer, the texture of the soils of the Black Rock area exert an influence upon the moisture conditions of the profile. This is especially true of those soils having a high clay content, which seemingly slows up the force of gravitational water on slope areas.

A tabulation of the moisture conditions of the 47 profile sets used for this study shows that approximately 80 per cent of them were classified in the field as "moist"; 10 per cent as "wet"; and 10 per cent as "dry." In the plate showing typical profiles (Figure 3), profiles 12, 26, 29, and 40 belong to the "moist" group, and profile 11, to the "wet" group.

HUMUS CONTENT

Appreciation of the importance of humus in maintaining forest soil fertility is just obtaining recognition. The variation from a mull to raw humus condition in the Danish forest soils was demonstrated several decades ago (Müller, 1884). More recently, the relationship between the rapidity of humus decomposition, the profile development, and nitrogen mobilization has been studied (Hesselman, 1926). Sherman, while emphasizing the importance of the duff, overlooked the effect of its rate of decomposition on the maintenance of soil fertility (Griffith *et al.*, 1930). Lowdermilk (1930) subsequently has shown the latter factor to be of the greatest importance in flood control measures.

The rôle played by humus in the mull-podsol variation of Danish soils can also be traced in the eastern part of the United States. In northern New England raw humus commonly develops under coniferous stands. The decomposition of humus, under the climatic conditions of this part of the eastern United States, is not rapid. Under these conditions podsol soils may be developed. On the other hand, the rate of humification is entirely different in the southern Appalachian Mountains where a warmer, more humid climate attends soil development. Here decomposition is more complete, and the profile characteristically develops into typical brown soil with mull condition.

From these generalizations one concludes that climate is a factor of no small importance in the character and rate of decomposition of the superficial organic layers of the forest floor. That this is actually the case is an established fact. Jenny (1931) found that in the eastern half of the United States "with increasing temperature, the organic matter of the soil decreases exponentially," and

Leighty and Shorey (1930) have made analyses of the carbon and nitrogen content of timbered upland soils from Maine to Florida which show a quantitative increase of both elements with decreasing annual temperature.

It is only natural, in the light of the effect of climate upon the character of the humus, that there should be differences of opinion as to the values of these organic materials as sources of soil fertility. It is not surprising, therefore, to find the statement that "the large amount of surface litter on the floor of the forest and the abundant organic material derived from it are the most obvious characteristics that distinguish fertile forest soils from agricultural soils" (Hursh, 1928). Hursh was speaking of the southern Appalachian forest region where the decomposition of humus is rather rapid and mull conditions of the soil are prevalent. Contrarily, it has been shown, with equal truth, that the accumulation of litter under old field stands of white pine in New England results in poor physical condition and deterioration of the soil (Griffith *et al.*, 1930). At first hand these opinions might seem to be contradictory, but in a final analysis they only restate what has already been said—that rapid decomposition, high fertility, and the mull profile are the result of a specific climatic effect and that slow decomposition, raw humus, and the podsol profile are a product of another and different climate.

To the extent that the Highlands of eastern New York lie in a climatic transition belt between these two regions, it would be reasonable to expect that the character of the forest humus would also be intermediate. This the field data for this study substantiate. The depth of the superficial dead organic layer is not ordinarily great—range, 1.0 to 2.0 inches, average 1.7 inches. This horizon is made up of three distinct zones:

1. A layer *(litter)* of undecomposed leaves and other debris from chestnut oak, red oak, red maple, white ash, white oak, yellow poplar, yellow birch, basswood, hard maple, beech, hickory, and occasionally hemlock. Range of depth, 0 to 1.5 inches; average, 0.3 inches.

2. A zone (*duff* or "F" layer) in which the material formerly of the litter layer has been markedly affected by the processes of decay. Range of depth, 0 to 1.0 inch; average, 0.5 inches.

3. A third zone (*humus zone* or "H" layer) in which the state of decomposition is so far advanced as to make the identification of the original source of the organic material difficult and oftentimes impossible. Range of depth, 0 to 4.0 inches; average, 0.9 inches.

Ordinarily this last layer constitutes about one half of the total thickness of the superficial dead organic layer and has a dark blackish brown color and granular structure. This organic profile, an intermediate type between the mull and the raw humus, is variously designated as "mor" by Müller (1884) and "mår" by Hesselman (1926).[1] The upper mineral horizons of the profile with this kind of humus are typically of granular structure and good tilth.

In a few instances raw humus was observed under hemlock stands, heavy in deep cool ravines and moderately thick on cool, moist northern exposures. The mår humus generally occurred under hardwoods; although in those situations where light and moisture conditions encourage earthworm activity, a mull profile was frequently found. The absence of the duff and humus zones, the more or less complete disintegration of the preceding year's fall of litter, and a crumb structure of the upper mineral layers are the distinguishing features of mull. Raw humus differs from mår and mull in the much greater thickness of the litter, duff, and humus zones, in the slow rate at which all three of these layers de-

[1] Since this study was written "The Types of Humus Layer in the Forests of Northeastern United States" by Messrs. L. G. Romell and S. O. Heiberg has appeared in "Ecology" (**12**:567-608, 1931). The confusion of nomenclature is there discussed. The descriptions of Messrs. Romell and Heiberg suggest that the following are equivalent for the soils described in this paper: mull for crumb mull; mår for leaf duff; raw humus for greasy duff. P. R. G.

compose, and in the much felted, tenacious, compacted physical condition. Raw humus is generally associated with soil leaching (podsolization) and poor tilth of the upper mineral horizons of the profile, and reaches its maximum development in cool, moist climates under coniferous forests.

The occurrence of both mull and raw humus on the Black Rock Forest points very strongly to the influence of local climate in modifying the character of the humus layers. The fact that a slightly podsolized soil has developed under the raw humus strengthens this surmise. In the light of the presence of these widely separated types of superficial dead organic layers, it is a little difficult to understand why the soils of the forest do not show a specific variation in the amount of colloidal organic matter, depending upon the nature of the forest floor (mull, mår, or raw humus) in the mineral horizons.

The depth and condition of the superficial dead organic layers show no definite correlation with the amount of colloidal humus in the soil as determined by oxidation methods. (See page 39 for a detailed description of the method.) It would seem that while the influence of local climate may be great enough to modify the character of the superficial dead organic layer, it is not strong enough to offset the gross effect of general climate in the final humification processes which take place in the mineral layers of the brown soils of the Forest.

With one possible exception, the humus content of the mineral soil fails to show any well defined trend with other factors. The one exception is the slightly greater amount of humus (determined upon the basis of averages from data showing a considerable scatter) in soils containing the highest clay content (Table 1). But even this relationship is not at all clear. If all factors other than general climate—such as soil texture and moisture, tilth, etc.—are disregarded, the following average values for the humus content of the Black Rock area are derived from Table 1: 2 to 3 inch depth, 5.05 ± 1.65[1] per cent; 4 to 6 inch depth, 3.24 ± 1.42 per cent; 8 to 10 inch depth, 2.06 ± 1.13 per cent; and 18 to 20 inch depth, 0.92 ± 0.78 per cent. These values are based upon 77 analyses which show a maximum and minimum range for the 2 to 3, 4 to 6, 8 to 10, and 18 to 20 inch depths of 2.20 to 8.86 per cent, 1.72 to 7.72 per cent, 0.40 to 5.27 per cent, and 0.00 to 2.76 per cent respectively.

TABLE 1

RELATIONSHIP BETWEEN THE PERCENTAGES OF HUMUS AND CLAY CONTENT OF THE SOILS OF THE BLACK ROCK FOREST

HUMUS CONTENT IN PER CENT

Soils Having a Clay Content of 25 Per cent or Less					Soils Having a Clay Content of More Than 25 Per cent*				
Profile No.	*Horizon Depth in Inches* *2-3*	*4-6*	*8-10*	*18-20*	*Profile No.*	*Horizon Depth in Inches* *2-3*	*4-6*	*8-10*	*18-20*
10	6.48	2.92	1.60	0.93	2	6.76	7.72	5.27	2.76
12	4.68	2.24	1.09	0.24	7	5.39	3.91	3.13	1.71
17	3.78	1.74	0.96	0.20	9		3.66		
20		3.58			11	6.49	3.24	1.95	0.18
22		2.05			14		4.94		
25	3.58	2.38	1.75	0.66	18	4.08	1.89	0.40	0.00
29	2.20	2.65	1.28	1.05	24	3.26	2.39	2.42	0.38
32	3.84	2.52	2.56	2.74	26	4.87	2.69	1.72	0.65
41	8.86	6.76	1.96	1.06	27	5.53	2.07	2.01	0.82
					31	4.12	3.04	1.05	1.06
					34		3.40		
					40	4.52	3.59	2.93	0.78
					42		2.86		
					43		2.48		
					44	7.47	4.15	2.90	0.46
					45		1.72		
					46		3.83		
Average	4.77 ±2.22[1]	2.98 ±1.43	1.60 ±0.54	0.98 ±0.85		5.25 ±1.34	3.39 ±1.47	2.38 ±1.33	0.88 ±0.81

* Because of the abnormally high clay and humus content, profile 13 was not included in these averages.

[1] ± values are the *standard deviations* of the groups, not the *standard errors of the means.*

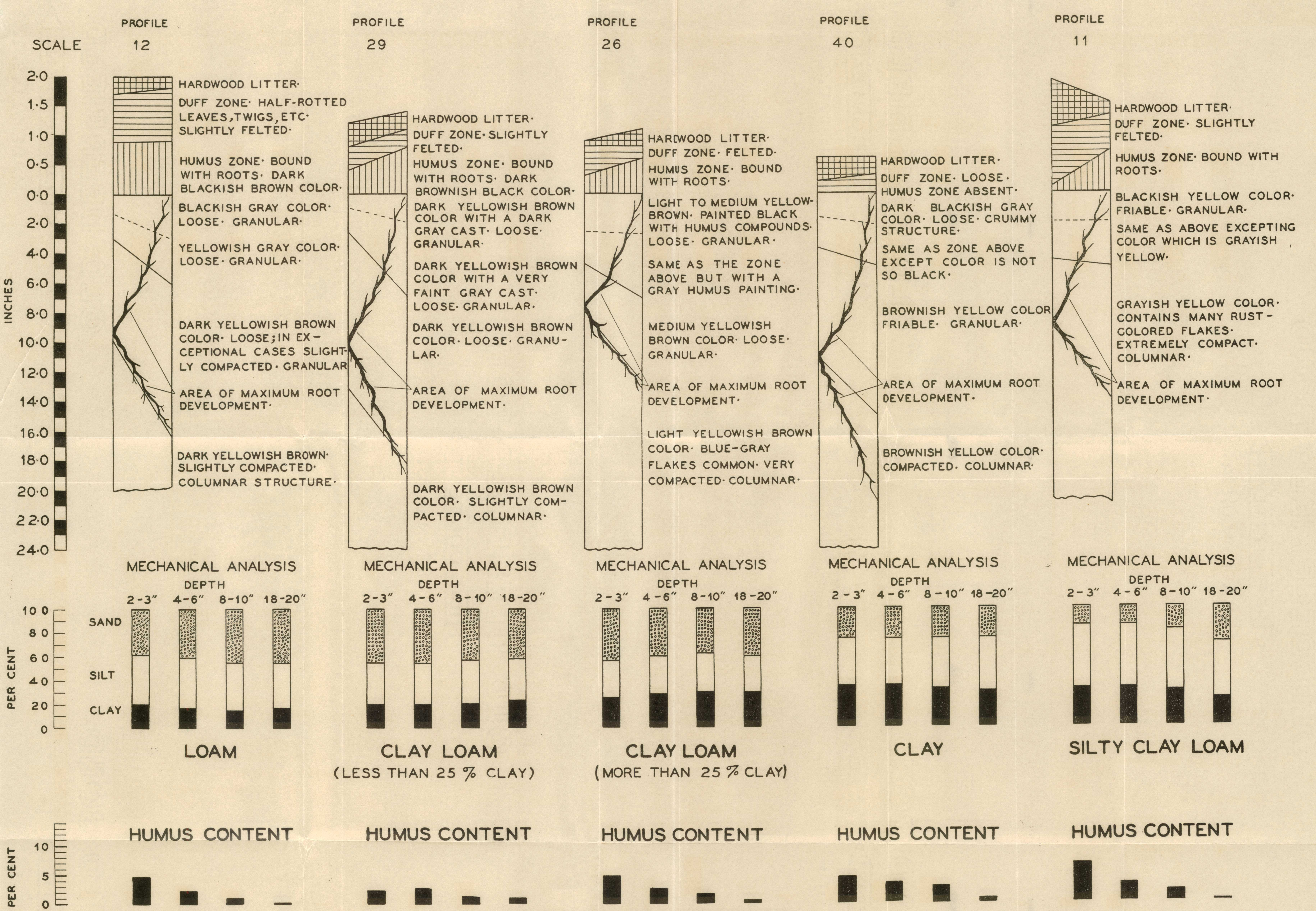


FIG. 3. TYPICAL SOIL PROFILES ON THE BLACK ROCK FOREST.
(See also Map., Fig. 1.)

CONCLUSIONS

1. Repeated coppicing for a period of over two hundred years has reduced the vitality of the growing stock and increased the percentage of less desirable species on the Black Rock Forest.

2. The abuse to which the Forest has been subjected is seemingly more strongly reflected in the degeneration of the growing stock than of the soil.

3. There is no great or convincing evidence of destructive surface erosion, a fact that might be explained upon the basis of the texture and structure of the soil—loam, clay loam, clay, and silty clay loam, oftentimes with a compact structure, especially in the deeper layers. These heavy soils are much less subject to surface translocation by run-off than lighter soils.

4. Mechanical analysis data reveal only a slight tendency toward the physical translocation of clay and colloidal materials from upper soil horizons to lower ones—erosion in one of its most subtle forms.

5. The humus content of the cove and slope soils of the Black Rock Forest is not abnormally low. Apparently humification processes have not been badly upset by the forces which have resulted in the gradual loss of the vitality of the growing stock.

6. The creation of a better physical condition of the soil should be an aim of the forest management on the Black Rock Forest area, since the factors tending to keep the soil from eroding—the high clay content and a compactness of the lower soil layers—also result in poor tilth unless the proper composition and density of the growing stock are maintained.

7. Brown soils are the predominant genetic soil type of the Black Rock Forest; but occasionally the effect of topography upon moisture and temperature, and the

character of the forest vegetation result in a definite leaching of these brown soils and the formation of a slightly podsolized profile.

8. This same influence of local climate can be traced by the character of the superficial dead organic layer, which is ordinarily a mår humus, but is sometimes modified into a mull humus or raw humus.

9. All in all the situation on the Black Rock Forest, from the standpoint of management, appears to be one in which the first major task must be one of putting the growing stock back into a state of good health. This calls for the gradual conversion from coppice to seeding regeneration and the elimination of undesirable species, either by natural or artificial methods.

10. In restoring the health of the Forest certain questions must be settled, and among them will unquestionably be the one of the comparative value of different tree species as soil improvers or soil impoverishers. For the most part, conifers are known to have a less desirable effect on the soil than hardwoods; but usually the decision of what to grow will depend not only upon what is good or bad for the soil but also upon market demands for certain tree species and the cost and return of growing them. Obviously, other things being equal, it is more practical to grow hardwoods in a hardwood region upon hardwood soil than conifers, and vice versa; and the departure from the natural order of things will ordinarily assume the nature of a research experiment.

COMMENT

THE preceding detailed treatment presents a picture of a forested area with a soil in fair condition. The coves and slopes of the Black Rock Forest are covered with a mantle of moderately heavy soil, perhaps not as deep as desirable, but with an apparently good water supply, mostly of a favorable brown earth type, loose, with a granular structure.

Improvement in this soil is to be expected in the increase of available nutrients rather than in the physical condition. But an improvement in the physical condition will be accompanied by an increase in the mineral nutrients.

In the last decade the effect of the composition of the forest stand on the development of individual and characteristic soil conditions has been convincingly demonstrated. The various types of leaf litter result in the development of an associated microbiological population. The density and seasonal duration of the tree canopy determine the local soil climate. Changes follow cuttings, and it is the art of silviculture to adapt the treatment to the desired end, the increase of growth rate or the reproduction of the stand. The regional climate, the local conditions of insolation and reradiation, exposure, moisture supply and types of plant immigration which follow openings of varying severity must be considered.

The change in biological activity, the higher rate of metabolism of the soil population under more favorable conditions is readily revealed in the rapidly thinning superficial organic layer when a dense stand is severely thinned or clearcut. Professor Fisher emphasizes also the change which must ensue when the severed root systems are attacked by organisms of decay. The supply of root material must serve as an important source of food for organisms in the deep soil layers. Enriched dark brown pockets are frequently met in the lower horizons of forest soils examined ten to thirty years after culling.

The compacted deep horizon described by Mr. Scholz may be susceptible to correction when the method of coppicing which perpetuates a root system a century or more gives way to cutting methods which result in the decay of the root systems more frequently.

It is to be expected that management which favors the better hardwoods, which are at once more demanding and soil improving, will change a soil in fair condition to one in excellent tilth. That the granular structure may be raised to the crumb structure is suggested by the sporadic occurrence of this more desirable type.

A better physical condition will also increase the chemical elements essential to plant growth. These will be released if the biological activity of the soil can be increased through management. A higher rate of metabolism will increase the carbon dioxide content, and Tamm (1929) has shown that solutions containing carbon dioxide accelerate the decomposition of feldspars. The formation of the more soluble acid carbonates by the addition of carbonic acid is well known. There is little direct experimental evidence concerning the effect of the organic material on the rate of decomposition of the minerals and the reciprocal action of these newly released nutrient elements on the rate of decomposition of the organic matter. Both actions doubtless assist the seedling reproduction which follows the working of the forest floor. If brought about by natural influences in the forest floor, they should assist the growth rate.

The recognition of soil improvement in its early stages requires the development of sensitive techniques. For physical condition the change in structure can probably be best revealed by the determination of the air space, or percolation. The literature is replete with techniques more or less satisfactorily applied to agricultural and some forest soils. But with stony forest land the difficulties are much greater than with agricultural soils. The highly differentiated strata in the forest soil require separate measurement and many repetitions; the more homogeneous agricultural soil permits of generalization from fewer data.

For the detection of chemical changes there is probably no better method than the determination of the rates of growth of various tree seedlings in soil samples with and without the addition of nutrients. Preliminary work will be required to make possible the comparison of results derived from experiments in successive years. Implied is a knowledge of the corrections necessary to reduce to a comparable basis variations in the summer radiation intensities, temperatures, and relative humidities, factors of species, genetic strains, vigor of seed; all culminating in the establishment of the formula whereby the rate of growth can be reduced to a mathematical datum, accounting therein for the original vegetative material in the seedling and its development.

Management can alter the soil condition in its gross form; but for this to become apparent requires decades; to identify the subtle initiation of transformations, a more sensitive procedure is required.

P. R. Gast

LABORATORY ANALYSES

Method of Determining Humus Content

The humus content for typical soil samples of the Black Rock Forest was determined by a modified method after W. O. Robinson (1927).

To a 1 gram sample of oven dry soil in a tall electrolytic beaker is added 10 milliliters of 30 per cent hydrogen peroxide and 10 milliliters of distilled water. The beaker is covered with a watch glass and the soil, hydrogen peroxide and water mixture is digested for several hours at a temperature of about 95 degrees Centigrade. The organic material present in the soil should be completely oxidized by the hydrogen peroxide. If small pieces of organic material are present at the end of this period, more hydrogen peroxide should be added and the period of digestion lengthened. The watch glass is then removed and the contents of the breaker are reduced in volume to 5 milliliters by evaporation. Following this, the soil material is washed from the beaker into a weighed, hardened filter paper (Robinson uses an asbestos pad). The washings and filtrate are saved, evaporated to dryness, ignited to a dull red heat, cooled in a dessicator, and weighed to the nearest 0.1 milligram. Both the filter and the residue left on it are transferred from the glass funnel used for the filtering operation to a weighing flask and are dried over night in an electric oven at 105 degrees Centigrade. The following morning, the flask, filter, and soil are weighed to the nearest 0.1 milligram. The weight of the residue on the filter paper is the weight of the insoluble part of the soil sample. To this value is added the weight of the ignited filtrate and washings, and the sum of these is subtracted from the oven-dry weight of the original sample. The difference between the two is considered to be humus material and is expressed as a per cent of the oven-dry weight of the sample by dividing the loss by 1 gram.

In addition to the determinations made with hydrogen peroxide, ignition loss values were obtained by heating parallel samples of 5 grams oven-dry weight to a dull red heat in an electric furnace for three hours. A summary of these analytical data is given (Table 2).

TABLE 2

HUMUS CONTENTS IN PER CENT BY PROFILES AND LAYERS

Number of Profile	*Depth in Inches*	*Humus Content in Per Cent*		*Ratio of Ignition Loss to Hydrogen Peroxide Loss*
		Ignition Loss	*Hydrogen Peroxide*	
2	2- 3	12.45	6.76	1.84
	4- 6	12.21	7.72	1.58
	8-10	9.89	5.27	1.88
	18-20	8.90	2.76	3.22
7	2- 3	7.43	5.39	1.38
	4- 6	6.82	3.91	1.75
	8-10	5.60	3.13	1.79
	18-20	5.40	1.71	3.16
9	4- 6	6.19	3.66	1.69
10	2- 3	9.56	6.48	1.47
	4- 6	5.49	2.92	1.88
	8-10	5.90	1.60	3.68
	18-20	2.60	0.93	2.80
11	2- 3	8.41	6.49	1.30
	4- 6	5.85	3.24	1.81
	8-10	3.48	1.95	1.78
	18-20	2.06	0.18	11.42
12	2- 3	6.50	4.68	1.39
	4- 6	3.98	2.24	1.78
	8-10	2.59	1.09	2.38
	18-20	1.97	0.24	8.20
13	2- 3	20.50	14.76	1.39
	4- 6	14.80	9.05	1.63
	8-10	13.90	6.96	2.00
	18-20	9.74	5.05	1.97
14	4- 6	7.93	4.94	1.61
17	2- 3	6.10	3.78	1.61
	4- 6	5.09	1.74	2.93
	8-10	2.94	0.96	3.06
	18-20	2.38	0.20	11.90
18	2- 3	5.33	4.08	1.30
	4- 6	3.68	1.89	1.95
	8-10	2.50	0.40	6.25
	18-20	3.10	0.00	——
20	4- 6	5.75	3.58	1.61
22	4- 6	4.58	2.05	2.24
24	2- 3	7.60	3.26	2.33
	4- 6	5.47	2.39	2.29
	8-10	5.63	2.42	2.33
	18-20	2.69	0.38	7.08

TABLE 2 (*Continued*)

Number of Profile	Depth in Inches	Humus Content in Per Cent: Ignition Loss	Humus Content in Per Cent: Hydrogen Peroxide	Ratio of Ignition Loss to Hydrogen Peroxide Loss
25	2- 3	5.97	3.58	1.67
	4- 6	3.97	2.38	1.67
	8-10	2.80	1.75	1.60
	18-20	2.20	0.66	3.30
26	2- 3	6.94	4.87	1.43
	4- 6	4.10	2.69	1.52
	8-10	3.83	1.72	2.23
	18-20	2.74	0.65	4.22
27	2- 3	9.38	5.53	1.69
	4- 6	6.55	2.07	3.16
	8-10	3.42	2.01	1.70
	18-20	1.97	0.82	2.41
29	2- 3	5.01	2.20	2.28
	4- 6	4.19	2.65	1.58
	8-10	2.70	1.28	2.11
	18-20	4.50	1.05	4.28
31	2- 3	6.96	4.12	1.69
	4- 6	5.64	3.04	1.86
	8-10	4.44	1.05	4.23
	18-20	3.24	1.06	3.06
32	2- 3	8.70	3.84	2.26
	4- 6	5.44	2.52	2.16
	8-10	5.27	2.56	2.06
	18-20	5.42	2.74	1.98
34	4- 6	7.01	3.40	2.06
40	2- 3	8.29	4.52	1.83
	4- 6	7.23	3.59	2.01
	8-10	3.78	2.93	1.29
	18-20	4.16	0.78	5.33
41	2- 3	14.68	8.86	1.66
	4- 6	12.08	6.76	1.79
	8-10	4.26	1.96	2.17
	18-20	3.09	1.06	2.91
42	4- 6	6.61	2.86	2.31
43	4- 6	5.24	2.48	2.12
44	2- 3	12.86	7.47	1.72
	4- 6	5.66	4.15	1.36
	8-10	4.43	2.90	1.53
	18-20	2.66	0.46	5.78
45	4- 6	4.82	1.72	2.80
46	4- 6	8.30	3.83	2.17

Methods of Mechanical Analysis

A mechanical analysis of twenty-seven representative profiles sampled on the Black Rock Forest was preceded by a preliminary test of two popular methods now in use—the Bouyoucos hydrometer and the pipette.

Hydrometer Technique

A fifty-gram sample of air-dry soil from which all material coarser than 2.0 millimeters has been removed by sieving is dispersed with 50 milliliters of 0.1 normal sodium hydroxide (Bouyoucos uses 5 milliliters of normal potassium hydroxide) and agitated for nine minutes with the apparatus described by Bouyoucos (1929). At the end of this period, the dispersed sample is washed into a hydrometer jar and built up to a volume of approximately 1 liter. The temperature of the solution is then adjusted to 67 degrees Fahrenheit and the sand, silt and clay content determined with a hydrometer.

The contents of the cylinder are shaken thoroughly by upending, the jar quickly set down, the time noted, and a special soil hydrometer (Bouyoucos, 1927) placed in the soil suspension. At the end of one minute, the first reading is made. This reading gives the dry weight in grams of the soil material still in suspension. The maximum diameter of the particles remaining in suspension at the end of the first minute has been calculated mathematically as equal to 0.0778 millimeters (Bouyoucos, 1928). This is done using Stoke's Law for the velocity of falling bodies in a solution. A full description of the formula for this law can be found in Harvard Forest Bulletin 15, U. S. D. A. Technical Bulletin 170, and in "The Physical Properties of the Soil" by Keen (1931). Another hydrometer reading is taken at the end of two minutes. At the end of this time the particles of sand size have settled to a depth lower than 27 centimeters. Within two minutes, all material larger than 0.0550 millimeters has fallen beyond the range of the hydrometer and no longer influences the density of the mixture measured by it. A third reading is taken at the end of fifteen minutes, at which time only particles having equivalent diameters no larger than 0.0201 millimeters remain in suspension. Since a portion of the soil particles in suspension at the end of fifteen minutes is of silt size (in the standard classification, silt ranges from 0.05 to 0.005 millimeters in diameter), the soil in solution cannot correctly be called clay. For this reason the term "fifteen-minute clay" is used instead. The fifteen minute reading completes the analysis.

Percentage values for sand, silt and clay are calculated from the hydrometer readings. To obtain the total percentage of sand, the two-minute reading (it will be recalled that the hydrometer reading gives the dry weight in grams of the soil material in suspension) is subtracted from the air-dry weight of the sample, *i.e.,* from 50 grams. The difference multiplied by two is the percentage of total sand. Silt and fifteen-minute clay are calculated in a similar way.

Pipette Technique

A ten-gram sample of air-dry soil from which particles larger than 2.0 millimeters have been removed by sieving is digested over night with 20 milliliters of 30 per cent hydrogen peroxide and 20 milliliters of distilled water at a temperature of approximately 95 degrees Centigrade. To the digested sample is added 10 milliliters of 0.5 normal sodium oxalate solution, and the entire content of soil and oxalate is dispersed for fifteen minutes with a Bouyoucos agitator. The dispersed sample is washed through a Tyler 300-mesh phosphor bronze sieve into a hydrometer jar. The material remaining in the sieve includes all sands within the diameter range of 2.0 to 0.05 millimeters.

This sand is dried to a constant weight, separated into the desired size classes by further sieving, and weighed to the nearest 0.1 milligram. The soil solution in the cylinder is built up to volume (1060 milliliters in this study) and allowed to stand until the temperature is constant. At this time, the contents are thoroughly shaken; and at the end of a specific period, depending upon the temperature of the solution (Olmstead *et al.,* 1930) a 25-milliliter sample of soil solution is taken at exactly 10 centimeters from the surface with a Lowey pipette. This sample is emptied into a 50-milliliter weighing flask and the pipette is flushed with distilled water, the washings being added to the 25-milliliter aliquot. The solution in the flask is evaporated to dryness and allowed to remain about fifteen hours in an electric oven at a temperature of 105 to 110 degrees Centigrade. The weighing flask is then cooled in a dessicator and the weight of the dry soil material determined to the nearest 0.1 milligram.

This weight, minus the weight of the sodium oxalate in the 25-milliliter aliquot, is clay. The colloid is determined in the same way, the pipette sample being taken at 6½ hours from the beginning of the operation, at a variable depth depending upon the temperature of the soil solution.

To obtain the percentage of each fraction, *i.e.,* of sand, silt, and clay, the 10-gram sample is first corrected to an oven-dry, humus free basis by applying values obtained for moisture and humus on parallel 5 and 1 gram samples. This weight, which will be less than 10 grams, divided into the oven-dry weight of the total sand obtained by sieving gives the percentage of this fraction. Clay is determined in the same way, except that it is first necessary to multiply the oven-dry weight of the 25 milliliter clay aliquot by the factor expressing the ratio of 25 milliliters to the total volume, 1060 milliliters. This factor is 42.4. The percentage of silt is obtained by adding the total weight of the clay (42.4 x oven-dry weight of clay sample) to the total weight of the sand and subtracting the sum from the moisture free, humus free weight of the ten gram sample. The difference, divided by the mechanical analysis weight (the 10-gram sample — [humus + moisture]) gives the percentage of silt.

Preliminary Check of the Two Methods

Before any analyses were made solely for texture, the importance of the length of the dispersion period was determined. This check was deemed necessary because of the apparently high silt and clay content of the majority of the soils examined on the Black Rock Forest. Two samples, from the 8-10″ depth, were chosen at random from a total of 81. A duplicate 50-gram (air-dry weight) sample was weighed out for each of these two profiles. Two samples were dispersed for nine minutes with 50 milliliters of 0.1 normal sodium hydroxide; and the other two, fifteen minutes. Table 3 shows the results of this experiment.

TABLE 3

EFFECTIVENESS OF NINE AS COMPARED TO FIFTEEN MINUTES DISPERSION

	Hydrometer Readings			
Time of Reading	*Dispersed 9 Minutes*		*Dispersed 15 Minutes*	
Minutes	*Grams*	*Per Cent*	*Grams*	*Per Cent*
	Profile 18, 8-10″ Depth			
1 (Sand)	18.7	62.6[1]	17.7	64.6
2 (Sand)	18.2	63.6	17.0	66.0
15 (Clay)	16.5	33.0	15.5	31.0
	Profile 29, 8-10″ Depth			
1 (Sand)	17.0	66.0	17.5	65.0
2 (Sand)	16.6	66.8	17.0	66.0
15 (Clay)	13.5	27.0	14.0	28.0

[1] The original weight of the sample was fifty grams. At the end of one minute 18.7 grams remain in suspension, 31.3 grams having fallen beyond the range of the hydrometer. This material (31.3 grams) is sand and is converted to percentage by multiplying by two, which gives 62.6 per cent. The two-minute sand is calculated in the same manner. The fifteen-minute clay is the material still in suspension at the end of fifteen minutes and is converted to percentage directly by multiplying by two. Silt is determined by difference and amounts to 3.4 per cent.

Upon the basis of these data there appeared to be no advantage in increasing the period of dispersion from nine to fifteen minutes for the soils of the Black Rock Forest.

The check upon dispersion efficiency was followed by another which attempted to test the approximate accuracy of the hydrometer readings during the course of routine analysis. The yield of combined sands, as determined by the two minute hydrometer reading, was contrasted with values for sand obtained by sieving. A Tyler phosphor bronze 300-mesh sieve was used for this purpose. An exact percentage duplication by the two methods is not to be expected, since the hydrometer is measuring separates having a maximum equivalent diameter slightly greater than silt (0.055 plus millimeters); while the 300-mesh sieve retains particles down to a minimum equivalent of 0.061 millimeters. The measurement with a micrometer scale of the diameter of 100 of the smallest particles retained by the 300-mesh sieve revealed that 96 per cent of them had a diameter range of 0.0525 to 0.0700 millimeters with an average value of 0.061 millimeters. Two per cent of the separates measured had a diameter of 0.0350 millimeters, and two more per cent a diameter of 0.0437 millimeters. However, there should be a reasonable agreement between the values obtained by the two methods. This was not the case (Table 4).

TABLE 4

PERCENTAGE VALUES FOR TOTAL SAND BY THE HYDROMETER AND BY DIRECT SIEVING

Profile	*Depth in Inches*	*Percentage of Total Sand by Hydrometer* [1]	*Percentage of Total Sand by 300-mesh Sieve* [2]	*Difference in Per Cent*
7	8 to 10	70.6	39.4	31.2
10	8 to 10	69.2	47.8	21.4
18	8 to 10	63.6	45.0	18.6
25	8 to 10	70.0	55.4	14.6
29	8 to 10	66.8	42.8	24.0

[1] Includes particles having an equivalent diameter of 0.055 plus millimeters.
[2] Includes particles having an equivalent diameter of 0.061 millimeters or larger.

The failure of the sand content to check more closely than approximately fifteen per cent by the two methods naturally opened the question as to whether the silt and clay values would compare more favorably. In order to answer this question satisfactorily, parallel pipette and hydrometer determinations were run. The results obtained are presented in tabular form (Table 5).

TABLE 5

TEXTURE ANALYSIS BY PIPETTE AND HYDROMETER METHODS

		Pipette			Hydrometer		
Equivalent Diameters in m.m.		2.0 to 0.05	0.05 to 0.005 m.m.	0.005 and smaller	2.0 to 0.055	0.055 to 0.020	0.020 and smaller
Profile	*Depth in Inches*	*Sand*	*Silt*	*Clay*	*Sand*	*Silt*	*Clay*
7	8-10	36.1	33.2	29.7	70.6	2.4	27.0
10	8-10	42.0	33.2	24.8	69.2	5.2	25.6
18	8-10	40.8	33.8	25.4	63.6	3.4	33.0
25	8-10	48.6	30.6	20.8	70.0	5.2	24.8
29	8-10	42.8	36.4	20.8	66.8	6.2	27.0

These data prove conclusively that neither the sand nor the silt content of the soils of the Black Rock Forest area may be determined accurately by the unmodified hydrometer method.

With the hope that a modification of the hydrometer method might prove usable, another experiment was tried. Eight soil samples having a corrected weight (moisture percentage values and the per cent of humus were determined for parallel samples) of fifty grams each were given a rigorous hydrogen peroxide treatment and later dispersed with 50 milliliters of 0.5 normal sodium oxalate solution for nine minutes. The samples were then washed from the dispersing cup into a Tyler 300-mesh sieve and the combined sands separated from the silt and clay, the washings being caught in a standard hydrometer jar. The solution in the jar was built up to volume in each case and hydrometer readings were taken as quickly as the hydrometer could be read and again at the end of two and fifteen minutes. Later at the proper time and depths, as read from the temperature-time and temperature-depth curves of Olmstead *et al.* (1930), clay and colloid aliquots were taken with a pipette. Immediately the density of the soil suspension was determined with a hydrometer. A summary of the experiment is presented in Table 6.

TABLE 6

COMPARATIVE ACCURACY OF TEXTURE ANALYSES MADE WITH THE PIPETTE AND THE HYDROMETER

Profile	*Depth in Inches*	*Total Sand in Per Cent 300 Mesh Sieve*	*Total Silt[1] in Per Cent*		*Total Clay in Per Cent*			*Total Colloid in Per Cent*	
					By Hydrometer		*By Pipette*	*By Hydrometer*	*By Pipette*
			By Hydrometer	*By Pipette*	*15-Minute Clay*	*72-Minute Clay*	*72 Minutes*	*6½ Hours*	
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*
17	2- 3	31.1	25.5	47.8	32.5	24.5	21.1	16.5	13.4
	4- 6	30.9	34.0	45.0	34.5	26.0	24.1	18.0	15.1
	8-10	36.2	32.0	37.5	38.5	30.0	26.3	19.0	15.5
	18-20	39.0	35.0	38.1	34.0	25.0	22.9	18.5	14.6
32	2- 3	47.0	20.5	30.5	29.0	23.5	22.5	14.0	12.4
	4- 6	40.6	27.0	34.9	33.0	27.0	24.5	19.0	17.2
	8-10	38.3	31.5	36.1	35.0	26.5	25.6	21.0	17.6
	18-20	37.0	33.0	37.7	34.5	25.0	25.3	20.0	17.6

[1] Silt was determined by difference in the pipette method. In the case of the hydrometer technique silt was determined directly by the formula:

$$\frac{\text{hydrometer reading at 0 minutes—hydrometer reading at 72 minutes}}{\text{weight of sample (50 grams)}} \times 100 = \text{per cent.}$$

where the "0 minutes" reading is the one taken as quickly as the graduations on the hydrometer can be read after it has been placed in the hydrometer jar.

These same data were analyzed in another way. The sand percentage value was assumed to be correct, since it had been derived by a direct determination (sieving). Likewise the clay percentage value for a hydrometer reading taken simultaneously with a pipette aliquot was assumed to be approximately correct. It can be shown that this latter assumption is not at all unreasonable (Columns *G* and *H,* Table 6). Now, total sand plus this clay, when subtracted from 100 per cent, should check reasonably closely with pipette percentage values for silt, since in both instances this fraction has been determined by difference. That these values, columns *E* and *G* (Table 7), do check closely is shown below.

TABLE 7

COMPARISON OF MECHANICAL ANALYSES BY MODIFIED HYDROMETER METHOD AND BY PIPETTE

		By Hydrometer				
				Total Silt		
Profile No.	*Depth in Inches*	*Total Sand*	*72-minute Clay*	*100%—(C+D)*	*Direct Determinations from Hydrometer Readings*	*By Pipette Silt 100%—(Clay+Sand)*
A	*B*	*C*	*D*	*E*	*F*	*G*
17	2- 3	31.1	24.5	44.4	25.5	47.8
	4- 6	30.9	26.0	43.1	34.0	45.0
	8-10	36.2	30.0	33.8	32.0	37.5
	18-20	39.0	25.0	36.0	35.0	38.1
32	2- 3	47.0	23.5	29.5	20.5	30.5
	4- 6	40.6	27.0	32.4	27.0	34.9
	8-10	38.3	26.5	35.2	31.5	36.1
	18-20	37.0	25.0	38.0	33.0	37.7

One additional comparison was made. Silt percentage as determined directly with the hydrometer (column *F,* Table 7; compare also footnote to Table 6) was compared with silt values obtained by difference (Columns *E* and *G,* Table 7). If the pipette values are assumed to be correct, silt percentage values calculated directly from the hydrometer readings show a minus deviation of 3.1 to 22.3 per cent for profile 17 and 4.7 to 10.0 for profile 32.

Reasonable accuracy can be obtained with a hydrometer when sand is separated by direct sieving and silt determined by difference. With this technique, clay and colloid values determined with the hydrometer showed a maximum variation of 3.7 per cent for the former and 3.9 per cent for the latter from pipette values. However, this scheme was such a radical departure from the standard hydrometer method that there seemed little value in using it at all. Consequently the hydrometer was replaced by the pipette for texture analysis of the Black Rock Forest soils.

The Pipette Method

The pipette method is a modification of the standard technique of the United States Bureau of Chemistry and Soils (Olmstead *et al.*, 1930). The similarities of the two methods are: (a) use of a ten-gram air-dry sample for mechanical analysis; (b) moisture per cent determination upon a parallel five-gram sample; (c) hydrogen peroxide treatment of the ten-gram sample to remove organic matter; (d) dispersion with ten milliliters of 0.5 normal sodium oxalate solution; and (e) method of calculating silt, clay, and colloid from aliquots taken with the pipette.

In contrast, the dissimilarities are: (1) way of determining dry weight of the ten-gram sample after it has been treated with hydrogen peroxide; (2) type of dispersion apparatus used; (3) "wet" pipetting; (4) method used in calibrating the pipette.

1. The base used for calculating the per cent of sand, silt, clay, and colloid was determined by corection as follows:

The moisture per cent value obtained for the parallel five-gram sample was subtracted from the ten-gram sample. The humus per cent value and the solution loss per cent values obtained for a parallel one-gram sample by W. O. Robinson's method (1927) were likewise subtracted from the weight of the ten-gram sample. The humus of the soil is oxidized by digesting it several hours with hydrogen peroxide. The loss is expressed as a percentage of the oven-dry weight of the soil sample analyzed. This corrected weight when divided into the oven-dry weight of total silt, clay, and colloid, as determined from pipette aliquots, gave the percentage values desired.

2. Dispersion was affected in nine to fifteen minutes with the apparatus recommended by Bouyoucos (See page 44), the heavier soils being dispersed longest.

3. In the standard pipette technique as outlined in U. S. D. A. Technical Bulletin 170 (1930) the pipette is dried in an electric oven after each aliquot of soil suspension has been taken. This step was omitted for the Black Rock study and the pipette used in a wet condition, hence the term "wet pipetting" has been adopted to describe this part of the technique.

4. The U. S. Bureau of Chemistry and Soils calibrate soil pipettes for total volume with mercury. In this study the pipette was calibrated with water for volume content in the following way:

A weighing flask containing a folded filter paper was filled with distilled water, and the water, filter, and flask with cover in place were weighed to the nearest 0.1 milligram. An aliquot was then taken from the flask, the excess water removed from the outside of the pipette with the filter paper held between the points of a small pair of metal tweezers. When the filter paper had been returned to the flask, the volume of the aliquot was determined by reweighing the flask and calculating the loss.

Previous to the first trial, the pipette had stood in a wet condition for two hours. Just prior to taking the aliquot, the excess water which had collected in the point of the pipette was removed with a dry piece of filter paper. Total volume, when a temperature correction from 22 to 20 degrees Centigrade had been made, amounted to 25.11 milliliters.

A second aliquot was taken in exactly the same manner, the difference being that this time the pipette drained only seven minutes. The calculated total volume for this second trial was 25.00 milliliters.

The third and last aliquot was taken after the pipette had been thoroughly dried. The calculated volume for this trial was 24.96 milliliters. The method described by Olmstead *et al.* requires that a dry pipette be used always.

These experiments show that a maximum variation from the mean total volume is 0.09 milliliters for "wet pipetting." The practical significance of this variation may best be shown by discussing the maximum possible error of the pipette method as used for the analysis of Black Rock Forest soils.

From the data presented it is evident that the error of wet pipetting will be:

$$\frac{0.09 \text{ (maximum volume deviation)}}{25.02 \text{ (average or mean volume of pipette)}} = 0.36 \text{ per cent}$$

In addition to the volume error, the other principal source of inaccuracy in the pipette method of mechanical analysis is the error of weighing. The magnitude of the error in per cent will depend both upon the limit of accuracy of the balance and upon the weight of material.

An examination of the mechanical analysis data for the Black Rock Forest reveals that the oven-dry weight of the clay aliquot for soils having a minimum, average, and maximum clay content of 9.5, 25.5, and 33.8 per cent is 0.0218, 0.0563, and 0.0751 grams respectively. The sensitivity of the balance used is 0.1 milligram, but the maximum error due to zero shift, temperature changes, and inaccuracies in setting may approach, but should never exceed, 0.2 milligrams. Therefore, the maximum possible weighing errors for the clay values above are respectively:

$$\frac{0.2 \text{ milligrams}}{22 \text{ milligrams}} = 0.91 \text{ per cent}; \frac{0.2}{56} = 0.37 \text{ per cent}; \frac{0.2}{75} = 0.27 \text{ per cent}$$

Recapitulating then, the maximum error in volume is 0.36 per cent, and the maximum error in weight is 0.91 per cent. In the exceptional case where both errors are in the same direction, an aggregate maximum error of 1.27 per cent is possible. This means that the soil sample containing 9.5 per cent clay may have instead of 9.5 per cent an apparent value lying between 9.37 or 9.63 per cent—a maximum error of plus or minus 0.13 per cent.

These data seem to show that when the clay content of the soil is as much as 10.0 per cent, the maximum cumulative error of "wet pipetting" and weighing have little practical significance.

Comparison of the Hydrometer and Pipette Methods

The pipette method of mechanical analysis has several decided advantages over other methods now in use. In the first place, it is internationally standard, having been adopted as such by the last International Soils Congress. This in itself is a decided positive advantage in scientific work. Moreover, upon the basis of work done in this laboratory, it would appear that mechanical analyses can be made as rapidly with a pipette as with other types of apparatus, the hydrometer not excepted. No difficulty was experienced in completing five analyses a day with the pipette. Finally, the accuracy of the pipette is high. This point is fully discussed by Keen (1931).

Briefly, speed and accuracy are the cardinal advantages of the pipette method of mechanical analysis.

Among the avowed attributes of the hydrometer are its approximate accuracy, its simplicity, and its speed—only fifteen minutes being necessary for a complete mechanical analysis (Bouyoucos, 1928). Contrasted with these desirable features is one bad shortcoming: the failure of the soil separates remaining in suspension at the end of the time intervals (one, two, fifteen minutes) chosen by Bouyoucos to coincide with the standard size classes—compare headings of Table 5—recognized by the U. S. Bureau of Chemistry and Soils (U. S. D. A. Technical Bulletin 170, 1930). Also, since the removal of the sand by sieving is necessary for the heavy soils of the Black Rock Forest, a mechanical analysis in fifteen minutes is not possible.

ANALYSES OF TYPICAL SAMPLES

A total of 81 soil samples were analyzed for the Black Rock Forest area by the pipette method. This number included a complete texture analysis of eighteen typical profiles and a partial analysis of nine more.

A "Complete" profile analysis included four samples taken at depths of 2-3, 4-6, 8-10, and 18-20 inches respectively. A "partial" analysis, on the other hand, included only the sample taken from the 4-6 inch depth. (See also pp. 16 *et seq.*) These mechanical analysis data are presented in summary form (Table 8) along with the texture class name as interpreted from the equilateral triangle diagram (Davis and Bennett, 1927).

TABLE 8

MECHANICAL COMPOSITION OF THE SOILS OF THE BLACK ROCK FOREST IN PER CENT OF SAND, SILT, CLAY, AND COLLOID

Profile No.	*Depth in Inches*	*Fine Gravel and Coarse Sand 2.0-0.5 Millimeters*	*Medium, Fine and Very Fine Sand 0.5-0.05 Millimeters*	*Silt 0.05-0.005 Millimeters*	*Clay Less Than 0.005 Millimeters*	*Colloid[1] Less Than 0.002 Millimeters*	*Texture Class*
2	2- 3	5.6	37.1	27.7	29.6	19.2	clay loam
	4- 6	5.6	32.4	30.8	31.2	21.9	clay
	8-10	5.4	30.2	31.6	32.8	23.1	clay
	18-20	7.3	40.8	29.1	22.8	14.8	clay loam
Average		6.0	35.1	29.8	29.1	19.8	clay loam
7	2- 3	2.6	33.8	37.2	26.4	17.9	clay loam
	4- 6	3.3	30.8	35.6	30.3	19.0	clay
	8-10	5.5	30.6	33.2	30.7	20.1	clay
	18-20	5.4	32.0	32.0	30.6	21.8	clay
Average		4.2	31.8	34.5	29.5	19.7	clay loam
9	4- 6	10.6	31.2	31.8	26.4	17.3	clay loam
10	2- 3	4.8	37.5	29.9	27.8	21.1	clay loam
	4- 6	4.3	36.5	34.0	25.2	19.1	clay loam
	8-10	5.3	36.7	33.2	24.8	12.3	clay loam
	18-20	5.9	43.0	41.8	9.3	9.1	loam
Average		5.1	38.4	34.7	21.8	15.5	clay loam
11	2- 3	1.1	14.9	52.4	31.6	20.4	silty clay
	4- 6	1.4	14.4	52.0	32.2	21.2	silty clay
	8-10	2.0	17.5	51.8	28.7	18.9	silty clay loam
	18-20	5.1	25.2	47.0	22.7	13.0	clay loam
Average		2.4	18.0	50.8	28.8	18.4	silty clay loam
12	2- 3	2.8	34.7	41.4	21.1	14.3	clay loam
	4- 6	3.7	37.6	41.6	17.1	10.4	loam
	8-10	5.7	39.5	39.9	14.9	9.6	loam
	18-20	7.5	38.3	37.2	17.0	9.4	loam
Average		4.9	37.5	40.2	17.5	10.9	loam
13	2- 3	2.0	23.9	21.4	52.7	36.3	clay
	4- 6	2.3	23.1	30.5	44.1	30.8	clay
	8-10	1.9	26.6	36.8	34.7	23.0	clay
	18-20	2.9	20.9	36.9	39.3	25.2	clay
Average		2.3	23.6	31.4	42.7	28.8	clay
14	4- 6	1.6	26.1	40.4	31.9	22.6	clay

[1] Until quite recently, material 0.002 millimeters or less in diameter has not been separated from the clay fraction. Although this separation has been made in the analyses, the "clay" in the table includes all the material smaller than 0.005 millimeters. Consequently the total sand, silt, and clay give an aggregate percentage of 100 exclusive of the colloidal percentage value.

TABLE 8—(*Continued*)

MECHANICAL COMPOSITION OF THE SOILS OF THE BLACK ROCK FOREST IN PER CENT OF SAND, SILT, CLAY, AND COLLOID

Profile No.	*Depth in Inches*	*Fine Gravel and Coarse Sand 2.0-0.5 Millimeters*	*Medium, Fine and Very Fine Sand 0.5-0.05 Millimeters*	*Silt 0.05-0.005 Millimeters*	*Clay Less Than 0.005 Millimeters*	*Colloid Less Than 0.002 Millimeters*	*Texture Class*
17	2- 3	2.7	28.4	47.8	21.1	13.4	clay loam
	4- 6	4.3	26.6	45.0	24.1	15.1	clay loam
	8-10	5.9	30.3	37.5	26.3	15.5	clay loam
	18-20	4.7	34.3	38.1	22.9	14.6	clay loam
Average		4.4	29.9	42.1	23.6	14.6	clay loam
18	2- 3	3.7	36.6	31.3	23.4	17.5	clay loam
	4- 6	5.0	37.8	33.2	24.0	18.9	clay loam
	8-10	5.3	35.4	33.9	25.4	22.5	clay loam
	18-20	3.8	33.0	36.1	27.1	20.1	clay loam
Average		4.4	33.2	33.6	25.2	19.8	clay loam
20	4- 6	6.0	37.2	33.7	23.1	13.9	clay loam
22	4- 6	6.0	33.7	35.1	25.2	15.7	clay loam
24	2- 3	2.8	35.4	36.5	25.3	17.8	clay loam
	4- 6	3.8	32.2	34.1	29.9	18.8	clay loam
	8- 10	3.6	32.8	34.0	29.6	21.3	clay loam
	18-20	6.2	40.1	30.5	23.2	16.9	clay loam
Average		4.1	35.1	33.8	27.0	18.7	clay loam
25	2- 3	4.7	43.3	28.0	24.0	17.2	clay loam
	4- 6	4.9	40.7	33.1	21.3	13.4	clay loam
	8-10	5.9	42.7	30.6	20.8	13.6	clay loam
	18-20	6.2	40.0	34.2	19.6	12.9	loam
Average		5.4	41.7	31.5	21.4	14.3	clay loam
26	2- 3	7.5	35.6	31.4	25.5	16.9	clay loam
	4- 6	7.1	32.3	33.1	27.5	17.7	clay loam
	8-10	8.3	28.6	32.5	30.6	19.9	clay
	18-20	9.1	31.8	29.8	29.3	20.9	clay loam
Average		8.0	32.1	31.7	28.2	18.8	clay loam
27	2- 3	3.6	27.9	41.2	27.3	16.6	clay loam
	4- 6	2.7	25.3	44.0	28.0	14.7	clay loam
	8-10	3.5	26.7	45.2	24.6	13.2	clay loam
	18-20	5.3	26.6	42.8	25.3	14.9	clay loam
Average		3.7	26.6	43.3	26.3	14.8	clay loam
29	2- 3	3.6	42.0	34.2	20.2	13.0	clay loam
	4- 6	4.0	42.1	34.1	19.8	13.3	loam
	8-10	4.7	38.1	36.4	20.8	14.9	clay loam
	18-20	3.4	39.0	34.2	23.4	16.0	clay loam
Average		3.9	40.3	34.7	21.0	14.3	clay loam

TABLE 8—*(Continued)*

MECHANICAL COMPOSITION OF THE SOILS OF THE BLACK ROCK FOREST IN PER CENT OF SAND, SILT, CLAY, AND COLLOID

Profile No.	*Depth in Inches*	*Fine Gravel and Coarse Sand 2.0-0.5 Millimeters*	*Medium, Fine and Very Fine Sand 0.5-0.05 Millimeters*	*Silt 0.05-0.005 Milli-meters*	*Clay Less Than 0.005 Milli-meters*	*Colloid Less Than 0.002 Milli-meters*	*Texture Class*
31	2- 3	4.3	28.6	40.6	26.5	18.9	clay loam
	4- 6	4.2	26.5	43.0	26.3	17.8	clay loam
	8-10	3.8	27.7	41.7	26.8	18.1	clay loam
	18-20	3.3	25.3	43.6	27.8	18.9	clay loam
Average		3.9	27.0	42.2	26.8	18.4	clay loam
32	2- 3	6.7	40.3	30.5	22.5	12.4	clay loam
	4- 6	5.3	35.3	34.9	24.5	17.2	clay loam
	8-10	5.2	33.1	36.1	25.6	17.6	clay loam
	18-20	4.3	32.7	37.7	25.3	17.6	clay loam
Average		5.4	35.4	34.8	24.5	16.7	clay loam
34	4- 6	5.8	28.4	37.0	28.8	23.2	clay loam
40	2- 3	4.4	21.4	40.7	33.6	21.1	clay
	4- 6	5.7	20.8	39.7	33.8	20.7	clay
	8-10	4.6	21.3	41.9	32.2	19.0	clay
	18-20	3.3	22.8	44.7	29.2	18.1	clay
Average		4.5	21.6	41.8	32.2	19.7	clay
41	2- 3	5.7	31.7	32.1	30.5	18.7	clay
	4-6	8.6	32.5	37.1	21.8	12.6	clay loam
	8-10	7.2	34.5	38.1	20.2	12.9	clay loam
	18-20	6.1	36.5	38.8	18.6	12.0	loam
Average		6.9	33.8	36.5	22.8	14.0	clay loam
42	4- 6	3.5	19.9	43.5	33.1	24.1	clay
43	4- 6	3.9	30.7	38.4	27.0	16.3	clay loam
44	2- 3	1.8	18.6	48.2	31.4	19.3	clay
	4- 6	1.8	17.4	48.5	32.3	21.6	clay
	8-10	2.5	19.8	49.4	28.3	19.5	clay loam
	18-20	5.6	34.2	42.2	18.0	11.1	loam
Average		2.9	22.5	47.1	27.5	17.9	clay loam
45	4- 6	4.6	31.0	37.8	26.6	17.6	clay loam
46	4- 6	2.8	29.9	36.6	30.7	22.0	clay

APPENDICES

Appendix I

STORM KING GRANITE [1]

"The Storm King granite is a medium to coarse grained rock, rather dark colored, slightly greenish and sometimes greasy looking, with a marked but crude gneissoid structure. The feldspars are gray or red, the quartz is gray, and there is strong black streaking of hornblende or augite. The characteristic features are (1) intense pleochroism of the biotite and hornblende which turn from green and light yellow-brown to almost black, (2) abundance of microperthitic intergrowths.

"The essential minerals are quartz (in some specimens), perthite, microcline, oligoclase, biotite, hornblende, and light brown augite in the darker varieties. The accessories are a little garnet occasionally associated with the hornblende, rather rounded zircon, apatite, and magnetite. Allanite is rare. The magnetite appears in grains and also along the cleavages of augite."

Appendix II

BLACK SOILS [2]

Water-Laid Material—Mixed Derivation

Clyde Series

"The Clyde soils are prevailingly black in the surface section, but vary to dark gray or dark brown, the strength and color being related to the quantity of organic matter present. The sub-soils are gray, yellowish gray, and mottled gray and yellow and are usually heavier than the soils. The Clyde types occur in flat or depressed, poorly drained areas, distributed throughout the northeastern quarter of the United States. They are derived from materials of mixed origin; either water-laid deposits in lakes or ice-laid deposits that have been subjected to conditions of deficient drainage."

Two types of Clyde soils are common—Clyde silt loam and Clyde silty clay loam. *Papakating* soil, consisting of black alluvial or stream bottom material, is also included with the Clyde soils.

[1] Berkey and Rice, 1919.
[2] Crabb and Morrison, 1914.

BROWN SOILS[1]

Ice-Laid Material—Crystalline Rocks

Gloucester Series

"The soils of the Gloucester series are light brown, ranging to grayish; the subsoils are yellow. Scattered rocks and large boulders occur in places, and small quantities of mica are sometimes present. The topography ranges from gently undulating to rolling or hilly, the hills usually being high, broad, and rounded. Drainage is fair to good and in places excessive. The soils are derived from a rather local glaciation of crystalline rocks, consisting chiefly of granite and gneiss, with a small amount of schist, the material being left in a thin mantle of ground moraine. These soils are developed in northeastern United States."

"The soil of the *Gloucester stony loam* consists of a stony loam to a stony sandy loam, of light brown to yellowish brown color, varying in depth from 4 to 10 inches. The subsoil is reddish brown or yellowish brown loam of relatively high sand content. Both soil and subsoil are usually friable, and, where free from rocks, easily cultivated. The lower subsoil is sometimes partially residual. Both soil and subsoil frequently contain mica scales.

"This soil is encountered mainly in Cornwall, Highland, Tuxedo, and Warwick towns. Other areas are found in Monroe, Chester, and Newburgh towns. It is developed at the base of steep slopes as narrow bands paralleling the narrow valleys, on shelves of rock in rough districts. The type is mapped in irregular areas which are usually the less rough portions of the mountains.

"The topography is generally rough and broken, the surface varying from gently sloping to steep. The type is generally surrounded by areas of rough stony land or rock outcrop.

"The drainage is good, except in those areas at the base of the highlands which often lack proper drainage owing to the accumulation of seepage water. The natural surface drainage is excellent.

"Where the glacial deposits are thin, the underlying rock have influenced the soil in both color and texture. A large number of rounded boulders of glacial origin are distributed over the surface. The stone content is generally great enough to make cultivation extremely difficult. The stones are generally of the same material as the underlying strata—gneiss and granite of Precambian age. Where the glacial deposits are deepest, the subsoil is often compact."

[1] Crabb and Morrison, 1914.

REFERENCES

BERKEY, C. P. and RICE, MARION. 1919.
Geology of the West Point Quadrangle. New York State Museum Bulletins 225 and 226.

BIZZELL, J. A. 1930.
The Chemical Composition of New York Soils. Cornell University Agricultural Experiment Station Bulletin 513.

BOUYOUCOS, GEORGE J. 1927.
The Hydrometer as a New Method for the Mechanical Analysis of Soils. Soil Science **23**:319-331.

———. 1928.
Making Mechanical Analysis of Soils in Fifteen Minutes. Soil Science **25**:473-480.

———. 1928.
The Hydrometer Method for Making a Very Detailed Mechanical Analysis of Soils. Soil Science **26**:233-238.

———. 1929.
A New, Simple, and Rapid Method for Determining the Moisture Equivalent of Soils, and the Role of Soil Colloids on this Moisture Equivalent. Soil Science **27**:233-242.

BOWMAN, ISAIAH. 1911.
Forest Physiography. New York.

BÜSGEN, M. and MÜNCH, E. 1929.
The Structure and Life of Forest Trees. (English Translation by Thomas Thompson). New York.

CLINE, A. C. and LOCKARD, C. R. 1925.
Mixed White Pine and Hardwoods. Harvard Forest, Bulletin 8.

CRABB, G. A. and MORRISON, T. M. 1914.
Soil Survey of Orange County, New York. U. S. Department of Agriculture, Bureau of Soils.

DAVIS, R. O. E. and BENNETT, H. H. 1927.
Grouping of Soils on the Basis of Mechanical Analysis. U. S. Department of Agriculture, Department Circular 419.

EDGINGTON, G. and ADAMS, J. R. 1925.
Distribution of Nitrogen in the Podsol Profile. Soil Science **20**:177-179.

FISHER, R. T. 1928.
Soil Changes and Silviculture on the Harvard Forest. Ecology **9**:6-11.

Griffith, B. G., Hartwell, E. W., and Shaw, T. E. 1930.
The Evolution of Soils as Affected by the Old Field White Pine—Mixed Hardwood Succession in Central New England. Harvard Forest, Bulletin 15.

Glinka, K. D. 1927.
The Great Soil Groups of the World and their Development. (Translated from the German by C. F. Marbut.) Ann Arbor, Michigan.

Hesselman, Henrik. 1926.
Studies of the Humus Layer of Coniferous Forests, their Pecularities, and their Dependence upon Silviculture. Meddelanden från Statens Skogsförsökanstalt 22:169-552.

Hursh, Charles R. 1928.
Litter Keeps Forest Soil Productive. Southern Lumberman 133: 219-222.

Jenny, Hans. 1929.
Relation of Temperature to the Amount of Nitrogen in Soils. Soil Science 27:169-188.

———. 1931.
Soil Organic Matter — Temperature Relationships in the Eastern United States. Soil Science 31:247-252.

Kellogg, C. E. 130.
Preliminary Study of the Profiles of the Principal Soil Types of Wisconsin. Geological and Natural History Survey, Bulletin 77a, Soil Series No. 54.

Keen, Bernard A. 1931.
The Physical Properties of the Soil. New York.

Leighty, W. R. and Shorey, E. C. 1930.
Some Carbon-Nitrogen Relations in Soils. Soil Science 30:257-266.

Lowdermilk, W. C. 1930.
Influence of the Forest Litter on Run-off, Percolation, and Erosion. Journal of Forestry 28:474-491.

Marbut, C. F. 1927.
Outline of a Scheme for the Differentiation of Soils into Mapping Units on a Uniform Basis for All Countries. The First International Congress of Soil Science, Washington, D.C., Volume I. Report of Subcommission II, Subcommittee on the General Soil Map of the Americas.

Moore, Barrington. 1922.
Humus and Root Systems in Certain Northeastern Forests in Relation to Reproduction and Competition. Journal of Forestry 20:233-254.

Morgan, M. F. 1930.
The Soils of Connecticut. Connecticut Agricultural Experiment Station, Bulletin 320.

MÜLLER, P. E. 1884.
Studier over Skovjord. Denmark.

OLMSTEAD, L. B., ALEXANDER, L. T., and MIDDLETON, H. E. 1930.
A Pipette Method of Mechanical Analysis of Soils Based on Improved Dispersion Procedure. U. S. Department of Agriculture, Technical Bulletin 170.

ROBINSON, W. O. 1927.
The Determination of Organic Matter in Soils by Means of Hydrogen Peroxide. Journal of Agricultural Research **34**:339-356.

ROMELL, L. G. 1930.
Forest Soil Research in Relation to Forestry with Particular Reference to the Northeast. Journal of Forestry **28**:841-848; and **29**:150. 1931.

TAMM, OLOF. 1929.
An Experimental Study on Clay Formation and Weathering of Feldspars. Meddelanden från Statens Skogsförsökanstalt **25**:1-28.

———. 1930.
Om Brunjorden I Sverige. Svenska Skogsvårdsföreningens Tidskrift **30**:1-41.

TRYON, HENRY H. 1930.
The Black Rock Forest. Black Rock Forest Bulletin 1. Cornwall-on-the-Hudson, New York.

WILDE, S. A. and SCHOLZ, H. F. 1930.
The Basis for Subdividing Mountainous Forests for the Purpose of Management. Journal of Forestry **28**:1104-1109.