WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

ERNEST F. BEAN, Director and State Geologist
A. R. WHITSON, In Charge Division of Soils

BULLETIN NO. 77A **SOIL SERIES NO. 54**

PRELIMINARY STUDY OF THE PROFILES OF THE PRINCIPAL SOIL TYPES OF WISCONSIN

By
Charles E. Kellogg

PUBLISHED BY THE STATE
1930

GEOLOGICAL AND NATURAL HISTORY SURVEY

INTRODUCTION

The classification of soils in use in the Soil Survey of the state in common with that in use by the U. S. Bureau of Chemistry and Soils with which we are cooperating, is largely based on the geological origin of the soil. This includes the character of the underlying rock as well as that from which the soil material was formed, the agency or agencies involved in the formation of the soil material, the texture, organic matter, topography and other features affecting its agricultural character.

After these agencies have produced these various soil materials in their present form and location they have been subjected to the climatic conditions of temperature and rainfall, and of the natural vegetation, all of which have an important effect on the processes of weathering to which the soil is subjected. This weathering has been studied chiefly by Russian scientists and they have shown that radically different and characteristic soil profiles are produced under each of the great climatic regions of the world. The tendency is for each set of climatic conditions to develop its characteristic profile on all rock and basal soil material no matter how much these materials may vary. Nevertheless, the effects of these variations in parent soil material persist and always cause important and frequently the dominating differences in the local soils of each climatic region. Especially is this true in a region of recent glaciation such as that of most of Wisconsin where the time since the formation of the parent soil material, the glacial drift, has been too short to permit the full development of the climatic profile.

This report by Dr. Kellogg covers a brief description of the profiles of the chief soil types of the state as they have been mapped in our detailed soil survey. It is expected that a study of these profiles will be made later to determine what effects profile development has had on the chemical and physical nature of the soil and how these effects affect the agricultural nature of the soil.

A. R. WHITSON,
In charge of Soil Survey.

FOREWORD

Since the rise of the Russian school of soil science, soil classification has been recognized as a separate branch of science. Its object of study is the soil, considered as a dynamic body, produced through the operation of natural forces. The action of climate, vegetation, and other agencies upon the surface of the earth has produced soil bodies with certain characteristics. On the basis of these characteristics the classification is made. The soil itself, as the product of soil-building forces acting upon the formations, is the object of classification.

The important soils of Wisconsin have been studied in order to determine something of their character and how they are to be classified.

ACKNOWLEDGMENT

The writer wishes to express his gratitude to Dr. M. M. McCool, Michigan State College, under whose direction this work has been done, and to Professor A. R. Whitson, University of Wisconsin, for kindly interest and helpful suggestions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

PRELIMINARY STUDY OF THE PROFILES OF THE PRINCIPAL SOIL TYPES OF WISCONSIN

GENERAL FEATURES OF WISCONSIN

GEOLOGY

The surface geology of Wisconsin offers a wide diversity of features, both in lithological composition and mode of origin. The greater portion of the state is covered with glacial drift of the Late Wisconsin period. There is, however, a large area in the central part of the state, as well as a smaller area in the southern part, over which this ice sheet did not pass, thus leaving exposed the older drift. The southwestern part of the state has suffered no advance of the ice and is referred to as the "driftless area". A portion of this area has been covered with a mantle of loess of varying thickness; in fact, it is very probable that the glacial drift has received some loessial material.

The accompanying sketch map (Figure 1) shows the distribution of the principle features of surface geology. The arrows indicate the general direction of the ice movement within the several lobes. In Figure 2 the important rock formations are shown. A brief description of each of the general divisions shown on the glacial map will be given.[1]

(1) Wisconsin Drift

(a) Heavy red clay drift. The matrix of this material is heavy, reddish, lacustrine clay. Alden (1) has studied the deposits near Lake Michigan, and he points out that the red color is apparently due to a delicate coating of iron oxide. This type of weathering could hardly have taken

[1] For more detailed information on the geology the reader may consult the following: (1) (8) (19) (32) (49).

place under the climatic conditions of the region. The previous till sheet has very little red color, so that a new source must be found. It can hardly be imagined that the lakes were able to bring about the original formation of

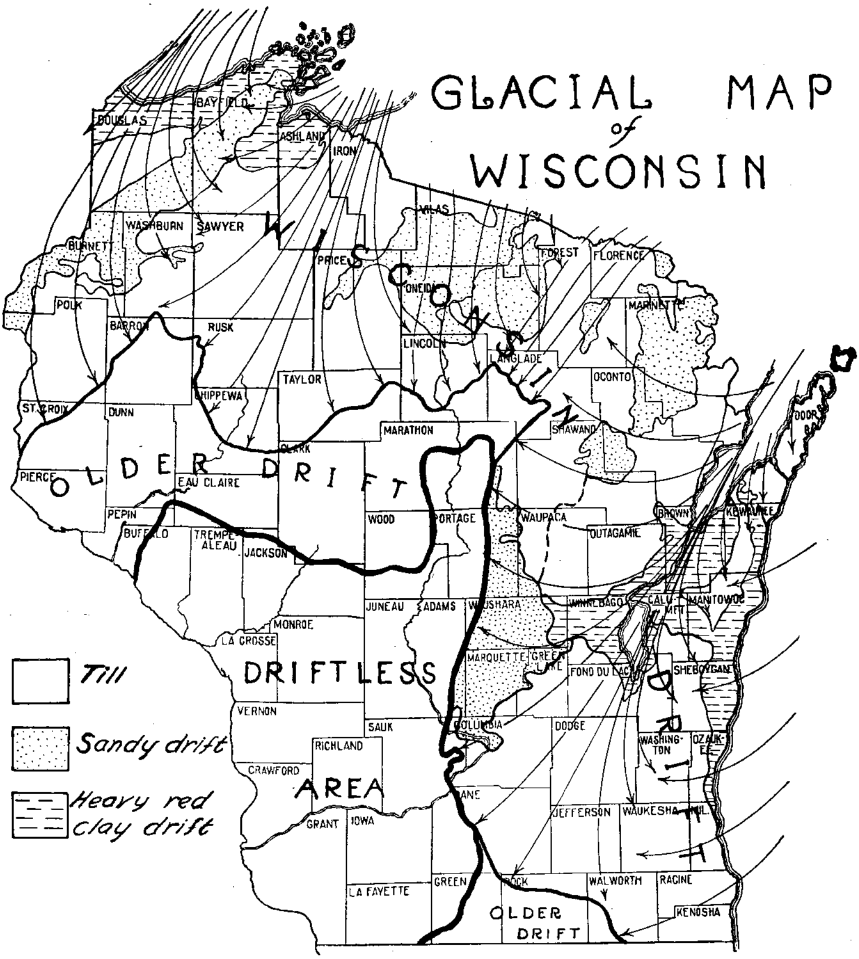


FIGURE 1. *Map showing the general conditions of surface geology in Wisconsin.*

The lines show the direction of the ice movements in the different lobes. The broken line extending north through Waupaca County separates the southern calcareous till from the acid drift to the north.

this material. The evidence seems to indicate that the clay came from some old northern deposits and was merely reworked by the lakes.

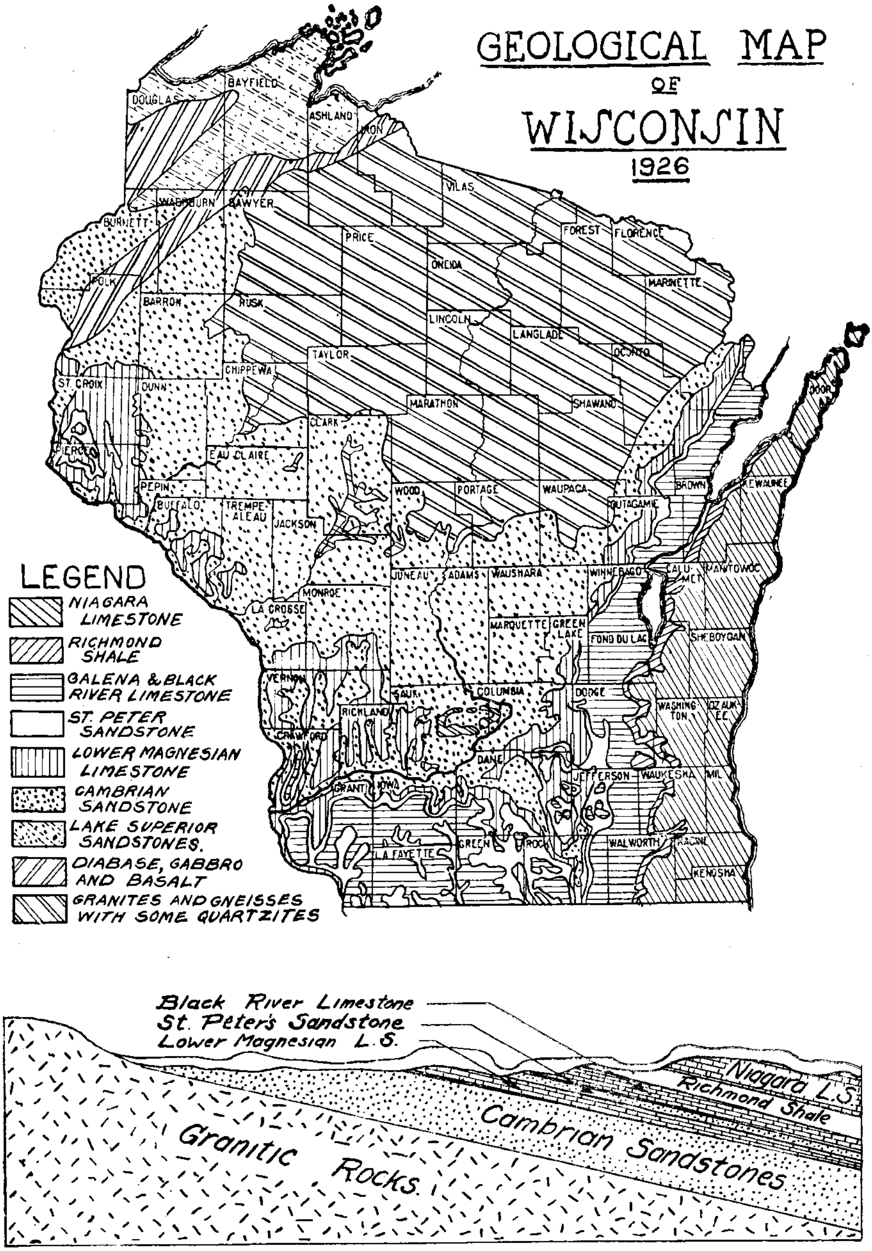


FIGURE 2. *Geological map of Wisconsin and cross section from Marshfield to Milwaukee.*
Taken from Wisconsin Geological Natural History Survey.

Below the weathered surface the clay has sufficient calcium carbonate to effervesce with acids. Some of the accretions are large enough to be seen with the naked eye but most of the lime exists in very small particles diffused through the mass. It is very probable that originally the clay was highly acid but that lime was admixed with it during its deposition by the glacial lakes. Where varves are still distinct one may observe differences in the lime content between the different layers.

Apparently most of the material has been influenced by minor ice movements since its original deposition. In some places this ice movement was sufficient to produce more relief and incorporate with the clay small amounts of sand and stones, while in other areas the varves are still very distinct. Sandy material has been deposited over the clay in small areas. These areas are most numerous in regions which have been disturbed by the ice. Some of the sandy material has been wind-deposited and a portion of it is alluvial. Of this alluvial material a part has been deposited by streams while some of it consists of a "slumping" of the sand down from the high morainic hills at the margins.

Much of this formation has been dissected by streams, which have cut V-shaped valleys into the clay. Some of these valleys have sharp, precipitous slopes. Between the valleys the land is only gently undulating or nearly flat in the undisturbed districts. The ice-moved areas are more generally undulating or gently rolling in topographic feature.

(b) Sandy drift. The areas shown on the map are those in which nearly all of the material consists of sandy outwash plains or moraines. The material comprising these formations is acid in character for the most part. The large area in the central part of the state includes considerable outwash which also extends well over into the driftless area.

(c) Till. This includes the ice deposited drift of medium texture. In topographic feature the formations vary from undulating or gently rolling in the till plains to hilly in the terminal moraines. Of course there are included many areas of glacial outwash too small to be shown on the small scale sketch map. As would be expected from an in-

spection of the two maps just mentioned (Figures 1 and 2), the till in the northern part of the state is derived largely from crystalline rocks and is acidic in character. That in the southern portion has been greatly influenced by limestone rocks and is usually calcareous below the weathered surface; i. e., below about four to six feet. A dashed line extending north through Waupaca County (Figure 1) approximately separates the acid drift from the calcareous drift further south. The till in the northern part is generally quite stony; in fact, stoniness is frequently the limiting factor in a consideration of these lands for agricultural development. Except in local areas the southeastern drift is comparatively free from stones. There is considerable reason to believe that a mantle of loess has been deposited on portions of the southern drift. The predominating texture of the soil developed from the acidic drift is loam, while the soils from the calcareous drift are chiefly silt loams, except that portion which lies north of the eastern red clay area. This till ordinarily gives rise to loam soils.

(2) Older Drift

These areas consist largely of till. The southern area is essentially of the same material as that composing the adjoining Wisconsin till. The western portion of the upper area is calcareous in nature, while the remainder is largely derived from crystalline rocks and is rather thin, overlying the granite and sandstone. It is probable that portions of this drift have received a thin mantle of loess.

(3) The Driftless Area.

By a glance at the outline map shown in Figure 2 it can be seen that the original rocks are mostly limestone and sandstone with some granite. Some of the sandstone is very fine in texture and approaches a shale. A large portion of this area has received a loessial mantle, especially near the western margin where it varies from a few inches to several feet in thickness. As a consequence the soils in this area offer a wide range in texture. Since the driftless area is older than the formations of glacial drift a more mature drainage system was developed. Only a few unimportant swamps are to be found, while in the region of Wisconsin drift there are large areas of peat and marsh border soils. The driftless area is characterized by considerable more relief than the other portions of the state. The slopes along the drainage channels are very steep and, for the most part, untillable. In these places the surface material has been eroded away leaving a thin stony soil.

CLIMATE[1]

Wisconsin is characterized by a continental climate which is somewhat ameliorated at the margins of the Great Lakes. The high elevation in the north central por-

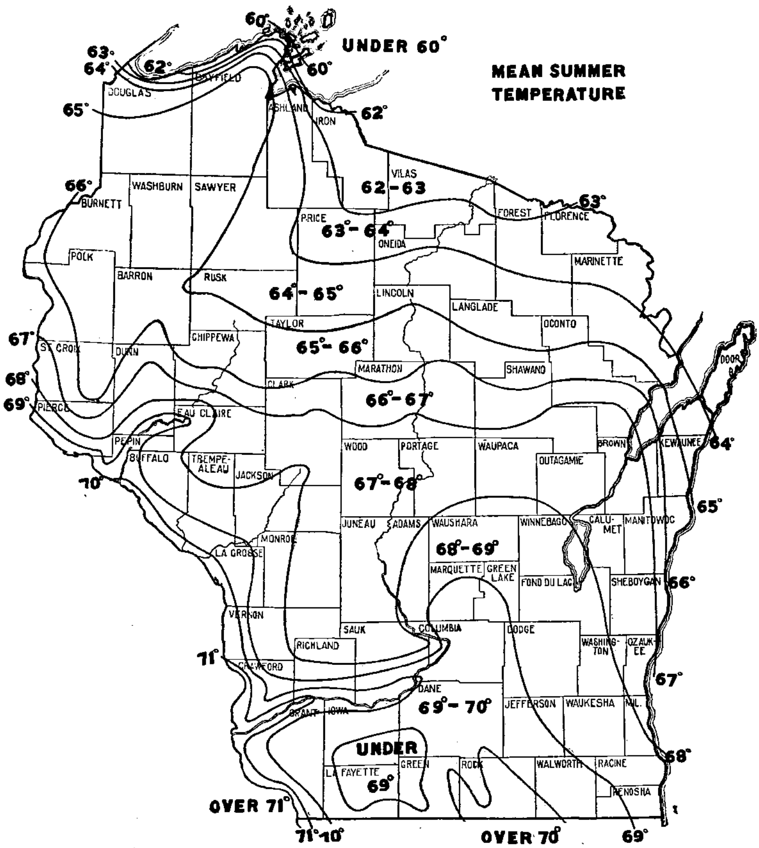


FIGURE 3. *Mean summer temperature for Wisconsin.*
Average of the daily maxima and minima for June, July, and August.

tion of the state also has the effect of lowering the annual temperature for that section. At Madison the highest and lowest recorded temperatures are 104° and —29° respect-

[1] Much of the material for this discussion of climate has been taken from the records of the United States Weather Bureau. To Whitson and Baker (50) the author is indebted for the maps showing the summer and spring temperatures and their work should be consulted for more detailed information.

ively, while for the more northern portion the minimum may be as low as —52° and the maximum about the same as for Madison.

The mean summer temperature for Wisconsin is shown in Figure 3. In Bayfield and Douglas Counties the great influence of Lake Superior on a small strip adjacent to its

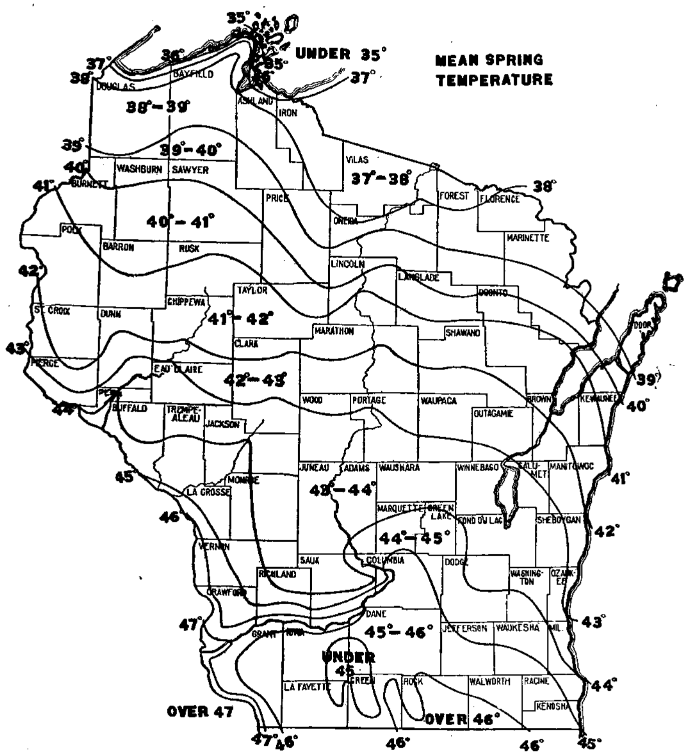


FIGURE 4. *Mean spring temperature for Wisconsin.*
Average of the daily maxima and minima for March, April, and May.

shores can be seen. In the north central region the temperatures are lower because of the greater elevation of that section. Lake Michigan also exerts a considerable influence, but not quite as sharp as that of Lake Superior; however, the former is felt at a much greater distance from the shore. An examination of Figure 4, showing the mean spring temperature, reveals that the influence of the lakes is marked at this period. There is more percolation of water through the soil in the areas which have the lowest temperature at the time when moistening is most pronounced.

Wisconsin lies in the western part of the strictly humid portion of the United States. The rainfall varies from 28 to 34 inches within the state, the general average being 31 inches. Of this rainfall approximately 70 per cent comes during the summer months, April to September. Most of this rainfall comes as frequent showers. The average annual snowfall amounts to about 45 inches. The deepest snow covering is found along Lake Michigan and in the northern part of the state. In the northern sections snow usually covers the ground from about December 1st to April 1st with an average winter depth of about a foot, although in February a depth of two to three feet is not uncommon. The relative humidity has not been recorded except at a few stations. The data show considerable variation from an annual mean of about 75 per cent.

TABLE 1.—*Climatic Data from Several Stations in Northern Europe and from Wisconsin*

Station	Mean Annual Temperature	Mean Annual Rainfall	Authority*
Riga, Latvia	42.4	21.3	24
Helsingfors, Finland	39.6	24.4	9
Archangel, U. S. S. R.	32.5	15.3	24
Tromsö, Norway	36.3	41.81	5
Harparanda, Sweden	33.1	17.7	11
Ostersund, Sweden	35.6	19.7	11
Finland (Average of 8 stations for 20 years)	----------	18.85	18
London, England	49.5	25.1	24
Paris, France	50.5	20.8	24
Berlin, Germany	47.3	22.9	24
Copenhagen, Denmark	45.9	21.5	24
Madison, Wisconsin	45.7	31.18	U. S. Weather Bureau
Superior, Wisconsin	38.1	25.9	

*Numbers refer to Literature Cited.

For comparison a few data from some stations in Northern Europe having somewhat similar soils, have been included (Table 1). Those stations from the region of strong Podsol soils in northern Europe have a mean annual temperature somewhat lower than in northern Wisconsin, but not appreciably so in some. A considerable variation obtains in annual rainfall. The amount of water actually percolating through the soil is of great importance in its development and is dependent upon the rainfall and evaporation. The rate of evaporation is largely influenced by temperature and humidity. Although no precise data were obtained except for a few stations, it is believed that the relative humidity in Finland, Sweden, and that general section is between 70 and 85, as for northern Wisconsin. It is the temperature above the freezing point with which we are primarily concerned because when the soil is frozen no percolation can be expected to take place and evaporation is low. Therefore it is not the mean annual temperatures but the temperatures above the freezing point which are important. In Figure 5 the yearly temperatures

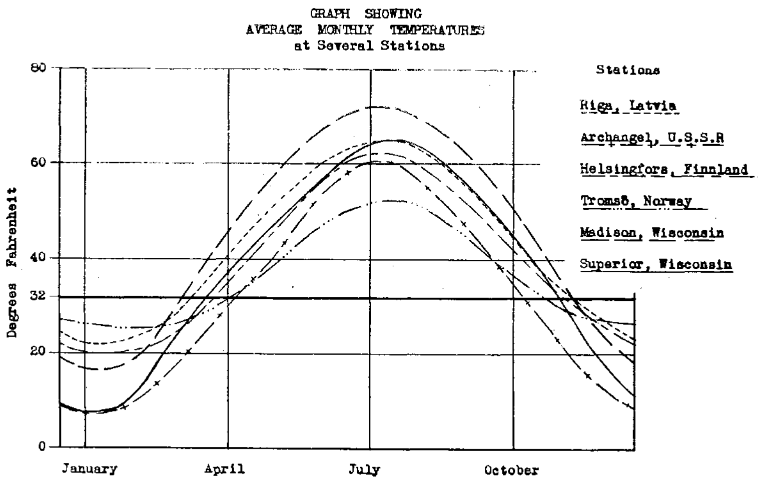


FIGURE 5. *Curves showing temperatures at several stations in Europe and in Wisconsin.*

These are plotted from the monthly averages. The area under the curve and above 32° F is the most important consideration in soil-building.

of a few stations are shown by curves. The temperatures in Wisconsin fall low in winter but the areas under the curve and above the line of freezing are considerably greater than for the other stations except Riga. Thus, during the period above freezing, evaporation is greater in Wisconsin than at the other stations and, with equivalent amounts of rainfall, we would expect more percolation at the stations in northern Europe. Even with less rainfall, a corresponding decrease in the temperatures above freezing will lower the evaporation and maintain percolation in the soil.

In areas where the snow covering comes before the ground is frozen, and is sufficiently deep to prevent freezing, the water from the melting snow can penetrate the soil. If the snow lies on frozen ground, the larger part of the water will run off. During an average year the ground freezes less in northern Wisconsin than in the lower part

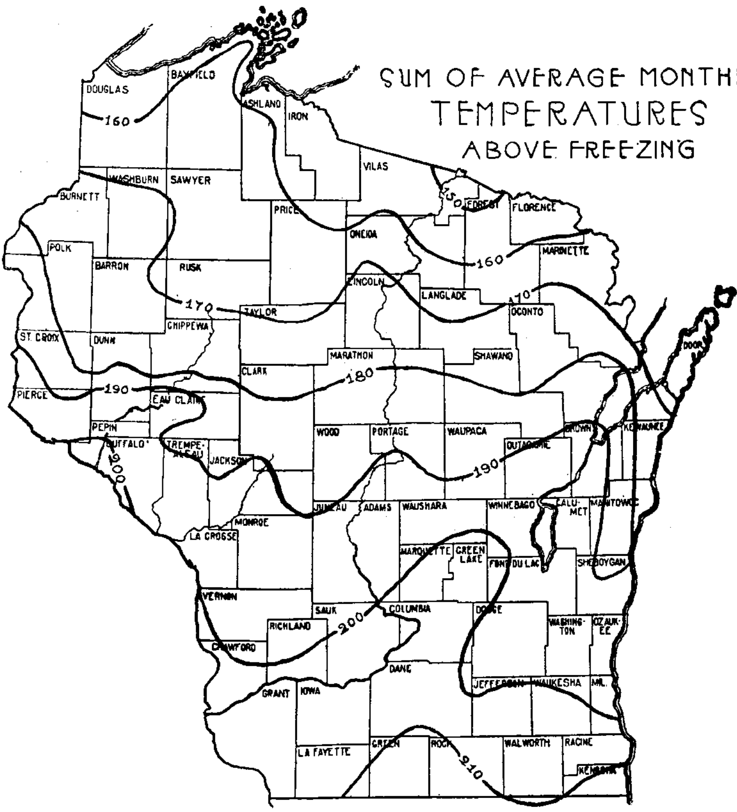


FIGURE 6. *Sum of the average monthly temperatures above freezing.* From the monthly mean value 32 was subtracted and the sum of the positive numbers taken for each station.

of the state by reason of the earlier and heavier snow covering in the north. Quite similar conditions are reported for northern Sweden (43).

In order to obtain some idea of the variation in temperature above the freezing point in the state, Figure 6 was drawn. From each mean monthly average above freezing

32 was subtracted and the sum of the values taken. It was thought that this value would, perhaps, give a better indication of the temperatures active in the prevention of percolation of the water. It is interesting to note that the region

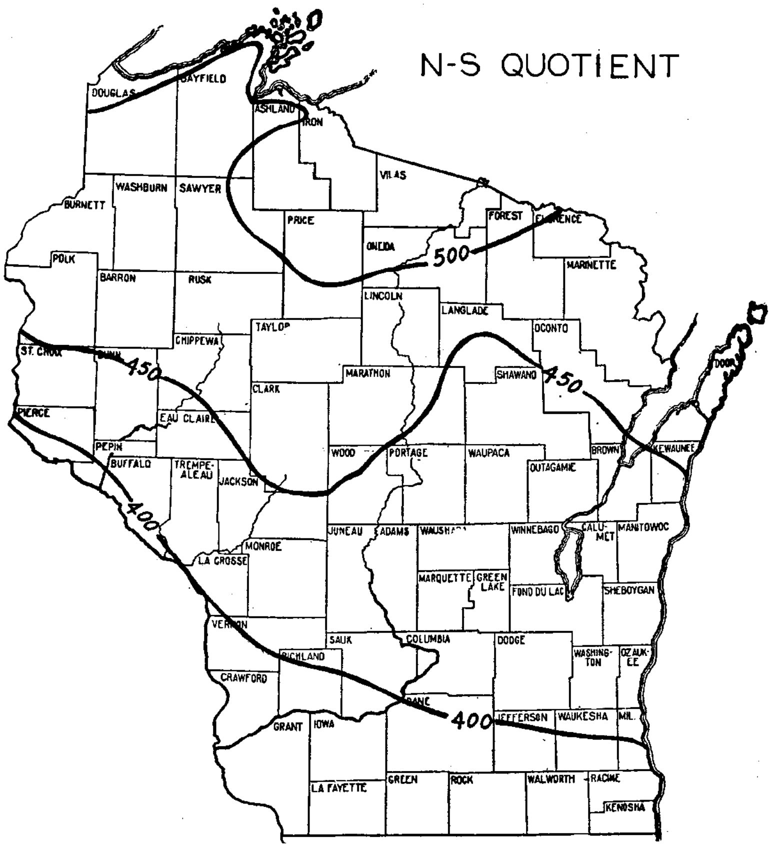


FIGURE 7. *N–S Quotient for Wisconsin.*

The calculation is made as follows: The water vapor pressure, in mm of mercury, for the average annual temperature is taken from a table of physical constants. This value is multiplied by the relative saturation of the air (100—relative humidity) and thus the absolute saturation deficiency of the air is obtained. The annual precipitation in mm is divided by the absolute saturation deficiency of the air to obtain the N–S (Niederschlag: Sättigungsdefizit) quotient. These values were taken for comparison with the investigations of other workers (27) (35). The data for relative humidity were too meagre to justify their detailed use.

of stronger Podsols is fairly well bounded on the south by the isotherm for 160°; and that the true Gray-Brown Forest soils are bounded on the north quite exactly by the isotherm for 190°, except in the eastern portion where the line extends slightly to the north of them. The area between these two isotherms is occupied by transitional soils that do not belong to either group. The rainfall was not considered because of its comparative uniformity over the state.

The value for the N. S. quotient used in Europe (27), (35), and in America by Hans Jenny (20) also was calculated and shown in Figure 7. The data for relative humidity were too meagre to give these values any more than a comparative significance with those of other areas.

After the soil profiles of the state have been examined the importance of considering these differences in climate will be appreciated; and of particular importance is the temperature during the months when the soil is pervious to percolating waters. Podsols will be found in the cooler, extreme northern region, Gray-Brown Forest and Prairie soils in the southern portion, while the north central portion represents a transitional area.

NATIVE VEGETATION

An attempt has been made to indicate the general nature of the native vegetation. The sketch map shown in Figure 8 has been compiled chiefly from the reports of various investigators in the Natural History Survey and from the

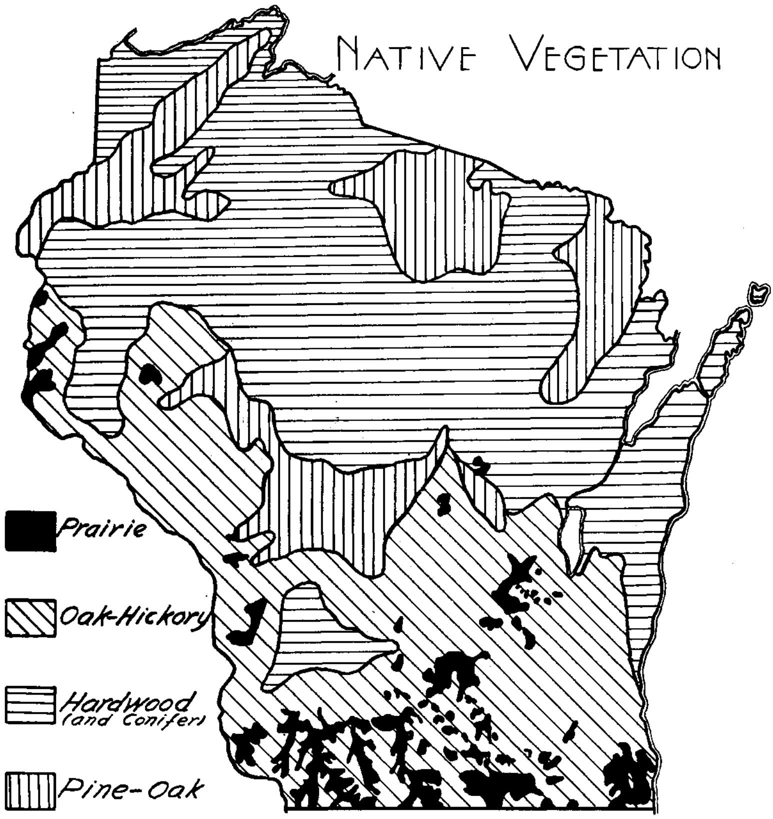


FIGURE 8. *Native vegetation in Wisconsin.*
This generalized map has been constructed from the reports of various investigators in the Natural History Survey and from observations of the writer.

observations of the writer. Four classes are shown on the map as follows:

(1) *Prairies.* These include the upland areas which had an original cover mostly of tall grasses.

(2) *Oak-Hickory.* In this group the oak predominates, particularly in its northern extension. The area as shown

on the sketch map also includes small spots with hard maple, ash, elm and other species. White pine occasionally forms a part of the association near the northern boundary.

(3) *Hardwoods.* Near Lake Michigan the hardwood association consists of hard maple, beech, yellow birch and hemlock for the most part. A short distance west from the Lake the beech disappears; and in the western portion of the area the hemlock is replaced by oak. The isolated area in the southwest is chiefly hard maple. Considerable white pine and balsam fir is found throughout the northern area and particularly in the northwestern part of the state. On the heavy red clays of that section white pine was the chief component of the original forest. On the heavier textured soils fire has had a strong influence: where there has been but little fire the present stand is very much like the original, except that more of the mixture is hard maple; whereas the badly burned areas are predominately trembling aspen and white birch.

(4) *Pine-Oak.* These areas are associated with the drier timber sites and include jack, Norway and some white pine with considerable oak, particularly in the badly burned sections. Fire has been very important in determining the present cover following the pine stands, particularly where the soil is very sandy. The roots of young pine trees are very shallow: most of the feeding roots are just below the forest mold, or even between the forest mold and the upper mineral soil. Apparently they depend upon the moisture supplied to this organic debris by frequent showers. On the other hand the scrub oak roots, even of the young trees, go deeply into the soil for their moisture. The destruction of this surface organic matter by severe burning evidently prevents the pines from establishing themselves, and the land is left to the scrub oak. A few hardwoods are included in the areas shown.

In the northern part there are many swamps with a coniferous cover consisting chiefly of white spruce, tamarack and cedar. The lowlands within the Oak-Hickory belt were chiefly covered with sedges, rushes and coarse grasses. Although there is a large amount of swampy land, its spotted occurrence would not permit it to be shown on this small scale map.

SOILS

Three distinct groups of well-drained mineral soils are to be found in Wisconsin—Podsol, Gray-Brown Forest, and Prairie soils. In the two former groups the podsolization process has been the dominant influence and the soils are podsolic in character. Even in the case of the Prairie soils there is now strong evidence of podsolization. Marbut (30) has outlined the general geographical limits of these zones. That there is a broad transitional belt between the Podsol zone and that of the Gray-Brown Forest has been emphasized by Veatch (46). Although a few areas may be seen which represent transitional belts between the Prairie soils and those of the other groups, in general the lines of demarcation are quite sharply drawn. The sketch map in Figure 9 indicates the general limits of the several groups as observed by the writer.

Some of the more salient characteristics of the several groups will be discussed before considering the detailed profile development.

Podsol Soils. In regions of normally developed Podsol soils the surface is covered by a layer of undecomposed, "raw" humus with only a narrow transition horizon of gray soil, stained with organic matter. This is underlain by a gray, or often whitish, leached horizon or "bleicherde", varying considerably in thickness according to the texture and stage of development of the soil. Beneath the gray layer is encountered a brown horizon, often indurated into a rock-like hardpan. Where indurated or cemented the name "ortstein" has been given it; the softer formations are frequently designated as "orterde". Beneath the brown horizon of concentration there is generally a transitional layer, stained with brown, which grades into the unweathered parent material.

Gedroiz (13) has concluded that the podsolization process, under conditions of moderate humidity, is directly dependent upon the quantity of water passing through the soil and upon the quantity of carbonic acid present. Sufficient moisture must be supplied to insure percolation downward through the soil. This also implies a low evaporation, but yet there must be sufficient evaporation to provide some upward movement of water. Glinka (16) emphasizes the importance of the organic acids produced, and especially of the protective action of the organic sols on the mineral colloids.

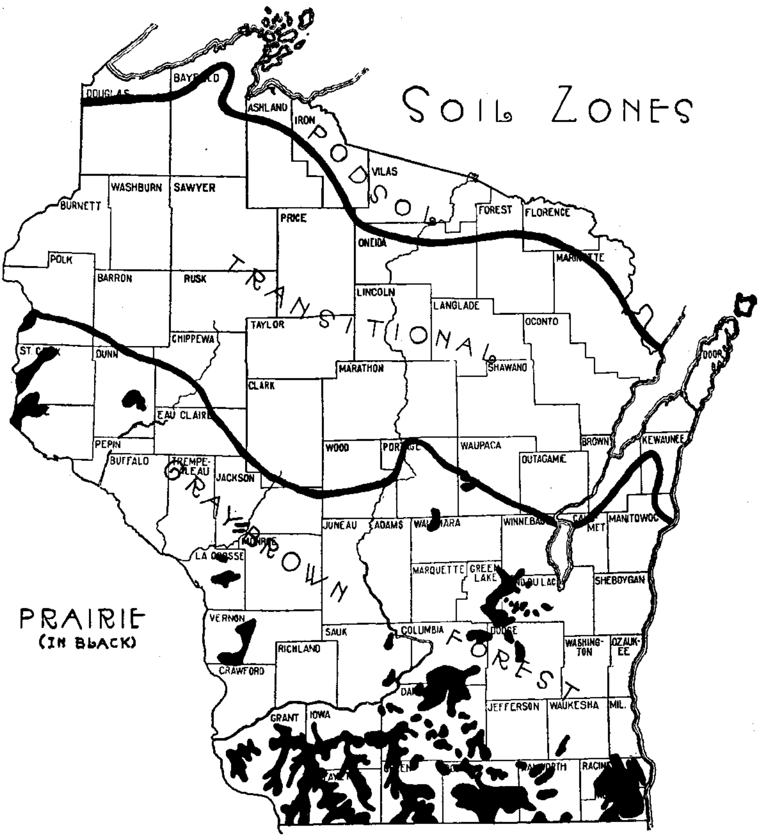


FIGURE 9. *Map showing the approximate limits of the main soil zones in Wisconsin.*

A coniferous forest vegetation is peculiar to Podsol formation. Under the dense shade of the forest in cool climates, and especially where the organic matter is largely of coniferous origin, its decomposition and incorporation with the upper mineral soil is retarded. Thus the Podsol soil is characterized by a peaty layer of raw, dark brown, acid organic matter. As under these conditions the decomposition of mineral matter is comparatively slow, descending waters can carry downward much of that portion which is formed. As the bases, such as calcium and magnesium, are removed, they are replaced with hydrogen giving to the colloidal absorbing complex, both organic and inorganic, an increased mobility[1]. It therefore becomes apparent that any vegetation which will furnish a leaf mold high in these bases will tend to retard the podsolization process. According to Ebermayer (10) the coniferous needles are lower in potassium, calcium and magnesium than are the deciduous leaves; further, the resinous nature of the coniferous forest accumulation retards its decomposition. Lundblad (29) has found that the coniferous vegetation has had an influence to accelerate Podsol formation, other factors being equal. Similar results were obtained by Kvapil and Nemec (28) in comparing beech stands with spruce. These authors found the quality of the forest soil best with mixed spruce and beech stands; but the pure beech was superior to the pure spruce. It is well known that the ash content of leaves varies considerably within the same species, according to the site conditions; thus in one case a given forest cover may produce a mild humus, while in another a raw humus may be developed (26). Müller (36) has given the name "mull" to the forest humus free from acid while the acid, raw humus, characteristic of Podsol formation, is designated as "torf" or "trockentorf". Thus the first evidence of Podsol formation is the development of the raw humus and conditions of acid weathering. Formations of a highly calcareous nature, even lying within the region of Podsol formation, will be delayed in the formation of the true Podsol profile until the calcareous material has been removed from the surface. Excellent examples of the steps in the formation of the Podsol profile under such conditions are furnished by J. Wityn from his studies of the soils of Latvia (52).

It is apparent at once that the nature of the vegetation

---

[1] It is interesting to note that if sodium replaces the other bases instead of hydrogen, as in the Soloti, that a somewhat similar morphology is developed, especially in the leached horizon. (37) (39)

under which soils have developed, together with the processes involved in the decomposition of its debris, is very important in determining their morphology. Certain amounts of the bases are removed from the surface and from the lower part of the soil depending upon the amount of water percolating through the soil and the amount of carbon dioxide dissolved in it. Depending upon the character of the vegetation and the rapidity of its decomposition, a quantity of these bases are brought up to the surface. The entire process might be termed a "base cycle" or rather, as calcium is the chief base concerned, a *calcium cycle.* In the Chernozem type of soil formation this cycle may be said to be practically complete: as the bases are returned by the vegetation as fast as they are removed. In the Podsol type the calcium cycle is only feebly exhibited. After the profiles have been examined it will be clear that the differences in the effectiveness of this calcium cycle have been of extreme importance in determining the character of the soils in Wisconsin.

TABLE 2.—*Material Lost from the Leached Horizon of Podsol Soils (After Tamm)*

	Percentage of each constituent removed in terms of the parent material.	Loss of each constituent expressed in percentage of the amount of that constituent in the parent material.
SiO_2	8.3	11
TiO_2	0.08	20
Al_2O_3	3.42	32
Sil. Fe_2O_3	1.41	55
CaO	0.56	33
MgO	0.49	51
K_2O	0.67	24
Na_2O	0.54	26
P_2O_5*	0.13	88

*The amounts were so small and the conditions between different soils so variable that these results can hardly be considered significant.

The bleicherde, or gray horizon, of the typical Podsol has been impoverished of silica, alumina, iron, and organic matter. Other constituents have also been removed to a lesser degree. O. Tamm has made a study of the chemical nature of the podsolization process. From a number of analyses of Podsol profiles he has calculated the amounts of the different materials removed from the leached horizon and also the percentages of the original amounts of each constituent in the parent material which have been removed. To make this calculation he has assumed that the quartz content would be constant. By averaging the results of seven of these analyses (42) the data in Table 2 were obtained. Much of this material has been deposited in the B, or lower horizon. A notable exception is the silica; also the alkalis and alkali earths do not appear to be concentrated in this layer. In fact the calcium is invariably higher in the surface, due to its continual renewal by decomposing vegetation. These statements are borne out by the analysis of a Podsol from north central Minnesota given by Baldwin (2) (Table 3)[1]. We notice that the silica is higher in the surface soil. This does not mean that none has been removed, but only an amount less in proportion to the other constituents. The soil has been developed from calcareous glacial drift of heavy texture under a dense forest cover of mixed conifers and hardwoods. This analysis has been included because the sample was taken in a region adjacent to the Podsol zone in northern Wisconsin and was developed under quite similar climatic conditions.

TABLE 3.—*Analysis of a Podsol Soil from North Central Minnesota (After Baldwin)**

Horizon	Leafmold	A_1	A_2	B	C
Thickness in Inches	3	1	5	8	
SiO_2	21.60	58.99	73.00	65.02	53.14
TiO_2	0.20	0.75	0.41	0.76	0.66
Fe_2O_3	1.79	4.50	3.38	5.34	5.26
Al_2O_3	5.56	13.00	12.66	16.63	14.62
MnO	0.168	0.18	0.172	0.18	0.14
CaO	3.24	1.57	1.42	1.03	7.00
MgO	1.06	1.30	1.05	1.66	3.72
K_2O	0.87	2.15	2.71	2.48	2.19
Na_2O	0.48	1.18	1.67	1.20	1.01
P_2O_5	0.31	0.17	----------	0.17	0.11
SO_3	0.45	0.12	0.08	0.05	0.06
Ignition loss	64.53	16.53	3.64	5.70	11.20
Total	100.26	100.44	100.20	100.20	99.11
N	1.862	0.44	0.074	0.12	0.05
Carbonate CO_2	None	None	None	None	7.59
H_2O at 110°	10.76	4.96	1.25	4.55	----------

*Analyses by R. S. Holmes and G. Edgington of the Bureau of Chemistry and Soils.

Gray-Brown Forest Soils.[2] These soils are podsolic in nature as the podsolization process has been the dominant

[1] For other analyses of Podsol soils see: (4) (16) (34) (42).

[2] There is no internationally accepted term given to this group of soils. In Europe Ramann was evidently the first to describe them; and he gave to them the name 'Braunerde'. This term, however, is easily confused with

soil forming agency in their development; but they are not, however, to be confused with the true Podsols. It has been pointed out that a forest growth consisting largely of coniferous species is the usual vegetation under which the true Podsol develops. In the Gray-Brown Forest zone, however, the conifers have largely disappeared and, as the forests are more open, the ground is less completely shaded. For Wisconsin and contiguous areas the dominant vegetation on the Gray-Brown Forest soils is the oak-hickory association with smaller areas of other such species as hard maple, beech, birch, elm and ash.[1] This type of vegetation tends to return more bases to the surface through the decomposition of the fallen leaves, and the tendency is for the development of Müller's mull type of forest humus.[2] Further, there seems to be better conditions for the growth of soil fauna and flora which tend to decompose the forest debris and mix it with the lower soil, making the leaf mold relatively thin.

In the true Podsols the surface organic layer gives way very abruptly to the white bleicherde, with only a narrow transitional horizon (A_1) consisting of both mineral and organic matter. The Gray-Brown Forest soils, on the other hand, have a much more prominent A_1 horizon, forming the transition between the leaf mold and the leached A_2 horizon. Both the leaf mold and A_1 horizon are less acid than in the Podsols; under virgin conditions these layers are neutral or only slightly acid in the Gray-Brown Forest profile. Instead of being the white bleicherde of the true Podsols, the A_2 horizon is yellowish, tan, or some shade of grayish-brown in color which would indicate that leaching had not been as complete. The light textured members have a single grain structure, while the heavier

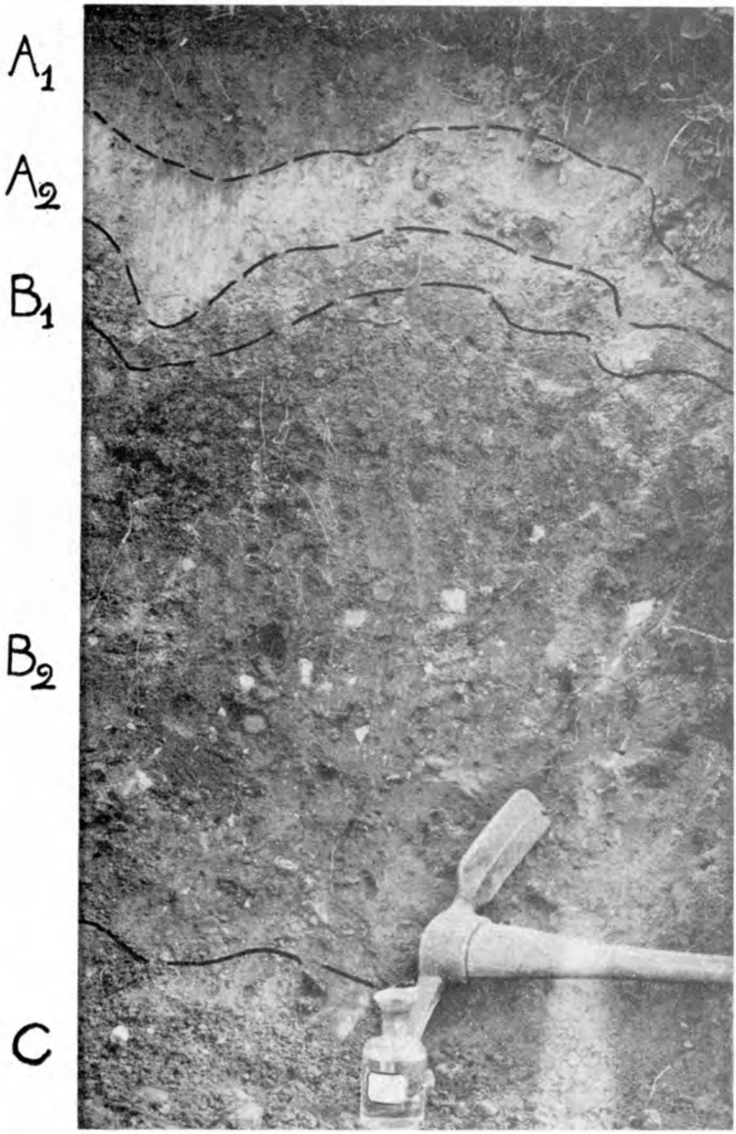
---

'Brown Soils', a name given to a group of soils developed under conditions of low rainfall, which makes its use objectionable. In Europe the soils are therefore referred to as Ramann's Brown Soils or some similar appellative. In this country Marbut has tentatively called them Brown Forest Soils to differentiate them from the Brown Soils which are developed under a grass vegetation. Other writers have used various terms. The author has decided that the term Gray-Brown Forest is more generally understood in America and least likely to cause confusion.

[1] In the eastern part of the United States and elsewhere in the world the oak-hickory association may not be the dominant forest on the well developed Gray-Brown Forest soils as it is in Wisconsin. The essential point is that the forest is chiefly composed of deciduous species, making a more open canopy than those peculiar to the Podsol soils.

[2] Glinka (17) claims that it is necessary for the parent rock to contain some calcium carbonate for Braunerde (Gray-Brown Forest soil) to form.

PLATE 1



Profile of Bellefontaine Silt Loam. A typical profile from the Gray-Brown Forest Zone ones have a soft crumb structure with a characteristic broadly platy breakage.

The B horizon of the Gray-Brown Forest soils is usually some shade of brown in color and is generally heavier in texture than any other portion of the soil. Except in the sandy members, the structure is characteristically angular nut with individual blocks ranging from ½ to about 1 inch in diameter. Although frequently some cementation is noticeable, the sandy ortstein found in the Podsols is never present in the Gray-Brown Forest soils.

The temperature is somewhat higher for the Gray-Brown Forest zone than for the Podsol zone; otherwise climatic conditions are about the same. With nearly equivalent rainfall it is obvious that there will be less water percolating through the soil in the southern zone.[1]

Prairie Soils. As regards the general classification of soils into world groups, it is doubtful if any soils have been so difficult to place as the Prairie soils. The European pedologists had not had an opportunity to study them and at first included all of the black soils of central United States with their Chernozem. This latter group is characterized by a definite zone of lime accumulation in the solum. This horizon of calcium carbonate is not found in Prairie soils. These soils are developed under practically identical climatic conditions with the Gray-Brown Forest soils with which they are associated. The only real difference between the conditions under which these two groups of soils have developed is the native vegetation: in the Prairie group it consisted of grasses, while the latter soils were timbered.

The surface horizon of the Prairie soils is very dark brown to nearly black in color and is characterized by a soft crumb structure which shows the same broadly platy appearance observed in the A_1 and A_2 horizons of the Gray-Brown Forest profile. The color gradually becomes a lighter brown in depth and the structure becomes less friable. At about three feet the soil has a rubbery, small nut

---

[1] It may be interesting to note that at the Wisconsin Dells located within the Gray-Brown Forest zone, true Podsol profiles may be seen down in the deep gorges near the river where the air is always cool and the humidity is high.

structure, which is softer and less pronounced than in the Gray-Brown Forest soils.

In the discussion of Podsol soils the importance of vegetation in bringing up to the surface mineral bases, particularly calcium and magnesium, was emphasized. This action, together with the downward movement of the bases in solution, was referred to as the calcium cycle in soils. It is obvious that a grass vegetation will be more efficient in this respect than a forest (38). Consequently in the Prairie soils (under virgin conditions) the soil absorbing complex of the upper horizon, both mineral and organic, is more completely saturated with cations of the alkaline earth metals and, therefore, will be less mobile. It is true that the eluviation process is only weakly exhibited in these soils as compared to the podsolic soils developed under the forest.

Thus in those areas in southern Wisconsin where the native vegetation consisted of grass rather than timber, we have the development of Prairie soils instead of Gray-Brown Forest soils. As to why the grasses were dominant in these areas the author cannot explain. We commonly think of grasses being able to crowd out the trees in the regions of rather low rainfall, due to their greater ability to survive in the competition for water. Although there is no exact correlation, it is generally true in Wisconsin that the prairie grasses have been dominant under conditions most conducive to moisture retention. The poorly drained areas in the region of calcareous drift largely supported a grass vegetation, whereas in Michigan similar areas were usually forested. Further, the Prairie soils are more commonly developed on the smooth portions of the loessial deposits and on that part of the calcareous drift which is more nearly level.

Under the climatic conditions which obtain there is a greater movement of bases downward in the percolating waters than there is movement upward through the action of the vegetation. Annually considerable amounts are, of course, entirely lost from the soil. Thus it is at once obvious that a time will be reached when the calcium and magnesium content of these soils will be diminished to the point where eluviation will be as great as in the Gray-

Brown Forest soils. For this reason Marbut (31) does not consider them as permanent soils and as time goes on they will approach the normal Gray-Brown Forest profile. We have, of course, been considering the virgin soils, but it may be added here that any system of farm management which tends to deplete these soils of bases will hasten their degradation. This is particularly important because, due to their great fertility, most of the Prairie soils are now under cultivation.

METHODS USED IN THE INVESTIGATION

The present investigation was undertaken for the purpose of describing some of the principal soil types in the state. The chief motive in mind was to examine the natural soils and study their morphology; and after they had been described it was hoped that an examination of the environment under which they have developed would throw some light on how this morphology has come about. The writer has drawn certain conclusions from these observations which he believes to be of interest and of practical value; yet it is to be emphasized that this portion of the work is subsidiary to the main purpose of describing the morphology.

The investigation naturally falls into two parts: (1) The field observations, including the examination of the soil profile as well as other physical features. Clearly this is the most important phase of any study of this kind. Any samples collected for subsequent use will be of value only insofar as they are carefully obtained from actually described soils. (2) The laboratory investigations made were those considered to be of the most value in describing a large number of samples in a reasonable length of time. It has been considered advisable to describe all methods used in some detail.

Profile Descriptions

The profiles of the main types are described in detail in the text as well as shown by diagram in Plate 6 (Insert at the end). The nomenclature of the horizons has been as follows:

A_{00}*—Recent forest accumulation of leaf litter and debris.
A_0* —Forest mold, the compact, partially decomposed portion.
A_1 —Dark gray or black upper portion of the mineral soil containing organic matter. In the timbered soils this layer is transitional between A_0 and A_2. This horizon is very thin in the true Podsols.
A_2 —Zone of greatest leaching. The bleicherde of the Podsol.

---

* All profile samples were virgin; however, it was not always possible to find a virgin forest growth. Consequently horizons A_{00} and A_0 were often wanting and A_1 may be slightly affected by previous pasture in some of the wood lots. The typical depth of these horizons has always been indicated in the descriptions.

A_3 —Transitional to B but with more characteristics of A than of B. Usually absent in mature soils.
B_1 —Transitional to B but with more characteristics of B than of A. This horizon usually appears as the weathered, upper portion of B_2 and is frequently too thin to be important.
B_2 —The maximum zone of accumulation. It usually has the more dense and compact structure and, in this state, is brown in color. It may not always be characterized by a great percentage of clay, but represents the region of "B horizon tendencies".
B_3 —Transitional to C but with strong characteristics of B.
C_1 —The upper part of C, slightly weathered. Usually not separated.
C —Parent material that has been unaltered by soil-building forces.
D —Any strata below the C horizon which have an influence upon the soil but cannot be considered as parent material. (An example would be clay under deep sand.)

In case any of these primary horizons has subdivisions within it they are indicated by a second numeral. For example, we might have A_2 and A_{21}, both belonging to the primary leached horizon but having a significant difference. If any horizon is absent or too thin to deserve consideration, it is simply omitted. This method thus permits each horizon to be given a definite, genetic position and yet allows minor horizons to be shown. The author has found this method to be vastly superior to the common plan of nomenclature which has no provision to show the genetic positions of the various sub-horizons that may be described. An examination of the literature has shown it to be almost impossible to compare the soils described by various investigators, or even different descriptions of the same investigator, because the horizon designations do not show their genetic position.

The depth of the horizons is measured from the surface of A_1. Samples were collected by horizon from typical locations for the laboratory investigations. In Table 33 are given the locations from whence samples were taken.

Acidity Determinations

Soil acidity determinations were made with Soiltex by the method outlined by Spurway (40). The results are shown in the tables with the laboratory results. The degree of acidity given is based upon several *field* trials. Spurway gives the following pH ranges for the several degrees given by the color:

Degree of acidity	Abbreviation used in the text	pH Range
Alkaline	Alk.	7.0–Up
Neutral	N	6.8–7.0
Slightly acid	Sl. A	6.2–6.7
Medium acid	M.A	5.7–6.1
Strongly acid	St. A	5.0–5.6
Very strongly acid	V. St. A	Down–4.9

The Clay Content

The clay content was determined by the hydrometer method of Bouyoucos (6). That this method determines material coarser than that ordinarily considered to be of colloidal size has been pointed out by Keen (23) and Joseph (21). The term 'colloid' as used by Bouyoucos includes the ultra-clay, clay, and probably a portion of the silt (7). The author has chosen to use the word 'clay' rather than 'colloid' in order to avoid any possible confusion. As a rapid method for comparing the content of fine material in the soil the writer considers it very useful and, if properly executed, as accurate for comparative purposes, as any other method that could be used on a large number of samples. It must be borne in mind that the results will be numerically higher than those obtained for clay by most other methods. Each value shown in the tables is the mean of two determinations. By calculating the standard deviation of each set of determinations and then taking an average, the mean was found to be ± 0.26 in terms of per cent clay. The standard deviation of this mean is ± 0.17.

The Base Exchange Capacity

For this determination, duplicate 10 gram samples of air dried soil were treated with 250 cc. of N/1 $CaCl_2$ and allowed to stand for 48 hours. In the case of sandy soils 25 grams were used. The soil is then thrown on a filter and washed with an additional 250 cc. of N/1 $CaCl_2$. The funnel is filled with solution and allowed to drain dry before another aliquot is added, care being taken to wash down the upper edges of the filter paper each time. Subsequently the soil is washed free of chlorides with distilled water. The last traces of chlorides are removed with ethyl alcohol to prevent the removal of the base exchange material. The samples are then washed with 500 cc. of N/1 NH_4Cl, the solution being added in the same way as in the treatment with $CaCl_2$. If the filtrate is colored with organic matter it is treated with $KMnO_4$ until a permanent color on boiling is obtained, and subsequently cleared with oxalic acid. Calcium is then determined in the filtrate as the oxalate in the usual manner.

In order to obtain a good quality of ammonium chloride it was made in the laboratory from ammonia and hydrochloric acid. If carbonates were present in the soil a subsequent leaching with 500 cc. of N/1 NH_4Cl was made to determine the amount of carbonate calcium soluble in this reagent. This value is then subtracted from the first to obtain the exchange calcium. In a few cases where there were very large amounts of calcium carbonate the soil was treated with N/20 hydrochloric acid, containing ammonium chloride, until the carbonates were gone. This ordinarily takes several days of frequent treatment. Neither of these methods is felt by the author to be entirely satisfactory and they were only used for those soils which had calcium carbonate in the parent material. As the soils of the state are acid in the solum, the methods were not needed on the important horizons.

The values given in the tables are means of two determinations and are expressed in milliequivalents per 100 grams of soil. The mean standard deviation between duplicates is ± 0.05, expressed in milliequivalents per 100 grams of soil. The standard deviation of this mean is ± 0.07.

MIAMI SERIES[1]

The Miami series is the principal one found in the lower portion of the state in the region of limestone till of the Late Wisconsin period of glaciation. Several types have been recognized during the past few years in the course of the field work. Of these the Silt Loam is the most common; but also Silty Clay Loam, Fine Sandy Loam, and Loam members have been recognized. As will be subsequently pointed out, the Miami Loam as recognized by early workers in the more northern portions of the area, particularly in the Door Peninsula (14), does not belong with the Miami Series as now defined.

The Miami series exhibits the normal profile of the Gray-Brown Forest region. The other timbered soils of the region have the same general profile with minor variations due to drainage conditions, character of the original material, and such local factors. Marbut (31) has called attention to the fact that the Miami soils are, in general, somewhat darker in color in Wisconsin than the Miami as mapped in Ohio and Indiana. That these soils were influenced by an early prairie vegetation seems probable; but the forces tending to produce the normal Gray-Brown Forest profile have almost entirely erased the influence of the early prairie vegetation.[2]

As the Silt Loam is the most important member of the Miami series and as this series exhibits the normal profile of the area, it is desirable to examine that profile first.[3] The profile is developed on undulating to gently rolling terraine (Plate 2A). Drainage has not been well developed in the area and although the Miami soils themselves are well drained, numerous areas of peat and marsh border soils occur associated with them. The original material consisted of calcareous till of the Late Wisconsin period of

[1] The names used for the soils discussed in this paper are in accordance with those given by the U. S. Bureau of Chemistry and Soils in cooperation with the Wisconsin Geological and Natural History Survey. In a few cases these organizations have adopted slightly variant nomenclature; and in such instances have been noted in the legend for Plate 6. Also a few local names have been introduced for such soils as have not been previously recognized.

[2] See the discussion of the Thurston series in this paper.

[3] For most excellent descriptions of this profile see the work of Baldwin (2) (3).

PLATE 2

A. *View on Miami Silt Loam.*

B. *View on Carrington Silt Loam.*

glaciation. There also appears to have been a thin covering of loess deposited on the surface.

PROFILE OF MIAMI SILT LOAM

A_{00}—Surface covering of loose leaf litter from the deciduous forest, about 1 to 3 inches in thickness.

A_0 —Dark brown to nearly black leaf mold, varying from ½ to 1 inch in thickness.

A_1 —Dark gray silt loam, relatively high in organic matter. Smooth, velvety texture. The soil has a brittle, platy structure which easily crumbles to a soft fine crumb. At about 2 to 3½ inches is encountered

A_{11}—A transitional horizon of yellowish-gray silt loam, not quite two inches in thickness. (In the profile drawings this is divided between A_1 and A_2.)

A_2 —Grayish-brown silt loam with gray variegations. The soil has a brittle, platy structure with numerous fine pores through the mass. It easily pulverizes to a velvety silt loam of tan color. At 8 to 10 inches the soil grades into

B_1 —Grayish-brown heavy silt loam. The soil has an angular nut structure with the pieces about ¼ to ½ inch in diameter. The material is more friable than in B_2 but much less so than in A_2. After pulverizing, the color is a light brownish-yellow. From the general appearance and from laboratory results to be subsequently examined, it is evident that this horizon is one of A-forming tendencies impinged upon material developed by B-forming tendencies. This transitional layer is 4 to 5 inches thick and extends down from 12 to 15 inches below the surface.

B_1 —Grayish-brown heavy silt loam. The soil has an angular nut structure with pieces about ½ inch in diameter; the pieces are smaller in the upper part, while in the lower portion they are larger and the structure is less definitely defined. These soil blocks are plastic when moist but hard when dry. The outside of the blocks is dark brown in color, especially in the lower part, while the inside is yellowish. Most of the root growth and drainage is along the cleavage lines between the soil blocks; but root growth is not entirely confined to these channels as is evidenced by the root holes through the soil mass, especially in the upper portion and in B_1. At about 31 inches the soil gives way to

B_3 —A transitional horizon of brownish-yellow heavy, clayey till. Although the material has some calcium carbonate left in it there has been considerable accumulation of colloidal material as shown by the laboratory results. A structure of large, irregular blocks is only weakly developed. At approximately 4 to 5 feet this material merges into

C_1 —Lighter in color and lighter in texture than B_3. Only a slight alteration has been made in this material. At 6 to 7 feet is encountered

C —Grayish-yellow calcareous till of the Late Wisconsin period. Pebbles and bowlders are fairly numerous throughout the mass. In structure it is compact and massive, breaking into slivery pieces when dry. The till has sufficient bowlder clay to make it sticky when wet and to give it a fairly high capacity for water. When exposed to the weather, joint planes divide the mass into large, irregular pieces.

---

[1] See Plate 6 at the end for drawings of the profiles described.

That the soil building forces operating in this region have been effective in producing a definite and distinct profile is still further shown by the data presented in Table 4. The surface A_1 horizon shows a large quantity of base exchange material. There are probably two reasons for this: (1) This horizon is the highest of any in organic matter. Although there is no entirely satisfactory method for separating the organic from the inorganic, it is quite certain that a large portion of the total is organic base exchange material.[1] (2) In this surface horizon the soil is subject to considerable weathering and inorganic base exchange material is being produced. According to the work of Truog and Chucka (44) this material is formed by alkaline weathering from the felspars. This does not mean that the entire soil must be alkaline all of the time. From the decomposition of vegetation considerable calcium and magnesium is being released so that the A_1 horizon is the least acid of any of the upper layers. It is obvious that the base exchange colloids will be formed the most rapidly and will be the least mobile in this layer.

TABLE 4.—*Clay Content, Base Exchange Capacity and Acidity of Miami Silt Loam*

Horizon	A_1	A_{11}	A_2	B_1	B_2	B_3	C_2
Depth in inches	0—2	2—4	4—9	9—13	13—30	30—48	72—
Per cent clay	41.1	41.9	40.8	46.0	47.2	34.6	18.5
Base exchange capacity	17.12	7.71	9.11	15.75	19.38	15.83	4.99
Reaction toward Soiltex	M.A	V.St.A	V.St.A	V.St.A	V.St.A	Alk.	Alk.

The A_{11} and A_2 horizons are both very acid; the base exchange colloid is highly acid and easily removed. The data clearly show that this material has largely accumulated in the B_2 horizon. The B_1 horizon shows the influence of "A-forming tendencies" being impinged on the true B. An inquiry regarding the factors which apparently control the accumulation in the B horizon will be made after more profiles have been discussed. For the present it will suffice to

[1] Kerr has given some results obtained by removing the organic matter with hydrogen peroxide (25). The author has tried burning the soils at temperatures sufficiently high to destroy the organic matter without injuring the inorganic. Neither method can be depended upon to give precise results and it is to be hoped that one can be found for this important study.

remark that B_3 represents a horizon transitional to C in which chemical precipitation of the colloidal material may have taken place.

Because of the climatic conditions associated with it and because of its desirable physical characteristics the Miami Silt Loam is one of the most highly developed soils in the United States. The agriculture of a large portion of southern Michigan, southeastern Wisconsin, northern Indiana, Ohio and Illinois is built on the Miami series. Attention has been called to the slightly darker color of the Miami soils in Wisconsin as compared to Ohio and Indiana. This fact is reflected in the somewhat higher native productivity of the Miami in Wisconsin. The other members of the series will not be discussed except to point out that in profile character the only important difference is one of texture.

LINDLEY SERIES

The Lindley series is very similar to the Miami. The only important difference is the more pronounced development in the Lindley of the horizons which characterize the Miami profile. Under the discussion of geology it was pointed out that in two places there were areas of calcareous drift of earlier age than the Late Wisconsin. The southern area,[1] at least, is probably Illinoisian.[2] The Lindley soils are developed on the undulating or gently rolling till plains and, like the material giving rise to the Miami soils, may have a thin covering of loess. Drainage may be said to be slightly better than on the typical Miami. The parent material is calcareous and appears to be almost identical with that of the Miami. The only important member in the series is the Silt Loam.

PROFILE OF LINDLEY SILT LOAM

A_{00} —Surface accumulation of loose deciduous leaves, 1 to 3 inches in thickness.

A_0 —Dark brown to nearly black leaf mold, varying from ½ to ¾ inches thick.

---

[1] All of the writer's observations have been confined to the southern area. From the various soil reports and from the unpublished notes of Prof. W. J. Geib it would appear that the two areas are similar.

[2] For a description of the Illinoisian drift see Alden's work (1).

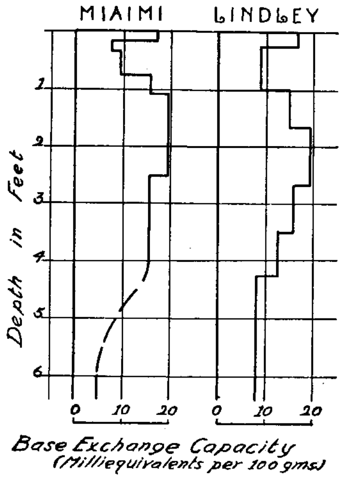


FIGURE 10. *Diagram showing the comparison of the base exchange capacity in Miami Silt Loam and Lindley Silt Loam.*

Note the similarity between the horizons; the variance is one of depth rather than percentage.

A_1 —Dark gray silt loam, relatively high in organic matter. The soil has a soft, coarse crumb structure, easily pulverized. At about 3 inches is encountered

A_2 —Grayish-yellow silt loam. The soil has a friable crumb structure with faint relicts of an old blocky structure in the lower part. A faint platy breakage is noticeable. At 12 to 13 inches this gives way to

B_1 —Yellowish-brown silty clay loam. The soil has a friable, fine nut structure. The old blocky structure is losing its original character. When pulverized the soil appears quite uniformly dark yellow. At about 20 inches the soil grades into

B_2 —Brown clay loam, with tinge of yellow. The soil has a definite angular nut structure, with individual pieces about ¼ to ½ inches in diameter and grading into larger pieces in the lower part. When rubbed at ordinary moisture contents the soil is somewhat rubbery. Water can apparently pass between the blocks and roots do not encounter much difficulty. At about 32 inches the soil changes to

B_3 —Dark yellowish-brown gritty clay loam. The soil breaks into large lumps but does not have a well-defined blocky structure. The material is plastic, even at ordinary field moisture content. That roots penetrate this material is evidenced by the numerous tubes which have been formed in them. At about 40 to 44 inches this horizon gives way to

B_{31}[1]—Dark yellowish-brown sandy clay. The soil is quite plastic and massive, with no definite structure. Numerous small tubes penetrate the mass. This horizon extends down to about 48 to 54 inches.

---

[1] The B_{31} is more frequently designated as C_1, but the writer feels that to use a consistant nomenclature its designation should indicate its genetic relation to B_2.

C —Yellow sandy clayey till. This material is highly calcareous. Numerous stones and pebbles are to be observed at this depth. The soil is quite compact and massive, but breaks into slivery pieces when dry. When wet it is sticky and plastic; and the water holding capacity is relatively high as in the Miami Silt Loam.

The similarity of this profile to the Miami Silt Loam may be seen from the data in Table 5. In order to bring the two profiles into direct comparison Figure 10 has been constructed. It is to be observed that the amount of base exchange material per 100 grams of soil is almost identical for each similar horizon of the two soils; the only difference is in the depth and thickness of the horizons. As time goes on the horizons change their positions but in proportion to the texture the content of base exchange remains constant for each genetic horizon. Further evidence bearing on this point will be subsequently noted.

TABLE 5.—*Clay Content, Base Exchange Capacity and Acidity of Lindley Silt Loam*

Horizon	A_1	A_2	B_1	B_2	B_3	B_{31}	C
Depth in inches	0—3	3—12	12—20	20—32	32—42	42—51	51—
Per cent clay	34.1	41.3	47.4	48.5	34.4	27.9	22.0
Base exchange capacity	16.82	8.87	14.76	19.14	15.98	12.45	8.00
Reaction toward Soiltex	Sl.A	V.St.A	V.St.A	V.St.A	St.A	M.A	Alk.

BELLEFONTAINE SERIES

The Bellefontaine series is associated with the Miami soils in the region of calcareous drift. Whereas the Miami soils are quite generally confined to the gently undulating till plains, the Bellefontaine soils are developed on the more rolling till deposits, including the Kettle Moraine[1] in eastern Wisconsin. A view illustrating the typical relief is shown in Plate 3A. The original till giving rise to the Bellefontaine soils has a larger proportion of sand and commonly more stones than that giving rise to the Miami soils. It was pointed out that the ice-laid material probably

[1] The Kettle Moraine of Wisconsin is the name given to the bold interlobate moraine formed between the Green Bay and Lake Michigan lobes of the Late Wisconsin period of glaciation. (See Figure 1.)

received a thin covering of loess; however, the parent drift of the Bellefontaine series evidently was not so covered.

There are several types within this series but of these the Silt Loam and Fine Sandy Loam are, perhaps, the most important. The profile of the Bellefontaine Silt Loam will be examined first and the important characteristics distinguishing it from the Miami noted. In Plate 1 is shown a typical profile of this soil.

PROFILE OF BELLEFONTAINE SILT LOAM

A_{00}—Surface covering of loose leaves from the deciduous forest, about 1 to 2 inches in thickness.

A_0—Dark brown to nearly black leaf mold, about ½ inch in thickness.

A_1—Dark gray silt loam, relatively high in organic matter. The soil is quite brittle but easily pulverizes to a soft crumb structure. Usually the soil has a broadly platy breakage but often this is absent. Small pores are noticeable in the mass. At about 3 or 4 inches is encountered

A_2—Grayish-yellow light silt loam. The soil is broadly platy in the upper part, while the lower part shows faint relicts of an old blocky structure; it easily pulverizes into a mellow, fine crumb structure. At depths ranging from 8 to 15 inches the soil grades into

B_1—Dull brown or yellowish-brown friable sandy clay or heavy silt loam. The soil has a fine blocky structure, quite easily pulverized. This layer is about 4 or 5 inches thick and at 12 to 20 inches gives way to

B_2—Heavy reddish-brown sandy clay. The soil has a well-defined angular nut structure about ¼ to ¾ inches in diameter. Small white specks of cherty material are characteristic of this material. Roots apparently penetrate the soil with comparative ease, not only along the cracks but also through the soil mass. When wet the soil is very sticky and plastic and it is hard and intractible when dry. In depth the soil becomes more massive, the blocks are much larger, and numerous pebbles make their appearance. At 3 to 4 feet the soil passes to

B_3—A transitional horizon of reddish gritty clay, more pervious than B_2. This layer is sometimes almost absent and again it may be over 12 inches in thickness.

C —Yellowish sandy, clayey till, highly calcareous and frequently stony. The water holding capacity of this material is somewhat less than that of the material under the Miami, but it is otherwise of the same general nature.

The laboratory results are set forth in Table 6 and it is noticeable at once that the soil building forces are of the same order as those which formed the Miami soils. The total quantity of base exchange material is less but the relation between A_2 and B_2 is about the same.

TABLE 6.—*Clay Content, Base Exchange Capacity and Acidity of Bellefontaine Silt Loam*

Horizon	A_1	A_2	B_1	B_2	B_3	C
Depth in inches	0—4	4—14	14—19	19—45	45—54	54—
Per cent clay	29.1	32.6	37.3	39.0	38.8	26.6
Base exchange capacity	23.63	6.62	11.60	15.06	13.49	10.41
Reaction toward Soiltex	N	St.A	St.A	V.St.A	N	Alk.

The Bellefontaine Fine Sandy Loam is developed on the more sandy moraines and is usually quite rolling in topographic feature.

PROFILE OF BELLEFONTAINE FINE SANDY LOAM

A_{00}—A loose layer of recently fallen deciduous leaves, about 2 inches in thickness.

A_0 —Dark brown or black leaf mold, about ½ inch thick.

A_1 —Dark gray fine sandy loam, containing considerable humus. Soft, fine crumb structure. This layer is about 2 or 3 inches in thickness.

A_2 —Grayish-yellow fine sandy loam. In places the soil is faintly platy. Numerous pores give the mass a suggestive cellular appearance. The friable soil easily falls into a crumb structure. At 6 to 10 inches this gives way to

B_1 —Yellowish-brown, brittle, friable loam. The soil has a coarsely granular or fine blocky structure which is quite easily pulverized. This layer is transitional and is usually only about 4 inches in thickness.

B_2 —Reddish-brown sandy clay. There is noticeable gravelly material, especially small white chert fragments. This material is very plastic when wet and brittle when dry; but the dry soil is more friable than in the Silt Loam type. The soil breaks into lumps about ½ inch in diameter at the top of the horizon, grading into larger pieces beneath; but there is not as well-defined blocky structure as in the Miami B_2. Roots penetrate the mass with ease. The change to C is quite abrupt and occurs from about 20 to 36 inches.

C —Grayish-yellow till. This material is quite sandy and stony but has sufficient bowlder clay to give it a definite coherence.

The data in Table 7 show that there has been a very marked movement of the base exchange material into horizon B_2. This movement is also very clearly expressed in the figures for the clay content.

From the standpoint of the soil profile as well as the geological substratum, the differences between the Miami and Bellefontaine series do not appear to be great. The following appear to be significant: (1) The Miami, taken as a whole, has a higher content of base exchange material;

(2) the Bellefontaine has a characteristically red B_2 horizon as compared to the yellowish-brown of the Miami; (3) the Bellefontaine has more thorough drainage, both external and internal, than the Miami.[1] That these differences amply justify the separation of the two soils is evidenced by their relation to agriculture. The general farming conditions of the Bellefontaine soils are poorer than on the Miami soils.

TABLE 7.—*Clay Content, Base Exchange Capacity and Acidity of Bellefontaine Fine Sandy Loam*

Horizon	A_1	A_2	B_1	B_2	C
Depth in inches	0—3	3—7	7—11	11—32	32—
Per cent of clay	15.9	18.3	21.5	26.7	14.5
Base exchange capacity	21.20	6.71	7.05	10.66	6.80
Reaction toward Soiltex*	N	N	N	N	Alk.

* The writer makes no apology for the 'seemingly unnatural' neutrality of this soil. These reactions were obtained in the field from repeated trials.

FOX SERIES

The Fox series occurs associated with the Miami and Bellefontaine soils in the regions of calcareous glacial drift. The soils are developed on the outwash plains. The parent material contains large amounts of limestone and is very gravelly, especially in the substratum. Like the soils with which it is associated, it was formed under the oak-hickory type of forest. The profile character of these soils approaches the normal Gray-Brown Forest profile of the Miami and is almost identical with that of the Bellefontaine. Whereas the Bellefontaine soils are characterized by a topography more pronounced than that of the Miami, the Fox soils are more nearly level. The outwash plains on which they are developed are typically flat, although frequently the surface is modified by benches, valleys, pits and such features of water laid deposits.

There are several types mapped in this series with the same general profile, varying only in texture. Several factors have probably had an influence in determining the

[1] Wheeting (51) has discussed some of the chemical differences between these soils.

texture: (1) the surface of the deposit probably received a covering of varying thickness of fine material laid down during the later stages of its formation; (2) the percentage of limestone and shale in the parent material is evidently important; and (3) the amount and nature of the gravel in the substratum is obviously important. If the lower soil (at about 3 to 5 feet) is sandy the capillary pull of water downward is continuous, whereas if the capillaries are broken by a gravel layer there is a "hanging" of water in the upper soil. Consequently, other factors being equal, a well drained soil with a gravelly substratum at some depth will have a higher water content in the soil above than one with a sandy substratum. This fact is of extreme importance in a consideration of soil building, especially with the lighter textured, well drained, soils. The most important member of the Fox series is the Silt Loam and is the only one to be described in detail.

PROFILE OF FOX SILT LOAM

A_{00}—Loose surface layer of leaves from deciduous trees, about 2 inches thick.

A_0—Dark brown to black leaf mold, about ½ to ¾ inch in thickness.

A_1—Dark gray silt loam, relatively high in organic matter. The soil has a mellow crumb structure and a faint, broadly platy breakage. At 3 to 4½ inches this changes to

A_2—Grayish-yellow, ashy silt loam. The soil has a friable, platy structure that easily pulverizes to a mellow, fine crumb. When rubbed the soil becomes smooth and velvety and the color distinctly yellow. At 10 to 12 inches this gives way to

B_1—Grayish-brown or yellowish-grayish-brown silt loam. The soil has a fine nut structure. This transitional layer is about 4 inches thick.

B_2—Brown or dark reddish-brown silty clay, becoming gritty in the lower part. The color becomes somewhat yellowish when rubbed. The soil is quite compact and has an angular pea-size structure. Roots seem to be able to penetrate the mass without difficulty. At 30 to 34 inches the soil changes to

B_3—Reddish-brown gravelly, gritty clay. Plastic when wet. The material has a nut structure somewhat coarser than B_2. This transitional horizon is very variable as to thickness. It ranges from almost nothing to about 12 inches. At depths ranging from 36 to 48 inches is encountered the parent drift.

C—Calcareous sand and gravel. The upper portion is somewhat stained with red and brown, while the lower portion is yellow and gray. This material is very pervious.

The laboratory investigations did not include this soil but its nature is very much like the Bellefontaine. The soil reaction is as follows: Slightly acid in A_1; medium

PLATE 3

A. *View on Bellefontaine Silt Loam.*

B. *View on Knox Silt Loam.*

or strongly acid in A_2, B_1 and in upper B_2; slightly acid in lower B_2; becoming alkaline in lower B_3 and in C. From the profile description it is obvious that soil building forces have been very pronounced. The importance of the gravally substratum mentioned previously, is evident. This soil is high in fertility but is probably not quite as valuable as the Miami.

KNOX SERIES[1]

The Knox series is the most prominent one in the southwestern portion of the state. In general, the parent material consists of loessial deposits over limestone rock. In some places, particularly in the more northern part of the area, fine-grained sandstone rocks underlie the mantle of loess. As the country was not glaciated, drainage is much better developed. The surface is much more rolling than that of the Miami area (Plate 3B). Because of the pronounced relief and the action of erosion, the depth of the loessial mantle and the thickness of the residual rock over the solid rock is extremely variable.

The soil is developed under an oak-hickory forest and the profile is almost identical with that of the Miami series: i. e., it closely resembles the normal Gray-Brown Forest profile. Like the Miami it is probable that the Knox area had an early prairie vegetation, the effects of which have almost entirely disappeared. By reason of local conditions of parent material and erosion, minor types have been recognized, but the Silt Loam is the typical condition and will be the only member of the Knox considered. Because of the great variation in depth, two profiles will be considered: (1) A deep phase where the soil profile lies entirely in the loessial material and is acid in every horizon; and (2) a shallow phase in which weathering has extended into the limestone material and the profile has been influenced by the high amount of calcium carbonate at shallow depths.

---

[1] These soils have been variously named by the Bureau of Chemistry and Soils: On some of the older maps they appear as Knox, on others as Union, while now the accepted term is Clinton. The name Knox is retained by the writer because of its wide use in Wisconsin. See Marbut (31).

PROFILE OF KNOX SILT LOAM (Deep Phase)

A_{00}—Loose leaf litter of deciduous leaves, about 2 inches thick.

A_0—Dark brown to nearly black leaf mold, varying from about ½ to ¾ inch in thickness.

A_1—Dark grayish-brown silt loam, relatively high in organic matter. Smooth, velvety texture. The soil has a brittle, platy structure which easily crumbles to a fine crumb. At about 2½ to 4 inches this gives way to

A_2—Brownish-gray silt loam, smooth and velvety. The soil has a well-defined brittle, platy structure which easily pulverizes to a fine crumb. When pulverized the soil appears more gray in color. Below 6 to 8 inches this A_2 horizon may be described as follows

A_{21}—Light brownish-gray silt loam. The soil has a brittle, platy structure which easily crumbles to a fine granular mass, but is not as smooth as A_2. At 9 to 11 inches from the surface the soil grades into

B_1—Dark grayish-brown heavy silt loam. The grayish material exists on the outside of the soil blocks. The soil has a friable, small nut structure with faint indications of a broadly platy breakage. This layer is about 5 inches in thickness so that at 14 to 16 inches from the surface the soil changes to

B_2—Dull, dark brown silty clay loam. The soil has an angular nut structure, the individual pieces being about ½ inch in diameter. These pieces are quite easily pulverized into a coarse granular structure. The ultimate granules are quite rubbery. In situ the soil blocks have gray specks which appear as floury coatings on their surface. The interior of the block is more yellow in color. At depths ranging from 32 to 38 inches and without any distinct line of demarcation the soil grades into

C—Yellowish-brown silt loam. The soil is quite compact and easily breaks into large, angular, walnut-size pieces. These blocks are friable and the material rubs into a mealy mass. There is some gray mottling but when rubbed the soil is distinctly yellow in color.

This material extends to a considerable depth and is usually underlain by limestone, although occasionally the underlying stratum is sandstone. In the deeper loess small limestone concretions may be seen, but as far as the soil is concerned all of the calcium carbonate has been leached out.

TABLE 8.—*Clay Content, Base Exchange Capacity and Acidity of Knox Silt Loam (Deep Phase)*

Horizon	A_1	A_2	A_{21}	B_1	B_2	C
Depth in inches	0—3½	3½—7	7—10	10—15	15—36	36—
Per cent clay	36.6	39.0	38.7	41.8	40.6	34.9
Base exchange capacity	14.21	6.92	5.71	8.14	15.64	15.81
Reaction toward Soiltex	St.A	M.A	St.A	V.St.A	V.St.A	V.St.A

The examination of this soil in the laboratory reveals a distinct difference as compared to the Miami (Table 8). Although the results show a "normal" solum, we notice that the C horizon has nearly as much clay and slightly more base exchange material than the B_2. The relation between the A_2 and B_2, however, is almost the same in the two soils; further, the ratio of clay to base exchange capacity is practically identical in the same genetic horizons of the two soils. This interesting fact will be discussed in more detail later; it will suffice to suggest that the loessial material undoubtedly has a much higher content of base exchange material than the glacial drift at the time soil building forces began.

It was pointed out that the above profile was not influenced by the limestone rock. The following profile was developed on a much thinner mantle of loess over limestone.

PROFILE OF KNOX SILT LOAM (Shallow Phase)

A_{00}—Surface covering of loose leaves from deciduous trees, about 2 inches thick.

A_0—Dark brown or black leaf mold, about ½ to 1 inch thick.

A_1—Dark grayish-brown silt loam, relatively high in organic matter. The soil has a friable platy structure which becomes finely granular when rubbed. It is quite noticeably fluffy. When rubbed the color is more nearly a yellowish-brown. At depths ranging from 2½ to nearly 6 inches[1] the soil changes to

A_2—Yellowish-brown silt loam, somewhat gray in situ. The soil has a friable, platy structure easily crumbled to a fine granular one. A small amount of humus is noticeable. At about 8 or 9 inches is encountered

A_{21}—Grayish-brown silty clay loam. In situ the soil has a broadly platy breakage, but it is easily pulverized to a granular structure. When rubbed the material is brownish-yellow in color. At depths ranging from 10 to 14 inches the soil grades into

B_1—Reddish-brown light clay loam. The soil has a coarse, granular structure with a broadly platy breakage. There are faint relicts of an old blocky structure, yet the soil is friable. At 16 to 21 inches this changes to

B_2—Dull brown clay loam with an angular nut structure. At ordinary moisture contents the pieces are rubbery and elastic; but the material is brittle when dry. In situ the cracks between the soil blocks are quite large, indicating that the soil swells and shrinks to a high degree. The outside of the soil blocks are more brown than the interior. At depths ranging from about 20 to 36 inches the soil changes to

B_3—A transitional horizon of darker brown clay loam, about 3 to 5 inches thick.

B_{31}—Very dark reddish-brown clay loam. The soil has an angular nut structure with blocks about walnut-size and larger. This material is very hard and intractable when dry and

[1] Where the A_1 horizon is as thick as 6 inches it is undoubtedly due to the influence of an earlier prairie vegetation.

plastic when wet. The soil swells and shrinks to a great degree. This layer is only 2 to 4 inches thick and overlies

C —Yellowish, cherty, disintegrated limestone. At depths ranging from 4 to 7 feet this material grades into limestone rock.

It is obvious that the calcium carbonate has had a great influence on the solum of this soil. The data in Table 9 show that there has been a great deposition of colloidal matter just above the limestone. Any colloidal matter in suspension will obviously be flocculated by the electrolytes, whereas this is not the case, at least not to the same extent, in the Deep Phase of the Knox.

TABLE 9.—*Clay Content, Base Exchange Capacity and Acidity of Knox Silt Loam (Shallow Phase)*

Horizon	A_1	A_2	A_{21}	B_1	B_2	B_3	B_{31}	C
Depth in inches	0—4	4—8	8—11	11—19	19—34	34—37	37—39	39—60
Per cent clay	41.7	38.6	45.4	47.0	49.6	52.3	55.2	7.7
Base exchange capacity	13.43	8.44	12.03	16.61	22.60	24.79	33.53	1.34
Reaction toward Soiltex	St.A	St.A	St.A	V.St.A	V.St.A	St.A	N	Alk.

The Knox soils are very important in agriculture; as has been pointed out, they are the counterpart of the Miami soils in that portion of the unglaciated region which has received a mantle of loess. Because of the much greater relief, the Knox soils are not, however, as valuable producers as the latter.

BAXTER SERIES[1]

The Baxter soils are confined to material residual from limestone but without more than a very thin mantle of loess. In the Knox the principal part of the solum was developed from the loess, whereas in the Baxter the solum is mainly derived from residual limestone as is evidenced from the cherty fragments throughout the profile and on the surface. The important type in this series is the Silt Loam. Other minor types and phases have been recognized in order to describe those conditions where the soil is developed

[1] The Bureau of Chemistry and Soils changed the nomenclature of this soil in Wisconsin to Dubuque in order to differentiate it from the Baxter developed in the Ozark region.

from very stony material or on steep ridges. The typical Baxter Silt Loam occurs on the mesa-like table-lands, most of which have been greatly dissected by erosion. External drainage is usually good to free, but the internal drainage is rather slow, as will be seen from the profile description. This soil was developed under the oak-hickory forest for the most part, and approaches the Miami in general profile character.

Profile of Baxter Silt Loam

A_{00}—Loose accumulation of leaves from deciduous trees, about 2 inches thick.

A_0—Dark brown to nearly black leaf mold, about ½ to ¾ inch thick.

A_1—Dark gray silt loam, relatively high in humus. The soil has a broadly platy breakage but easily pulverizes to a fine crumb structure. At about 3 to 4 inches this gives way to

A_2—Brownish-gray velvety silt loam with some spots of dark gray. In situ the soil has a friable platy structure which easily pulverizes to a fine crumb. At 6 to 8 inches the A_2 horizon alters to

A_{21}—Grayish-yellowish-brown silt loam. In places the soil is broadly platy with faint relicts of an old blocky structure. The material is friable and makes a fine crumb structure, although not as velvety as A_2. At about 10 inches is encountered

B_1—Somewhat grayish, brown silt loam becoming more yellow when rubbed. The soil contains some pebbles and irregular cobbles of chert. In structure it is friable and slivery but with strong relicts of an old blocky structure. This layer extends down to about 16 inches.

B_2—Slightly reddish, brown clay loam, containing a considerable quantity of cherty pebbles and small cobbles. The soil has an angular nut structure and the mass is somewhat cheesy at ordinary moisture contents. This material has a high water holding capacity, even though some coarse material is present. At depths ranging from 18 to 26 inches the soil changes to

B_{21}—Stiff, heavy, gritty, red clay, containing a considerable quantity of cherty pebbles and angular cobbles. The soil is very plastic and sticky when wet and hard when dry. This clay has a very high water holding capacity. At depths ranging from about 32 to 40 inches the soil grades into

C —Pink and yellow speckled, stony clay. This material is plastic and highly retentive of water, although not as much so as B_{21}. In some places this clay has a distinct red color. At depths ranging from less than 6 feet to nearly 150 feet the soil is underlain by solid limestone.

Note: In the steeper phases the surface soil has been largely eroded away, exposing the red clay.

For this soil the author has data for the clay content only; but this shows a decided development of profile character of the same general nature as that expressed by the Miami (Table 10).

TABLE 10.—*Clay Content and Acidity of Baxter Silt Loam*

Horizon	A_1	A_2	A_{21}	B_1	B_2	B_{21}	C
Depth in inches	0—3	3—7	7—10	10—16½	16½—24	24—36	36—
Per cent clay	38.0	35.2	32.8	34.9	45.1	57.7	43.9
Reaction toward Soiltex	St.A	St.A	M.A	M.A	St.A	St.A	St.A

The Baxter Soils have, in general, about the same agricultural use as the Knox soils and in certain sections support a highly developed agriculture.

CARRINGTON SERIES[1]

The Carrington soils are developed on the undulating till plains in the region of calcareous glacial drift. In general topographic and geologic features they resemble the Miami soils; but the Carrington was developed under a prairie vegetation, while the Miami was timbered. The original glacial drift received a thin mantle of loess after its deposition by the ice and it seems that this mantle was thicker on the material giving rise to the Carrington than on that from which the Miami was derived. A further difference is that the Carrington soils have a somewhat less pronounced relief than the Miami series (Plate 2B). Neither of these geological differences may be consistently observed, however.

The Lindley series, a soil very similar to the Miami, was described as occurring in the regions of older (i. e., older than the Late Wisconsin) drift. The Carrington soils are also developed in this section and have a slightly different profile than that described for the area of the Late Wisconsin drift. Both of these profiles are shown in Plate 6 and laboratory data are given for both. As the chief difference lies in the depth of the horizons, only the profile of the Carrington developed on the Late Wisconsin drift will be described. The Silt Loam is the important member of the series.

[1] This series is now mapped as Parr by the U. S. Bureau of Chemistry and Soils.

PROFILE OF CARRINGTON SILT LOAM

A_1—Very dark grayish-brown to black silt loam, high in organic matter. The soil has a broadly platy breakage in situ which easily crumbles into a coarse granular structure. At about 9 to 11 inches this grades[1] into

A_2—Very dark brown heavy silt loam. The soil has a fine blocky structure and is friable and mellow. When rubbed the pieces have a brownish-tan color. Broadly platy breakage is noticeable. At about 15 to 16 inches the soil merges into

B_1—A transitional horizon of heavy silt loam, darker than B_2 but lighter than A_2. At about 20 inches is encountered

B_2—Brown silty clay loam. The soil has a small nut structure. The pieces are somewhat rubbery and usually have numerous fine pores. At 32 to 36 inches the soil merges into

B_3—Dark brownish-yellow silty clay loam. The material has a fine blocky structure which pulverizes to a coarse, rubbery crumb structure. At 50 to 60 inches this material gives way to

C —Yellowish, clayey, sandy till. This material is highly calcareous and closely resembles that under the Miami.

TABLE 11.—*Clay Content, Base Exchange Capacity and Acidity of Carrington Silt Loam*

A. *Developed from Late Wisconsin drift*

Horizon	A_1	A_2	B_1	B_2	B_3	C
Depth in inches	0—10	10—15	15—20	20—34	34—54	54—
Per cent clay	44.4	45.4	44.7	43.7	41.0	15.8
Base exchange capacity	18.71	11.71	11.63	15.25	17.94	4.50
Reaction toward Soiltex	N	St.A	V.St.A	V.St.A	V.St.A	Alk.

B. *Developed from Illinoisian Drift*

Horizon	A_1	A_2	B_1	B_2	B_3	B_{31}	C
Depth in inches	0—8	8—13	13—22	22—32	32—54	54—74	74—
Per cent clay	46.7	51.0	49.8	48.7	41.5	27.6	22.5
Base exchange capacity	21.64	12.62	13.07	18.16	17.54	9.60	7.61
Reaction toward Soiltex	N	V.St.A	V.St.A	St.A	M.A	Sl.A	Alk.

The laboratory investigations regarding this profile together with the one developed on the Illinoisian drift are shown in Table 11. An examination of the drawings in Plate 6 will reveal the difference between the two profiles. The data for the clay content show no significant differences between the horizons in the solum of either profile,

[1] Those who have examined the profiles of the Prairie soils are familiar with the fact that the horizons are not as sharply defined as in the Gray-Brown Forest and Podsol soils, but gradually merge, one into the other.

except for horizons B_3 and B_{31} which are transitional to C. There is, however, a noticeable accumulation of base exchange material in the A_1, due to the organic colloids and again in the B horizon, evidently due to a movement downward. It has been pointed out that these soils have not been subjected to the podsolization process to the extent that the timbered soils have. The grass vegetation is more efficient in returning calcium, and other bases, to the surface; this prevents the colloids from becoming acid, the first step in the podsolization process of soil formation. Further it was suggested that these soils represent an unstable condition, and that eventually they will become podsolized as the bases are leached out of the soil.[1] From these data it is very apparent that the soils are now becoming acid and that the podsolization process is well under way. Poor systems of farm management will intensify the process. How important that factor will be in changing the character of the profile has not been studied.

These soils are probably the best in the state for agricultural purposes. Nearly all of the desirable soil characteristics are combined to make them easily managed and highly productive. The high content of base exchange material in the surface is an important factor in their water holding capacity and fertility.

WAUKESHA SERIES

The Waukesha soils are developed from nearly level outwash deposits in the region of calcareous drift of the Late Wisconsin. In the character of the original material these soils are very similar to the Fox series; but the latter are developed under the oak-hickory forest, while the Waukesha developed under a native vegetation of tall prairie grasses. As a general statement it may be said that the formations giving rise to the Waukesha are more generally level and have a finer texture in the surface; however, this

[1] The Chernozem soils represent mature soils with a black surface. And because these soils are developed under a prairie vegetation and in regions of comparatively low rainfall, the bases (calcium and magnesium) are not leached entirely out of the reach of grass roots, but accumulate as a carbonate horizon. With the exception of A_1, due to the decomposing vegetation, bases do not tend to accumulate in any horizon of the Prairie soils.

distinction is by no means applicable to all areas of the two soils. Thus the Waukesha stands in the same relation to the Fox as the Carrington stands to the Miami.

The chief member of the series is the Silt Loam, although there are some areas of Loam and Sandy Loam.

PROFILE OF WAUKESHA SILT LOAM

A_1 —Very dark gray silt loam, high in organic matter, becoming grayish-brown when rubbed. The soil has a broadly platy breakage and quite easily crumbles into platy granules, a little larger than buckshot. At about 8 inches it grades into

A_2 —Dark grayish-brown silt loam, relatively high in organic matter, becoming slightly yellowish brown when rubbed. The soil has a faint broadly platy breakage. It breaks into small angular, somewhat flattened, blocks, about pea-size. At 13 to 14 inches the soil merges into

B_1 —A transitional horizon similar to B_2 except a little darker brown in color. This gives way at about 20 inches to

B_2 —Dull, dark brown clay loam, becoming dark yellowish-brown when rubbed. In situ the soil is compact but when removed it is friable and easily crumbles to a granular pea structure. This layer extends down to about 36 inches.

B_3 —Yellowish-brown clay loam, containing some sand and gravel. This layer is usually somewhat moist and when wet the material is highly plastic. When dry it crumbles into an angular nut structure. At 44 to 52 inches it gives way abruptly to

C —Stratified sand and gravel, dark brown in the upper part fading into yellow below about 10 inches.

No laboratory results were obtained for this profile. In reaction it is somewhat less acid than the Carrington. The Soiltex reaction showed A_1 to be neutral, A_2 slightly acid, B_1 and B_2 strongly acid, while B_3 and C were alkaline. As can be seen from the profile description, considerable podsolization has already started as in the Carrington. Like the other Prairie soils, the Waukesha soils are very fertile and comprise some of the best agricultural land in the state.[1]

MARSHALL SERIES

The Marshall soils are developed under a prairie vegetation from formations consisting of loess over limestone in the unglaciated area. Geologically these soils are almost equivalent to the Knox but the latter soils were developed

---

[1] The Warsaw series is now recognized by the U. S. Bureau of Chemistry and Soils to include a profile similar to the one described above, but with a more shallow A_1 and a generally shallower solum.

under an oak-hickory forest for the most part. In general the Marshall is confined to the least hilly portion of the region and is especially found on the gently rolling, plateau-like uplands. The Silt Loam is the important member of the series.

PROFILE OF MARSHALL SILT LOAM

A_1 —Very dark brown to nearly black silt loam, high in organic matter. In situ the soil has a broadly platy breakage which crumbles to a granular structure. In the lower part the soil is more brown in color. At about 9 to 12 inches the soil merges into

A_2 —Dark brown silt loam, relatively high in organic matter. The soil has a fine blocky structure. At 15 to 16 inches is encountered

A_{21}—A transitional horizon similar to A_2 except lighter brown in color and somewhat coarser in structure. This changes at 19 to 22 inches to

B_1 —Dark yellowish-brown silty clay loam. The soil has an angular nut structure and is quite compact in situ. At 28 to 32 inches the soil grades into

B_2 —Yellowish-brown clay loam or silty clay loam with an angular nut structure. This material has a high capacity for water. At about 48 to 60 inches is encountered

B_3 —Reddish-brown heavy clay, with a coarse, walnut-size, angular nut structure. The soil is very hard when dry and very plastic when wet. This immediately overlies the rotten limestone which is encountered at depths ranging from 60 inches to greater.

C —Yellow, clayey, cherty material residual from limestone, grading into solid limestone.

The data on this profile, presented in Table 12, are especially interesting. Down to the B_3 horizon at 52 inches the data show only a relatively small, though definite, tendency toward profile development. The same condition obtained in the profile of the Deep Phase of Knox Silt Loam. It is to be noted, however, that the influence of the calcium carbonate in stopping material that would otherwise probably have been lost in drainage, has been very marked. These results may be explained as follows: The original loessial material was undoubtedly high in base exchange material at the time of its deposition and contained about as much as would be contained by the B_2 horizon of a mature soil under the environmental conditions which obtained. As a result, any base exchange colloid leached from the A horizon instead of being deposited in the B_2, would leach out of the soil unless flocculated by a high concentration of calcium carbonate or similar material. In the case of the

TABLE 12.—*Clay Content, Base Exchange Capacity and Acidity of Marshall Silt Loam*

Horizon	A_1	A_2	A_{21}	B_1	B_2	B_3	C
Depth in inches	0—10	10—15	15—20	20—30	30—52	52—78	78—
Per cent clay	40.8	47.4	46.1	45.9	43.0	70.7	22.2
Base exchange capacity	16.81	11.08	12.69	17.44	18.17	31.66	4.99
Reaction toward Soiltex	St.A	V.St.A	V.St.A	V.St.A	V.St.A	N	Alk.

Deep Knox the limestone was so deep that its effect was not observed; however, in the case of the Shallow Knox and the Marshall profiles it is very pronounced. Thus in these soils the greatest zone of accumulation will be controlled by the depth of the loess over the limestone. In Figure 11 the relationship between the texture and the content of base exchange material in the same genetic horizons is clearly brought out.

The Marshall soils are very fertile and are considered as the best agricultural soils of southwestern Wisconsin.

DODGEVILLE SERIES

The Dodgeville soils are developed under grasses from deposits of loess over limestone in the unglaciated area; briefly they may be considered as a shallow phase of Marshall. For the most part they are found on the gently rolling plateau-like up-lands.

PROFILE OF DODGEVILLE SILT LOAM

A_1—Very dark gray to nearly black silt loam, high in organic matter. In situ the soil has a broadly platy breakage and crumbles to a granular structure. In the lower part of the soil there is a more noticeable shade of brown. At 8 to 11 inches this changes to

A_2—Dark brown silty clay loam, containing some humus. The soil has an ill-defined blocky structure merging to a coarse granular. The material has a cheesy consistency. At 14 to 18 inches this gives way to

B_1—A transitional horizon of brown silty clay loam, lighter in color than A_2 but darker than B_2. At 19 to 22 inches the soil merges into

B_2—Brown clay loam. The soil has an ill-defined, fine blocky structure and is rubbery or cheesy in consistency with a high water holding capacity. At depths ranging from 21 to 32 inches the soil changes tc

B_3—Brownish-red heavy clay, sometimes cherty. The soil has an angular nut structure. This material is relatively impervious, except as water may pass between the blocks. It is quite plastic when wet. Frequently there are blackish spots in the soil mass. This horizon is only about 1 to 4 inches in thickness and overlies

C —Yellowish, cherty material, residual from limestone, grading into limestone rock in depth.

Although this soil was not examined in the laboratory the effect of the limestone in flocculating the base exchange colloids is obvious. The B horizons show about the same general character as those of the Shallow Phase of Knox and the B_3 of the Marshall.

THURSTON SILT LOAM[1]

Thurston Silt Loam is a relatively unimportant soil observed about six miles south of Devil's Lake in Sauk County. The profile is interesting, however, as it represents a condition transitional between the Miami and Carrington families. The soil is developed on gently rolling calcareous till of the Late Wisconsin period of glaciation. It will be recalled that the suggestion was made that probably most of the soil of the Miami family had a prairie vegetation at one time for a short period immediately following the retreat of the ice. In the case of Thurston it appears as if prairie grasses had persisted longer before the invasion of the oak-hickory forest than in the case of the other timbered soils.

PROFILE OF THURSTON SILT LOAM

A_{00}—Surface covering of loose leaf litter from deciduous trees, about 1 to 2 inches in thickness.

A_0—Dark brown to nearly black leaf mold, about ½ inch in thickness.

A_1—Dark gray silt loam, high in humus. The soil is finely granular in structure and except for a few pebbles, has a velvety feel. This horizon is about 6 inches in thickness.

A_2—Rather dark, gray, ashy silt loam. The soil has a platy breakage and is brittle and friable, crumbling to a fine granular structure. At 9 to 12 inches this changes to

B_1—Grayish-brown light silty clay loam. The soil has a broadly platy appearance in situ and is removed as friable, slivery pieces. Relicts of an old blocky structure can be observed. At about 16 inches this changes to

[1] A local name that has not been approved as yet for published Soil Survey reports.

B_2—Rather dark, brown clay or silty clay with a well-defined angular nut structure. Except for a slightly darker color the soil resembles the B_2 of Miami Silt Loam. At 32 to 38 inches this alters to

B_3—Very dark reddish-brown sandy clay, slightly cemented. The soil is lumpy, but not definitely blocky in structure. This extends down to about 50 to 60 inches.

C—Yellowish, sandy, clayey till. This material is quite stony and contains a great quantity of rotten granitic material.

TABLE 13.—*Clay Content and Acidity of Thurston Silt Loam*

Horizon	A_1	A_2	B_1	B_2	B_3	C
Depth in inches	0—6	6—11	11—16	16—36	36—52	52—
Per cent clay	34.1	33.1	35.8	36.0	20.7	12.0
Reaction toward Soiltex	M.A	St.A	V.St.A	V.St.A	N	Alk.

In Table 13 are shown the data for clay content. The profile clearly shows the characteristics of both Miami and Carrington. It may be interesting to note here that although there is a broad transitional area between the Podsol and Gray-Brown Forest zones there are but few transitional regions between the Prairie soils and those of the other groups. The dominant influence in the development of the Prairie soils is the grass vegetation and it would appear that once this is removed their degradation is rapid.

PLAINFIELD SERIES

The Plainfield soils are characterized by their extreme sandy nature; and because this feature has been so prominent, the well-drained sandy soils in Wisconsin developed from non-calcareous sand, occurring in nearly level deposits, have been included in the series. The land is generally level, or nearly so, and usually of glacio-fluvial origin. From the standpoint of profile development, however, these soils exhibit marked differences in various parts of the state: those in the southern portion are related to the Miami, while in the northern part they are closer to the true Podsols. For this reason the discussion will be divided between the northern and southern groups.

Southern Group

Plainfield soils are scattered over considerable portions of the glaciated sections and along the water courses and flood plains which have been built into the unglaciated region by water pouring from the former area. There is a large contiguous area of these soils in the central part of the state. The native vegetation was originally oak and pine and at present it is chiefly "scrub oak" of a poor quality. Much of this land has been repeatedly burned and is almost bare of organic covering (Plate 4A). The Sand type is the most general condition and may be described as follows:

PROFILE OF PLAINFIELD SAND (Southern)

A_{00}—Very thin covering of loose pine needles and oak leaves.
A_0 —Dark gray, scale-like trockentorf, normally very dry and brittle. This layer is about ¼ to ¾ inch in thickness, but there are cracks and spots where it is absent and the mineral soil is exposed.
A_1 —Brownish-gray sandy soil containing considerable humus. There are numerous specks of clean, white sand so that the soil has a 'salt-and-pepper' appearance. At 1½ to 2 inches this changes to
A_2 —Grayish-brown loamy sand with a small amount of humus. At depths ranging from 3 to 4 inches is encountered
B_1 —Dull brown, slightly grayish, sand. The soil has a slight coherence. This layer gives way at 5 to 6 inches to
B_2 —Brown, slightly loamy, sand. The soil is slightly coherent but loosened pieces easily fall into single grain structure. This layer extends down to about 24 inches where the soil grades into
B_3 —A transitional yellow sand grading at about 36 or 40 inches into
C —Straw colored loose, medium sand.

TABLE 14.—*Clay Content, Base Exchange Capacity and Acidity of Plainfield Sand (Southern)*

Horizon	A_0	A_1	A_2	B_1	B_2	B_3	C
Depth in inches	¾—0	0—1½	1½—3	3—5	5—23	23—39	39—
Per cent clay	--------	8.0	7.5	8.0	6.5	--------	2.3
Base exchange capacity	13.45	9.20	4.18	2.42	1.37	--------	0.35
Reaction toward Soiltex	V.St.A	V.St.A	V.St.A	V.St.A	V.St.A	V.St.A	V.St.A.

The data in Table 14 show that although there has been some movement downward there has not developed a profile with the same relationship between A and B as in the Miami. In any soil which supports vegetation there will be considerable base exchange material arise from the organic matter. It has already been pointed out that this material will be largely in the upper part of the soil and will have the effect of concealing the movement of the inorganic material. Water movement is rapid through this soil. Under the discussion of the Fox series attention was called to the important influence of a gravel substratum in arresting water movements. The lower portion of the Plainfield Sand is largely medium sand and is acid in reaction: there is but little tendency for the colloidal material to be removed from solution. If the statement of Glinka (17) is accepted this soil could not be included with the Gray-Brown Forest group because of the acid reaction of the parent material.[1] Although this profile cannot be said to belong with the Miami Family, it clearly lies within the Gray-Brown Forest zone.

Northern Group

In the northern part of the state the sandy outwash benches have given rise to soils with different profiles. From a study of these profiles there seems to be some doubt as to the justification of placing the several types in the same series, although from the point of view of their present adaptability to growing plants it seems logical. The two important types in the series to be discussed are the Sand and the Light Sandy Loam.

Both types are developed from sandy outwash benches and are characteristically level in surface feature, except for occasional pits and terraces peculiar to these formations. The forest cover was almost entirely coniferous: the Sand type was largely jack pine with some Norway pine, while the Light Sandy Loam had less jack, more Norway, and some white pine. At present most of the pine has been removed so that the cover consists of a scattered growth of pine with "scrub oak" in the badly burned areas. The ground cover is largely sweet fern and similar xerophytic plants with a noticeable admixture of bracken fern on the Light Sandy Loam.

---

[1] Glinka points out that there must be some calcium carbonate in the parent rock before the true Braunerde (Gray-Brown Forest soil) can develop. Following this line of reasoning the above profile does not belong with any recognized great soil group.

PROFILE OF PLAINFIELD SAND (Northern)

A_{00} and A_0—A thin layer of leaf litter and dark brown, dry, peaty organic matter (trockentorf) about 1 to 1½ inches in thickness.

A_1—A dark grayish loose mixture of sand and humus. The material has a 'salt-and-pepper' appearance. This layer has a thickness of only about one inch.

A_2—Grayish-brown loamy sand. There is present noticeable humus material. At 2 to 4 inches from the surface this horizon gives way to

B_1—Dull yellowish-brown loamy sand. The sand has some coherence and when wet has a crumb structure. At about 12 inches this grades into

B_2—More compact dull yellowish-brown loamy sand. The soil has enough compactness to be noticeable. At 24 inches this horizon is underlain by

B_3—A transitional layer of brownish-yellow loose sand. This extends to approximately 36 inches.

C—Pale yellow loose sand. This material generally has more or less stratification.

The results of the laboratory investigations on this profile are shown in Table 15. From the description of the profile and these data it becomes evident that this weakly expresses the Podsol profile and clearly represents a condition different from that obtaining in the southern area. Although the A_2 horizon is high in base exchange material, the larger portion of which is undoubtedly organic matter, there has been a noticeable drift of this material into the lower horizons. Now let us examine the Light Sandy Loam type.

TABLE 15.—*Clay Content, Base Exchange Capacity and Acidity of Plainfield Sand (Northern)*

Horizon	A_2	B_1	B_2	B_3	C
Depth in inches	1—4	4—11	11—24	24—36	36—
Per cent clay	8.0	8.3	7.5	4.2	3.8
Base exchange capacity	6.26	1.84	2.11	----------	1.73
Reaction toward Soiltex	St.A	V.St.A	V.St.A	St.A	M.A

PROFILE OF PLAINFIELD LIGHT SANDY LOAM (Northern)

A_{00} and A_0—A thin layer of leaf litter and dark brown, or nearly black, dry, peaty organic matter (trockentorf), ranging from 1 to 2 inches in thickness.

A_1—A very thin layer of dark gray loamy sand and humus with a 'salt-and-pepper' appearance. This horizon is only about 1 inch in thickness.

A_2—Dull gray loamy sand with a brownish tinge in the lower part. A small amount of organic matter is included. When wet the soil has appreciable coherence but when dry it is loose. At about 4 to 7 inches it grades into

B_1—Dull brownish loamy sand. A transitional layer only about one inch thick.

B_2—Dull, slightly yellowish, brown light sandy loam. The soil is quite compact and contains a few cemented lumps. When broken it has a rather poorly developed crumb structure. This material is apparently fairly retentive of water considering the large percentage of sand. At about 20 to 24 inches this horizon gives way to

B_3—A transitional horizon of sand or loamy sand, stained with yellowish-brown and rusty brown, extending down to about 34 inches from the surface.

C —Yellow, loose gravelly sand, grading into pale grayish-yellow, gravelly sand.

The results in Table 16 indicate a much greater development of profile than in the case of the Plainfield Sand.

TABLE 16.—*Clay Content, Base Exchange Capacity and Acidity of Plainfield Light Sandy Loam (Northern)*

Horizon	A_2	B_2	C
Depth in inches	2—6	7—22	34—48
Base exchange capacity	4.38	3.95	1.07
Per cent clay	8.78	11.28	2.82
Reaction toward Soiltex	V.St.A	St.A	M.A

Thus on almost identical parent material three profiles have been developed. The justification for placing all of these soils in the same series is that the extreme sandy texture is the predominating character influencing their utilization. The Light Sandy Loam represents the profile found in that portion of the state having the lowest summer temperature. Under the discussion of climate attention was called to the influence of Lake Superior in lowering the summer temperature. If the rainfall remains nearly constant, as it does in the northern area, those portions of the area having low summer temperatures will have an increased amount of percolating water; and this, in turn, will increase podsolization.[1]

The southern profile represents the conditions found within the Gray-Brown Forest zone.[2] The Plainfield Sand

[1] This more strongly podsolized Plainfield is similar to the Rubicon series recognized by the U. S. Bureau of Chemistry and Soils in Michigan.

[2] For a description of Plainfield Sand in Southern Michigan see (33) (31).

type described under the northern group occupies a transitional position between the Podsol zone in the north and the southern zone. It may be interesting to note that the two profiles from the northern area were observed only a few miles apart but between them was the rather sharp line bounding the narrow strip of land which is strongly influenced by Lake Superior.

Boone Series

The Boone soils are confined to those developed under a forest cover from material residual from sandstone in the driftless area. The chief member of the series is the Fine Sand, but heavier types are included.[1] The native vegetation consists largely of oak with some hickory. In some areas white and Norway pine were present in the original forest. The topographic feature of the land varies from gently rolling to hilly so that external drainage is free. Because of its extremely sandy nature, the Fine Sand type is excessively drained and subject to severe drought.

Proeile of Boone Fine Sand

A_{00}—Very thin covering of loose leaves.

A_0—Dark brown leaf mold, often appearing as a scale-like trockentorf. This layer is only about ¼ to ½ inch in thickness and frequently does not entirely cover the mineral soil.

A_1—Dark grayish-brown sandy soil containing considerable humus. The soil has a 'salt-and-pepper' appearance due to the numerous white specks of fine sand. This horizon is only about ¾ to 1½ inches in thickness.

A_2—Dark brown fine sand or loamy fine sand. Many of the sand grains are white. The soil has sufficient coherence to dig out in chunks that are easily crumbled. In situ the soil has a broadly platy breakage. At about 5 to 8 inches this grades into

B_1—Yellowish-brown fine sand, transitional to B_2 which is encountered at 10 to 12 inches.

B_2—Rather bright, yellowish-brown loose fine sand. At 24 to 30 inches this grades into

---

[1] The Knox soils are developed from residual limestone material overlain with loess, while the Boone soils are residual from sandstone. Obviously between these soils there are transitional areas having loess over sandstone. Some of these transitional soils have been placed with the Boone, others with the Knox. It seems more logical to classify with the Knox those soils which have the solum derived from loessial material. As this has not always been done, however, it should be borne in mind that such soils as Boone Silt Loam are more closely allied with the Knox than with the Boone soils as described here. See (15).

B_3—A transitional horizon of fine sand, changing at 40 to 48 inches to

C —Whitish-yellow, loose fine sand, containing occasional small pieces of chert or sandstone. This material grades into sandstone in depth.

An examination of the data in Table 17 shows that the clay content is similar to that of the Southern Plainfield profile. Data for the base exchange capacity are not available but it can be quite safely assumed to be similar to that of the Southern Plainfield. As with the Plainfield soils, there is considerable variation from the Miami profile. Weathering cannot be expected to proceed rapidly in material from which this soil is derived; nor can there be expected a high degree of flocculation of the descending colloids with such material. From the appearance of the soil profile and its location with respect to other soils the Boone apparently belongs in the northern part of the Gray-Brown Forest zone. But like the Plainfield this soil is not truly a member of the Gray-Brown Forest group of soils.

TABLE 17.—*Clay Content and Acidity of Boone Fine Sand*

Horizon	A_1	A_2	B_1	B_2	C
Depth in inches	0—½	½—6	6—11	11—28	43
Per cent clay	7.5	5.4	5.3	4.9	2.2
Reaction toward Soiltex	V.St.A	V.St.A	V.St.A	V.St.A	V.St.A

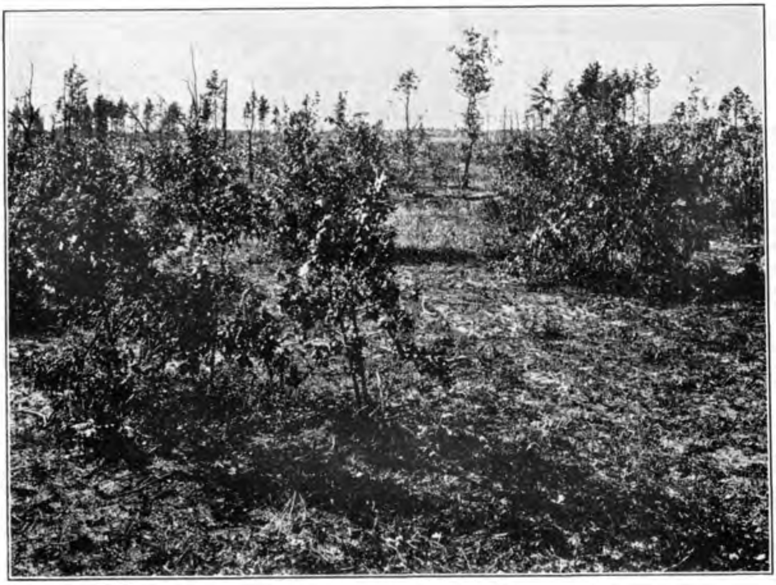
Like the Plainfield, the sandy members of the Boone series are subject to severe drought; the latter soils being rolling in surface feature are probably more seriously affected. Their utilization for general farm crops is of doubtful success at present.

COLBY SERIES[1]

The Colby soils, of which the Silt Loam is the only important member, occupy a large area in the central part of the state. Most of the soil is derived from old drift laid down during the early periods of glaciation; although there is a considerable area in Rusk, Tayor and Price Counties

[1] These soils appear as Spencer on the published reports of the U. S. Bureau of Chemistry and Soils.

PLATE 4



A. *View on Plainfield Sand (Southern)*
The present cover of scrub oak has replaced the original pine. Note the scanty leaf mold.

B. *View on Colby Silt Loam.*
This soil is typically developed under conditions of poor drainage.

developed in the region of the Late Wisconsin drift. (See Figure 1 for the outline of these drift sheets.) The till is quite thin in most places and has been strongly influenced by the character of the underlying rocks. Frequently it has been observed that the lower part of the soil has evidently been formed from material residual from these rocks rather than from glacial drift. Further, it might be noted that the Colby soils are very acid.

The land is typically undulating to nearly level in surface feature (See Plate 4B). This characteristic, together with the heavy nature of the soil material, has been responsible for rather poor drainage conditions. That portion of the Colby soils developed from the drift of the Late Wisconsin is more rolling and consequently better drained. The soil studied in the laboratory was collected from the nearly level, typical development; and poor drainage is reflected in its profile character.

The native vegetation was mixed pine and hardwoods. The pine was chiefly white with some Norway. Hard and soft maple, elm, and ash were the chief species among the hardwoods; although yellow birch, hemlock, and similar species were doubtless common in the northern part of the area; while oak and hickory were prominent in the southern portion.

PROFILE OF COLBY SILT LOAM

A_{00}—Thin covering of loose leaves and forest debris, 1 to 2 inches thick.

A_0—Nearly black forest mold ½ to 1 inch in thickness.

A_1—Very dark brownish-gray silt loam, high in humus. The soil has a rather coarse granular structure; the individual particles are somewhat cheesy. At about 4 inches this gives way to

A_2—Dark brownish-gray mellow silt loam. The soil has a platy breakage and easily pulverizes to a fine crumb structure. The material has a whitish-gray color when dry. This layer extends down about 7 to 8½ inches.

A_{21}—Light yellow, floury, velvety, silt loam, mottled with gray and brownish-yellow. The soil has a noticeable platy breakage. At 10 to 12 inches this layer gives way to

B_1—Mottled gray, yellow, and yellowish-brown heavy silt loam. The soil is compact and the texture is smooth, but not as velvety as A_{21}. There is a faint, broadly platy breakage and relicts of an old blocky structure. When removed the pieces are slivery and friable. At 20 to 24 inches is encountered.

B_2—Light brown sandy clay mottled with gray and yellow. The color is quite variable from place to place. The soil is quite compact and has a relatively high content of water.

This material is quite impervious to water and evidently not easily penetrated by roots under natural conditions. The soil gradually merges at 40 to 50 inches into

C —Lighter brown sandy clay, mottled with gray and yellow. The soil is lighter in color and somewhat more compact in structure than B_2. The material is quite plastic, even though considerable sand is present; it has about the consistency of cocoanut candy. When wet the soil is very sticky. Water percolation is slow through it.

The laboratory data regarding the Colby Silt Loam are set forth in Table 18. The A_1 horizon is quite thick and has a high content of base exchange material, most of which is doubtless organic. In this respect the Colby is clearly differentiated from the true Podsol which has only a poorly developed A_1 horizon. The A_2 and A_{21}, and also the B_1, horizons show that the podsolization process has been active. From the data for B_2 and C it is apparent that this material has not accumulated to any significant degree in B_2, but has been leached out of the soil: therefore it cannot be classified with the Miami Family of the Gray-Brown Forest zone.

TABLE 18.—*Clay Content, Base Exchange Capacity and Acidity of Colby Silt Loam*

Horizon	A_1	A_2	A_{21}	B_1	B_2	C
Depth in inches	0—4	4—7½	7½—11	11—22	22—47	47—
Per cent clay	33.8	40.4	34.6	34.4	35.2	33.4
Base exchange capacity	29.37	9.54	5.29	9.39	15.43	14.97
Reaction toward Soiltex	V.St.A	V.St.A	V.St.A	V.St.A	V.St.A	V.St.A

The most prominent separate in this soil is the silt, rather than the clay. The following data (Table 19) is interesting in this connection. The samples were not collected by horizons but the general nature of the soil material is evident. In the case of such heavy clays as Su-

TABLE 19.—*Mechanical Analysis of Colby Silt Loam (After Whitson (49))*

Depth in inches	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
0— 8	0.2	3.5	2.6	4.0	5.7	70.3	13.6
8—24	0.3	3.5	3.7	5.8	7.0	64.3	15.2
24—36	0.4	7.2	8.5	14.8	11.5	34.9	22.4

perior Silty Clay Loam the percentage of clay is much higher. This comparison is reflected in the structural condition of the two soils: the Superior soils have a blocky structure in the B horizon, such that water can pass through the soil along the cracks between the soil blocks; the Colby soils, however, do not have a large content of active colloidal clay and do not swell and contract with changes of moisture content sufficiently to produce this sort of structure to a marked degree. But in the Colby Silt Loam the soil material has sufficient clay, with the high amount of silt, to produce a soil highly retentive of water. For this reason soils like the Superior are easier to drain than the Colby soils, despite the higher clay content of the former. Therefore the Colby Silt Loam exhibits an immature profile; it is even less mature than those of soils with the same surface features and with a higher content of clay.

The Colby Silt Loam is one of the most important soils in the state from the point of view of agricultural utilization. Its high water holding capacity insures a good growth of pasture and hay crops and this, coupled with the desirable climate, makes the area one of the important dairy sections of the world. Applications of lime and tile drainage make the soil suitable for intertilled crops and legumes.

Vesper Series

The Vesper series occupies a region transitional between the Colby soils and the unglaciated section to the west and southwest of them. The small areas of Vesper Silt Loam are very similar to the Colby Silt Loam and will not be considered. The chief type in the series is the Fine Sandy Loam. The underlying rocks are sandstones of fine texture. The land surface is very gently undulating to nearly level and gives the appearance of poor drainage. The original vegetation was chiefly jack and Norway pine and oak; at present there is a scrubby cover of oak, jack pine, trembling aspen and similar species. The ground cover consists largely of sweet fern, wintergreen, blue berries and such plants; there is but little herbaceous growth.

This soil has a very unusual and interesting profile, the characteristics of which have been largely inherited from the parent material.

PROFILE OF VESPER FINE SANDY LOAM

A_{00}—Very thin covering of leaves and forest debris.
A_0 —Dark brown forest mold, ½ to 2 inches in thickness.
A_1 —Dark brown fine sandy loam containing considerable humus. There is an unusually large number of plant roots in this layer. At about 2 inches the soil changes to
A_2 —Gray light fine sandy loam. In situ there is a noticeable broadly platy breakage. The soil has a faint crumb structure, which easily pulverizes into a single grain. This layer extends down to about 3 to 5 inches.
B_1 —Dark brown mellow fine sandy loam. At 5 to 7 inches this grades into
B_2 —Brownish-yellow light fine sandy loam. The soil is somewhat coherent but easily falls into a single grain structure. Small sandstone pebbles may be observed. At about 11 or 12 inches this grades into
C —Yellowish-gray pebbly loamy fine sand. This material is often white or has white blotches. At 18 to 30 inches is encountered
D_1 —Heavy slate-colored clay, containing much fine sand. The material frequently has a greenish tint, and spots of red are scattered throughout. The clay has an angular blocky structure; the outside of these blocks is often stained with brown from the roots. Roots, however, do not penetrate this material very generally. In the lower part the clay has definite laminations and grades into
D_2 —Sandy shale, sandstone, or rotten sandstone. In places there is nearly white sand, residual from sandstone, between D_1 and the underlying rock.

Data for the base exchange capacity are not available, but it is assuredly low in the solum. The results shown in Table 20 indicate the extreme nature of the clay horizon. According to the writer's nomenclature this clay horizon has been designated as D_1 rather than B because it is inconceivable that it could have arisen from the eluviation of the soil above. At first one might be lead to suppose this material to be formed from a thin sheet of till weathered to Kay's "Gumbotil" (22) and later covered with sandy outwash from the northeast. This explanation is quite in-

TABLE 20.—*Clay Content and Acidity of Vesper Fine Sandy Loam*

Horizon	A_1	A_2	B_1	B_2	C	D_1
Depth in inches	¼—1¾	1¾—4	4—6	6—11	11—23	23—35
Per cent clay	17.8	17.1	22.2	19.8	11.5	58.0
Reaction toward Soiltex	V.St.A	V.St.A	V.St.A	V.St.A	V.St.A	V.St.A

volved and unsatisfactory in view of the laminated character of the lower portion of the clay. According to the geologic column for Wisconsin as presented by Ulrich (45), a thin layer of shale (Eau Claire) might have been present above the sandstone. This shale, on being weathered, would give rise to such a clay as that described, and if the original layer was thin it would have been completely weathered. The sandy material from whence the solum has arisen has either been residual from an overlying layer of sandstone or, as is more probably the case, been deposited as outwash or old glacial lake bed during the Pleistocene.

The Vesper should probably be classified as an immature soil in the transitional region between the Gray-Brown Forest and Podsol zones along with the Colby. In this profile we have a soil with a heavy clay horizon which has been inherited from stratigraphic parent material, rather than formed by strictly soil-building forces.

MIAMI LOAM[1] (Door County)

This soil is developed from shallow limestone till overlying limestone rock and is limited to the region near Green Bay, mostly in Door County. The surface is gently undulating in topographic feature and drainage is relatively good. Limestone slabs and fragments frequently are too numerous to justify clearing although much of the land is suitable for agricultural use, especially fruit growing. The native forest was largely hard maple, beech and yellow birch, with some hemlock. A few white pine and other coniferous species were present but the forest was distinctly a hardwood association as compared to the mixed pine and hardwoods under which the Kennan soils developed.

PROFILE OF MIAMI LOAM (Door County)

A_{00}—Litter of loose leaves from the hardwood forest, 1 to 3 inches in thickness.

A_0—Nearly black forest mold, distinctly of the 'mull' type. This layer is about 1½ to 2 inches in thickness.

---

[1] This soil was mapped in Door County in 1916 (14). At present it would probably be divided between the Onoway series and the Posen series as recognized in Menominee County, Michigan. It clearly does not belong with the Miami series as now defined.

A_1 —Nearly black sandy loam, high in organic matter. It has the characteristic 'salt-and-pepper' appearance of the Podsol A_1 horizon. At about 1½ inches the soil gives way to

A_2 —Dark brownish-gray light loam, or sandy loam, containing some organic matter. The soil has a broadly platy breakage and is easily pulverized to a fine crumb structure. Podsol character is noticeable. At about 3 to 5 inches the soil changes to

A_{21}—Somewhat grayish, brown loam. In situ the soil has a broad, platy structure that easily pulverizes to a fine mellow crumb. At approximately 7 inches is encountered

B_1 —Yellowish-brown loam. The soil has a faint, broadly platy breakage and easily pulverizes to a mellow crumb structure. There are noticeable relicts of old rotten limestone fragments which appear as hard lumps. At about 18 inches this horizon changes to

B_2 —Dull reddish-brown sandy, stony clay. The soil has a friable nut structure; the pieces are about ¼ to ½ inch in diameter. White pebbles of limestone are scattered through the soil mass. At about 27 to 32 inches is encountered

C —Yellowish-tan stony, clayey till. The material is quite loose and appears mealy when removed. About one-half the volume is occupied by limestone slabs. In the lower part the soil grades into solid limestone rock at variable depths, depending upon the depth of the till sheet.

From the field description and the data in Table 21 it is quite clear that this profile does not belong with the Miami family as defined previously; neither should it be included with the true Podsols. The high amount of humus, typical of the mull type of organic layer, accounts for the high base exchange capacity of the upper portion of the soil. In this case there is evidently such a large amount of organic exchange material that the values for the clay content probably indicate more correctly the physical nature of the profile. In both cases the B_2 shows a very marked development. That this is, in part, due to the effect of the large amount of calcium present in flocculating the colloids in descending waters is obvious.

TABLE 21.—*Clay Content, Base Exchange Capacity and Acidity of Miami Loam (Door County)*

Horizon	A_1	A_2	A_{21}	B_1	B_2	C
Depth in inches	0—1½	1½—3	3—6	6—18	18—30	30—
Per cent clay	17.9	23.3	23.9	25.5	34.3	13.4
Base exchange capacity	24.36	12.18	5.59	4.04	12.49	5.95
Reaction toward Soiltex	M.A	M.A	St.A	V.St.A	N	Alk.

SUPERIOR SERIES

The soils of the Superior series are confined to those developed from red lacustrine clay. Several types are included in the series on the basis of the texture of the surface soil. The normal development is the Silty Clay Loam[1] member; others represent conditions produced by the deposition of sandy material on the surface of the lacustrine clay after its deposition by the glacial lake. Only those soils are included in the Superior series that have at least a portion of the solum derived from the clay.[2]

There are two general areas of this lacustrine clay in the state: one is in the northwestern portion of the state; and another is in the eastern portion in the vicinity of Lake Winnebago, along the Fox River, and bordering much of the Lake Michigan shore line. (See Figure 1). As the red clay is the predominating differential characteristic of the soils developed from these deposits, those of both areas have been included in the series. Three profiles are examined, two from the northern area and one from the southern part.

The topography varies from nearly level to gently rolling. Streams and drainways have cut many V-shaped valleys which are often very deep, especially near the Great Lakes and the larger streams. Along these valleys and on the hills the whitish A_2 horizon has been nearly or quite completely eroded away, leaving exposed the heavy red clay of the B horizon. In many places minor ice movements after the period of deposition by the glacial lakes have had the effect of producing more relief and sometimes of incorporating small amounts of coarse material. The typical condition is a nearly level surface with poor external drainage. (Plate 5A). Because of this drainage condition and the extremely heavy nature of the parent material these soils do not have a definitely mature profile.

The Superior series is characterized by a coniferous forest vegetation. The original cover was largely white

---

[1] On many of the soil maps this type is called Superior Clay Loam for simplicity.

[2] In the earlier mapping this distinction was not rigidly nor consistently made and some soils were included in this series that had deeper coverings of sand over the clay than this definition would indicate. Such soils are now classified as Orienta, Berrien and similar series.

PLATE 5

A. *View on Superior Silty Clay Loam.*
The original glacial lake bed has not been disturbed by the ice.

B. *View on Kennan Loam showing the forest under which the soil developed.*
Most of the original forest cover on the Kennan has been removed.

pine with some spruce and balsam fir. In the northern area some hardwoods were present on these soils, particularly on the Loam and Fine Sandy Loam members. These hardwood stands were mostly confined to areas near the shore of Lake Superior. The differences in climatic conditions between the southern and northern portions within this area of lacustrine clay are probably quite important. The southern area, near Lake Michigan, had more hardwoods in the original stand than did the northern area.

PROFILE OF SUPERIOR SILTY CLAY LOAM (Northern Area)

A_{00}—Thin layer of loose leaves and forest debris.

A_0 and A_1—Nearly black, granular peaty material with a small amount of silty humus soil. This layer is about 2 inches in thickness.

A_2—Faintly pinkish, gray, ashy silt loam to silty clay loam, containing only a very small amount of organic matter. The surface structure is platy, while the lower part has a blocky, nut structure. These lumps are more friable than those of the lower horizons. The layer extends down to 5 or 7 inches from the surface.

B_1—A transitional horizon of gray and pink clay loam with a blocky, nut structure. The surface of the soil blocks is gray, while the matrix is pink. At 7 to 12 inches this layer is underlain by

B_2—Pinkish-red, with some brownish-red, heavy clay. When dry the soil has an angular nut structure; when wet it is very sticky and plastic. The soil blocks have a thin covering of more brownish material. At about 24 inches this layer grades into

C—Pinkish-red, heavy, tough, lacustrine clay. Gray and blue streaks are noticeable. When dry the material has an angular nut structure. The clay is quite impervious and apparently very little water percolates into the mass. In the lower part the clay often has a shale-like appearance. In places where the original deposits have not been disturbed by the ice movements, varving is very noticeable. Stones are absent except for the few areas that have suffered a readvance of the ice. While the solum is entirely acid, the parent material has sufficient calcium carbonate to effervesce with acids.

Even though the parent material is apparently very impervious to water, considerable action by soil-building forces has taken place. As the heavy clay shrinks and swells, cracks are formed, and it is largely through these cracks that water passes downward. This is shown by the weathered surfaces of the soil blocks; these appear as gray coats in the B_1 horizon and as brown coats in the B_2 horizon. From the results in Table 22 it is evident that the portion of fine material which has moved downward into

TABLE 22.—*Clay Content, Base Exchange Capacity and Acidity of Superior Silty Clay Loam (Northern Area)*

Horizon	A_2	B_2	C
Depth in inches	1—6	9—24	24—48
Per cent clay	68.3	86.0	87.5
Base exchange capacity	10.62	35.34	25.19
Reaction toward Soiltex	V.St.A	St.A	Alk.

the B horizon has been largely the absorbing complex. The clay content of the B horizon and of the parent material is higher than that of the A_2 horizon. It is very probable that the original surface two feet was somewhat lower in clay content than the substratum. According to the values for the base exchange capacity a very large portion of the absorbing complex has moved from the A_2 into the B_2 horizon. Acid weathering has been active and the soil has the character of a true Podsol.

From the point of view of present agricultural development this soil is the leading type in the northern area. Despite its difficult cultivation and hardness of clearing, settlers have more commonly taken this soil in preference to others. Its high water holding capacity insures freedom from drought; and in this section where dairying is the chief agricultural pursuit, the ability of the soil to produce excellent pasture and forage crops explains its present development.

The next most important type in the northern area of the Superior series is the Fine Sandy Loam. As pointed out previously, this soil is developed from deposits consisting of wind-blown or alluvial-borne sand over the heavy lacustrine clay.

PROFILE OF SUPERIOR FINE SANDY LOAM (Northern Area)

A_{00}—Thin layer of loose leaves and forest debris.

A_0—Forest mold and nearly black, peaty organic matter, about 1 to 1½ inches thick.

A_1—A thin layer of very dark gray fine sandy humus soil forms the transition to the next horizon. This layer is about ½ to 1 inch in thickness.

A_2—Gray loamy fine sand, streaked with brown. A relatively small amount of organic matter is present. The soil has a very faint crumb structure. This horizon extends down to 7 or 11 inches.

B_1 —Grayish-brown fine sandy loam mottled with gray, rusty brown and faint pink. The soil is quite compact and some cementation is noticeable, yet it is friable. At depths ranging from 14 to 25 inches this layer gives way to

B_{11}—Light gray very fine sandy loam, streaked with yellow and brown. The structure is platy. The soil is quite compact and is saturated with water much of the time. This horizon is quite variable as to thickness and development. It is usually 2 to 4 inches thick.

B_2 —Pinkish-brown clay containing considerable sand, especially in the upper part. The soil has an angular nut structure. At about 25 to 32 inches this gives way to

C —Heavy pinkish-red clay. Often noticeable gray laminations are present. The dry material has a coarse blocky structure similar to the C horizon of the Silty Clay Loam type. Under ordinary conditions not much water penetrates into this clay but when it is wetted it becomes very plastic and sticky.

The Superior Fine Sandy Loam has developed from deposits consisting of heavy lacustrine clay overlain by fine sand. In many places this clay has been subjected to further movement by the ice so that it contains an admixture of sand and occasional bowlders. The slight change in the clay portion apparently has not influenced the resulting soil, except as more relief has been developed in the original lake bed. One would expect to find a somewhat variable profile in this soil because of variations in the depth of the original sand covering and of the drainage conditions as influenced by micro-relief. The profile description given is considered the average condition. In some instances the soil has developed under conditions of more rapid drainage with the result that horizon B_{11} may be absent and horizon B_1 may be yellowish-brown with very little mottling. On the other hand, under more moist situations the soil approaches a bog condition; and A_0 horizon becomes thicker and the B_1 horizon begins to disappear.

TABLE 23.—*Clay Content, Base Exchange Capacity and Acidity of Superior Fine Sandy Loam (Northern Area)*

Horizon	A_2	B_1	B_{11}	B_2	C
Depth in inches	1—10	10—16	16—19	19—26	26—43
Per cent clay	15.5	20.7	17.7	35.4	46.0
Base exchange capacity	2.65	4.74	3.89	13.88	24.70
Reaction toward Soiltex	St.A	V.St.A	V.St.A	V.St.A	Alk.

From the results in Table 25 we see that, as in the case of the Silty Clay Loam, there has been considerable movement of the base exchange material from the surface into the B horizon. The B_2 horizon is developed at the surface of the clay but yet contains a large quantity of fine sand. Although the total clay content, as measured by the hydrometer, is much greater in the Silty Clay Loam type as compared to the Fine Sandy Loam, the base exchange capacity remains nearly the same. Throughout the investigation there has been a noticeable lack of correlation between these two properties (unless the same genetic horizons of soils within the same zone are compared). Even though a field examination indicates some difference in the actual texture, the Fine Sandy Loam having a little more fine and very fine sand included in the clay of the C horizon, yet the parent materials of both types are apparently about equally retentive of water. The type of acid weathering which characterized the development of the Silty Clay Loam type has also influenced the Fine Sandy Loam, producing a definite Podsol profile; but one somewhat different than that of the Silty Clay Loam because of the stratigraphic nature of the parent material.

The next profile to be considered is one from the southern area, collected in the Fox River valley.

PROFILE OF SUPERIOR SILTY CLAY LOAM (Southern Area)

A_{00}—Thin covering of loose leaves and forest debris, about 1 to 2 inches thick.

A_0—Nearly black forest mold, somewhat granular and silty. This material is only about ½ inch in thickness.

A_1—Friable, dark gray heavy silt loam, containing a high amount of humus. At 2 to 3 inches this changes to

A_2—Dark brownish-gray heavy silt loam, containing a noticeable quantity of humus. The soil is friable and has a definite platy breakage. At 4 inches, or a little more, the soil grades into

A_{21}—Grayish-brown silty clay loam. The soil is broadly platy but there are relicts of an old blocky structure. Throughout the soil mass there are blotches having a tinge of reddish-brown. This horizon changes, at about 7 to 8 inches, to

B_1—Grayish-brown silty clay loam, noticeably mottled with brown and gray. The soil has an angular nut structure but it is more friable than B_2. At about 12 inches is encountered

B_2—Brownish-red heavy clay. The soil has a well-defined angular nut structure. The individual pieces are about ¼ to ½ inch in diameter, becoming somewhat larger with depth. The soil mass is quite impervious but water can flow through the cracks. Roots do not penetrate the mass easily but seem to be able to make growth along the passages between the soil blocks. This material is very sticky and plastic when wet and very hard when dry. The solum ends at depths ranging from 24 to 32 inches and gives way to

C —Pinkish silty clay loam. The soil is quite compact. In situ the material is laminated and when removed is slivery. Noticeable white specks and streaks are scattered throughout the soil mass. This material is also very plastic and sticky when wet, but not as much so as B_2.

This description, together with the data shown in Table 24, shows that this soil has undergone development of about the same order as the profiles from the northern area, except that the process is not quite as intensive. In this soil the A_2 and A_{21} together are not as well developed and A_1 is more prominent. As the original material is not as high in clay content, the two profiles may not be strictly comparable, yet it seems clear that an equilibrium is being attained. The northern profiles are quite definitely in the Podsol group, while the southern profile is in the transitional area.

TABLE 24.—*Clay Content, Base Exchange Capacity and Acidity of Superior Silty Clay Loam (Southern Area)*

Horizon	A_1	A_2	A_{21}	B_1	B_2	C
Depth in inches	0—2½	2½—4	4—7	7—11½	11½—30	30—
Per cent clay	49.7	51.5	56.3	61.2	67.2	48.4
Base exchange capacity	18.77	7.57	6.15	11.12	23.26	16.7*
Reaction toward Soiltex	M.A	St.A	V.St.A	V.St.A	M.A	Alk.

* Only one result, the duplicate was lost.

Other members of the Superior series are transitional between the Fine Sandy Loam and the Silty Clay Loam. These intermediate soils occupy a relatively small total area.

A soil very similar to the Superior of the northern area was recognized in Ontonagon County, Michigan, as the Ontonagon series (47). The Ontonagon as mapped in Chippewa County, Michigan, is a more nearly level counterpart of the Superior of Bayfield County, Wisconsin.

Broadly speaking, the podsolization process is one of soil deterioration. It tends to remove the fine portion of the soil, which is largely responsible for its fertility, from the surface. Some of this material is entirely removed from the soil; some is decomposed into its constituent oxides (37) ; and some is deposited in the B horizon causing a "pan" formation. But in the case of these soils, developed from such heavy clays, the podsolization process has been beneficial because it has reduced the clay content of the surface soil and thus improved the physical condition for tillage operations. It must be borne in mind, however, that the end product of continued podsolization, during the course of "geologic time", is an infertile soil.

KEWAUNEE SERIES[1]

Associated with the Superior soils of the eastern portion of the state are the Kewaunee soils. These soils are developed from formations consisting, for the most part, of material deposited by a minor ice sheet advancing over the lacustrine deposits of red clay. As well as giving rise to more relief, these ice movements had the effect of introducing some stones and sand with the original material. The original vegetation was evidently about the same as that on the Superior series.

A profile drawing of Kewaunee Silty Clay Loam is shown in Plate 6. As this profile is almost identical with that of the Superior Silty Clay Loam it will not be described in detail here. No chemical data are available for the Kewaunee profile. It is doubtful if there is any significant difference between the two soils. This is still further evidenced by the failure of the field men to make a consistant separation: sometimes the separation was made entirely on the basis of topography, while again it was made on the nature of the parent material, i. e., whether it had been disturbed by the ice or not. This latter character is sometimes easily observed, while again it is only determined with considerable difficulty.

Where actual soil differences can be observed, a new series is, of course, justified, but in a soil classification geological differences may or may not be reflected in the resulting soil. It seems much more logical to classify the Kewaunee soils with the Superior, making a phase distinction for topographical features or stoniness where the dif-

[1] These soils are shown as a topographic phase of Superior on some soil maps.

ferences have an agricultural implication. From the point of view of the soil profile no significant differences were observed between the two series. A thorough chemical and mechanical analysis might disclose a series difference; but if so, there is not the slightest possibility that it would apply to the areas mapped.

KENNAN SERIES[1]

The Kennan series is one of the most widely occurring groups of soils in the state. It is developed from glacial till derived from crystalline rocks. The series has three members: the Loam, Fine Sandy Loam, and Silt Loam. Of these the Loam represents the usual condition.

The gently rolling nature of the land affords good external drainage. Occasionally nearly level areas are so poorly drained as to merit the indication of a separate phase. In these situations the only essential profile difference is a noticeable mottling. Throughout the area of these soils are numerous bogs and swamps, most of which are acid in reaction. Where the original morainic formations were "choppy" in surface configuration, little bogs and swamps are very numerous. The forest cover on the Kennan Loam has been largely mixed hardwoods and white pine (Plate 5B). A higher percentage of pine characterized the original cover of the Fine Sandy Loam type.

Within the series as now defined, considerable variation obtains as to the color of the parent drift. In some areas this drift is distinctly pinkish, while in other places it is yellowish or grayish in color. As a general rule the land is very stony; this characteristic is the most common factor limiting its agricultural use at present. The profile described is from Bayfield County.

PROFILE OF KENNAN LOAM

A_{00}—Loose leaf litter and forest debris, about 1 to 3 inches in thickness.

A_0—Dark brown to nearly black forest mold, about 1 to 2 inches in thickness. In nearly all areas this material contains at present large amounts of charcoal, due to severe forest fires.

---

[1] These soils were shown as Gloucester on the old maps of the U. S. Bureau of Chemistry and Soils. On some of the old State maps they were shown as Mellon.

A_1 —A small amount of dark gray loam, high in humus, occurs as a transition to the lower horizon which is encountered at about ½ inch.

A_2 —Dull gray very fine sandy loam, containing considerable humus material. The soil has a more or less well defined laminated structure. This horizon extends down to 3 or 5 inches below the surface.

B_1 —Yellowish-brown loam. The very fine sand separate forms a large part of the material. The soil has a fine crumb structure. At about 13 to 17 inches this gives way to

B_2 —Dull, brownish-gray fine sandy loam. A tinge of red of varying intensity is noticeable. The soil is compact, yet friable. At about 24 to 30 inches the soil grades into

C —Reddish-pink sandy, clayey till. This is generally very stony. Although there is considerable coarse material, very fine sand forms a large part of the mass. The till has a rather high water holding capacity, yet it is sufficiently pervious to allow drainage of excess water.

TABLE 25.—*Clay Content, Base Exchange Capacity and Acidity of Kennan Loam*

Horizon	A_2	B_1	B_2	C
Depth in inches	2—4	4—16	16—27	27—
Per cent clay	24.29	24.38	20.64	17.35
Base exchange capacity	10.55	5.86	5.01	5.80
Reaction toward Soiltex	St.A	V.St.A	V.St.A	St.A

The Kennan Loam probably represents the normal profile for the northern portion of the state, exclusive of the small belt of true Podsols along the most northern boundary. (See Figure 9.) Table 25 gives the laboratory results. It is evident at once that this soil is only a weak Podsol. The development of a rather dry, acid surface organic covering, together with the gray A_2 horizon, point to its Podsol nature. The figures for the base exchange show that the A_2 horizon still contains a larger quantity of the absorbing complex than the lower horizons. It is very probable that at least one-half of this material is organic[1]

It would seem that illuviation processes have not been greatly active in this soil. Here is a case where the A, B, and C horizons are distinguished from each other on the basis of color and structure, rather than texture.

The general profile character of the Silt Loam is similar

[1] Ignition at 300° C. showed this layer to lose about one-half of its exchange capacity; however, the writer does not venture to assume that none of the inorganic material would be injured at this temperature. See note page 40.

to that of the Loam with the exception of the mottling in the lower part of the B horizon and the finer texture. The Fine Sandy Loam has more evidence of Podsol nature; the gray horizon is somewhat better developed, particularly in the more northern portions of the Kennan area; and a slight cementation is noticeable in the B horizon.

Agriculture is limited by the topographic feature and particularly by the degree of stoniness. Most of the land is suitable for farming, except for an often excessive amount of bowlders. The soil is sufficiently retentive of water to produce good crops and pasture, and the less stony areas have made excellent farms.

MASON SERIES[1]

The Mason series is represented by only the Sandy Loam type. Its occurrence is limited as it is found almost exclusively on the less prominent islands of till within the northwestern area of the lacustrine clay deposits. These islands are very stony and appear to have been washed considerably by the waves during the stormy periods of the glacial lakes. Although the margins are often quite steep, their surfaces are nearly level. Much of the finer material had evidently been removed from the upper part of the drift before soil-building forces commenced to operate. While the Mason had some hardwoods in the original forest, it was chiefly white pine. On the more level areas balsam fir and white spruce are important constituents of the forest growth. Even though the profile is complex it was found to be quite uniform.

PROFILE OF MASON SANDY LOAM

A_{00}—Thin covering of loose leaves and forest debris, 1 to 2 inches thick.

A_0—Nearly black forest mold, about 1 to 2 inches in thickness.

A_1—Dark gray to nearly black sandy loam, high in humus. This layer is about ½ to 1 inch in thickness.

A_2—Dull gray light sandy loam. A relatively large amount of humus is present as compared to the A_2 horizons of other Podsol soils. The sand grains are rather coarse but the material has noticeable coherence. This horizon extends down to about 4 to 6 inches.

---

[1] This soil has only been recognized in Bayfield County. That other small areas are to be found under similar conditions is probable.

B_1 —A thin layer of dull brown sandy loam. The soil has a fine crumb structure. At 6 to 8 inches the next horizon is encountered

B_2 —Dark rusty brown sandy loam containing coffee-brown cemented lumps (The orterde of the Podsol). With the exception of the cemented lumps the soil has a fine crumb structure. This material is apparently very high in iron (qualitative test only). The lower limit of this layer is about 12 to 17 inches from the surface.

B_3 —Light rusty loamy fine sand fading to a lighter shade in depth. The material is rather loose and resembles the transitional horizon between the B proper and the parent material in a sandy Podsol. At about 18 to 24 inches this grades into

B_{31}—Dull pinkish-gray loamy sand or light sandy loam. The soil is very compact and is cemented in the lower part. When dry this layer is almost impenetrable with ordinary sampling tools. This hardpan is very brittle but pulverizes into a rather loose sandy material. The entire thickness of this layer is about 5 to 7 inches and at depths ranging from 24 to 32 inches it grades into

B_{32}—Pink, heavy sandy loam mottled with gray and yellow. Like the lower part of B_{31} this layer is cemented, making it almost impenetrable. Its thickness is about 3 inches.

C —Pinkish sandy clay till. This till is similar to that from which the Kennan Loam is developed except that it contains somewhat more clay. Stones and pebbles are plentiful.

TABLE 26.—*Clay Content, Base Exchange Capacity and Acidity of Mason Sandy Loam*

Horizon	A_2	B_1	B_2	B_3	B_{31}	B_{32}	C
Depth in inches	1—5	5—7½	7½—16	16—24	24—31	31—35	35—
Per cent clay	18.3	16.2	15.6	9.2	12.6	22.1	23.5
Base exchange capacity	7.74	--------	6.05	2.79	2.49	--------	4.92
Reaction toward Soiltex	St.A	St.A	St.A	St.A	St.A	St.A	St.A

On comparing this soil with the Kennan Loam, a close relative as far as parent material is concerned, we notice considerable difference. The data in Table 26 show that podsolization has been active. Although sufficient humus and other fine material persists in the A_2 horizon to give it a higher base exchange capacity than the B_2, we see that there has been much more movement downward than in the Kennan.

By reason of the comparatively heavy texture of the underlying till the drainage, particularly on the more level areas, is rather slow. The laboratory results also indicate the change in the parent material previous to the commencement of soil-building forces. The more pervious nature of this upper material as compared to the heavy till beneath has produced a situation somewhat comparable to that which obtains in the Orienta series. In the Orienta series, however, a gray hardpan in the lower part of the solum has not been observed. Frequently there is a somewhat compact, gray layer in the sand immediately above the clay but the writer has never observed appreciable cementation in it. No explanation can be offered for the cause of this indurated layer in the Mason, except that it is apparently associated with the rather abrupt change in the permeability of the soil at this depth.

Mr. Schoenmann[1] has observed approximately the same profile on Sugar Island in the St. Mary's River.[2] He describes the geological features to be the same as that of the Mason in Bayfield County, Wisconsin.

ANTIGO SERIES

The Antigo soils are developed from non-calcareous outwash material in the region of the Kennan series. The Antigo bears the same relation to the Kennan as the Fox bears to the Miami.

The land is typically nearly level or gently undulating in surface feature, except where it is developed on the more pitted outwash plains. The lower layers of the deposits usually consist of sand and gravel so that the soils are well drained. Under the discussion of the Fox series the importance of a gravel substratum in maintaining a high content of water in the soil above was pointed out. The native vegetation on the Antigo consists of white, Norway and jack pine with a varying admixture of hardwoods.

There are two rather large and important areas of these soils: one in Langlade County and another in Rusk County; but smaller areas are scattered throughout the Kennan area. It was one of these smaller areas that was sampled. The profile studied was obtained very near the Kennan profile which has already been examined. The solum is probably a little shallower and the entire soil lighter in texture than the Antigo series further south.

---

[1] By personal communication of unpublished observations.
[2] The St. Mary's River forms the boundary between the Upper Peninsula of Michigan and Canada.

PROFILE OF ANTIGO FINE SANDY LOAM

A_{00}—Loose leaf litter and forest debris, about 1 to 2 inches thick.
A_0 —Dark brown forest mold of coniferous origin, about 2 inches in thickness.
A_1 —'Salt-and-pepper' colored sandy loam, high in humus. This layer is only about ¼ to ¾ inches in thickness.
A_2 —Dull gray sandy loam or fine sandy loam containing considerable humus material. The soil has only a slight coherence. At about 3 to 7 inches this gives way to
B_1 —Brownish-yellow or dull brown fine sandy loam. The soil has a rather loose crumb structure. This horizon extends down to 9 or 11 inches below the surface.
B_2 —Light brown heavy fine sandy loam or loam. The soil has a crumb structure, but is quite coherent. This horizon is pervious to water and is easily penetrated by roots; however, it has a good water holding capacity. Pebbles are quite numerous, especially in the lower part. At depths ranging from 18 to 26 inches this layer grades into
B_3 —A transitional horizon of loose loamy sand and gravel, stained with light reddish-brown. At approximately 24 to 30 inches the soil passes abruptly into
C —Pinkish-yellow, loose stratified sand and gravel. A few well-rounded cobbles are not uncommon in the parent drift. The material appears to be largely derived from acidic igneous rocks.

As with the Kennan, the Antigo is a rather weak Podsol. The results in Table 27 show, however, that podsolization has progressed to a considerable extent already. The A_2 horizon, as pointed out in the description, contains considerable organic matter to which its high base exchange capacity may be attributed. The fact that this soil is not developed in the most northern part of the area probably accounts for its rather weak profile development as other conditions are apparently favorable for the podsolization process. The Antigo, as developed in Vilas County at a higher elevation, shows somewhat more Podsol development, both in the depth of the A_2 and its more complete leaching. The acid nature of the parent material, together with an original coniferous forest cover of white, Norway

TABLE 27.—*Clay Content, Base Exchange Capacity and Acidity of Antigo Fine Sandy Loam*

Horizon	A_2	B_1	B_2	B_3	C
Depth in inches	1—4	4—9	9—18	18—28	28—48
Per cent clay	15.3	14.7	14.1	5.6	4.7
Base exchange capacity	4.71	5.59	3.30	....	1.80
Reaction toward Soiltex	St.A	St.A	V.St.A	St.A	St.A

and jack pine would tend toward acid weathering. When the figures for this profile are compared to those for the Kennan Loam it can be seen that the latter is not as far advanced as the Antigo. Both samples were collected within a distance of five miles and at nearly the same elevation so that the climatic conditions are similar. In both cases the soil reaction is acid. The Kennan, however, had a cover of mixed hardwoods with some white pine, while the Antigo developed under an almost entirely coniferous forest. By reason of the somewhat lower water holding capacity of the material, the Antigo soil is drier than the Kennan. Both the vegetation and the drier surface would tend to produce the trockentorf more rapidly in Antigo and hasten the podsolization process.

VILAS SERIES

The Vilas soils are developed from the sandy drift in the region of non-calcareous rocks. For the most part they are found in the regions of bold moraines, but also there are areas developed from the ground moraines and badly pitted outwash. In surface features the land is gently rolling to very hilly so that the soil is usually excessively drained. The native forest consisted largely of Norway pine, jack pine and white pine. The relative percentages of these varied a great deal. Occasionally, as in Vilas County, there is considerable hardwood in the present stand and probably there was some in the original cover. The profile discussed was examined in Bayfield County. The evidence in the fire-devastated country is quite meagre, but would seem to indicate that the original stand of timber was rather thin. Some areas within the Bayfield Ridge country have been free from timber growth since the region has been known to white man (41). The present cover is chiefly composed of a rather open stand of jack pine and scrub oak with such species in spots as trembling aspen, cherry, etc. Many areas are open and devoid of vegetation except for a ground cover of sweet fern and a few scattered clumps of jack pine and aspen.

Profile of Vilas Sand

A_{00}—A thin covering of loose leaves and forest debris (often wanting).
A_0 —Leaf mold and nearly black sandy humus. This is very thin, and ranging
A_1 from scarcely 1 to 2 inches in thickness
A_2 —Dull gray or brownish-gray, loose loamy sand. Some humus material is mixed with the mineral soil. This gray horizon is very poorly developed and is frequently very thin. At about 2 to 4 inches is encountered
B_2 —Brown loamy sand. The sand is loose and open with very little evidence of structure. Occasionally some slight cementation may be observed. This horizon is quite variable as to depth but may be said to extend down to between 12 and 24 inches.
B_3 —A lighter brown transitional layer of loose, pervious sand. At 26 to 40 inches the soil grades into
C —Pale pinkish-yellow, loose, sandy drift. Occasionally this drift is stony, but usually it is nearly stone-free. Most of the pebbles and stones are acidic igneous rocks.

In the Fine Sand type the A_2 horizon is also poorly developed but it is generally a little thicker than indicated by the above description.

From the data presented in Table 28 it is evident that the soil is not a strong Podsol even though located in the northern portion of the state. Before discussing these data it will be well to consider the Cornucopia series and then the two will be considered together.

TABLE 28.—*Clay Content, Base Exchange Capacity and Acidity of Vilas Sand*

Horizon	A_2	B_2	C
Depth in inches	1—3	3—12	32—48
Per cent clay	6.6	4.9	2.7
Base exchange capacity	3.15	2.66	1.61
Reaction toward Soiltex	V.St.A	V.St.A	M.A

Cornucopia Series[1]

Only one type, the Loamy Sand, is included in this series. It is confined, almost entirely, to the northern part of Bayfield County where it is found on the sandy morainic knolls

[1] This is a local name given to soils developed from material identical with that giving rise to the Vilas. The difference, as will be brought out, is entirely one of profile character. On the published maps this series is combined with the Vilas.

within the Superior Lowland and also on the northern end of the Bayfield Ridge. The original material, natural drainage, and native vegetation are practically identical with that of the Vilas, except that the hardwoods may always have been somewhat more numerous.

PROFILE OF CORNUCOPIA LOAMY SAND

A_{00}—A thin covering of loose leaves and forest debris, about ½ to 2 inches thick.
A_0—Dark brown, peaty organic matter (trockentorf) about 1 to 2½ inches in thickness.
A_1—Dark gray sandy soil high in humus, about ½ inch thick.
A_2—Pale gray loose sand. Ferquently the sand has a faint pinkish tinge. There is but very little organic matter in this material. At depths ranging from 4 to 10 inches this horizon gives way to
B_1—Dull brown loamy sand, about 1½ inches in thickness.
B_2—Dark rusty brown loamy sand. Considerable fine sand and gravel are present. The sand is irregularly cemented into an ortstein. Sometimes this cementation is limited to lumps about the size of walnuts, while in other places it is quite uniformly indurated into a sandy hardpan 4 to 10 inches in thickness. At about 26 inches the soil grades into
B_3—A transitional horizon of dark yellowish or brownish-yellow gravelly sand extending down to about 36 inches.
C —Pale yellowish-gray, gravelly and stony, sandy till. Most of the stones are sandstone. The material is very open and pervious.

TABLE 29.—*Clay Content, Base Exchange Capacity and Acidity of Cornucopia Loamy Sand*

Horizon	A_2	B_2	B_3	C
Depth in inches	3—8	10—22	22—36	36—48
Per cent clay	4.9	8.2	3.4	2.9
Base exchange capacity	1.26	4.16	----------	1.22
Reaction toward Soiltex	St.A	V.St.A	M.A	Sl.A

From this description and the data set forth in Table 29 it is evident that this soil is definitely a Podsol. As in the case of the other strong Podsol soils, the figures for base exchange indicate a greater movement downward than do those for the clay content. The absorbing complex appears to be the more mobile portion of the fine material. In this case the B_2 horizon has not quite twice as much clay as the A_2, but it has over three times as much base exchange material. Acid weathering has been active. This soil is developed under a coniferous forest vegetation. The rolling to hilly surface insures rapid external drainage, while the pervious nature of the substratum provides free internal drainage.

In the case of the Cornucopia and Vilas we have two soils developed under almost identical conditions of forest cover, drainage, elevation, and from nearly the same parent material. The Vilas soils were not found to any extent closer than six miles to Lake Superior; and from this point to the Lake they were replaced by the Cornucopia soils in Bayfield County. The Cornucopia, associated with the Plainfield Light Sandy Loam, has a much stronger Podsol profile than the Vilas, associated with the Plainfield Sand.

It has already been mentioned that the climate of northern Wisconsin changes rapidly as one proceeds from Lake Superior south; the lake belt more nearly approaches the climatic conditions of the regions of well developed Podsol soils in northern Europe. During that portion of the year when the ground is not frozen, evaporation is less and more water is allowed to percolate through the soil. It is interesting to note that nearly all of the Cornucopia and Plainfield Light Sandy Loam occur north of the southern margin of this area, while the Vilas and Plainfield Sand are south of it. There is only a narrow region in which the Vilas and Cornucopia occur side by side; very few areas of the latter are found south of this general region. In Vilas County the sandy soils developed from the sandy moraines are about midway between the Vilas described here and the Cornucopia. Unfortunately their profiles have not been studied in the laboratory.

ORIENTA SERIES[1]

The Orienta series is largely confined to the region of the heavy lacustrine clay. The soils have been developed from formations consisting of sandy material, usually fine sand, over heavy clay. The Fine Sand, Fine Sandy Loam and Sandy Loam have been recognized; of these the Fine Sand is probably the most common.

[1] Orienta is a local name used by the State Survey in Bayfield County. The soil is identical with the Ogemaw series recognized by the Bureau of Chemistry and Soils in Michigan and Minnesota (48).

The surface is gently undulating in topographic feature with occasional areas that have a "billowy" appearance. The surface drainage is good but the lower soil may be water logged. If the surface of the underlying clay has a gentle gradient, good drainage is assured; but if the clay floor is uneven the lower part of the soil above the clay will have water pockets. This condition may not be at all apparent on the surface but will be injurious to the roots of shrubs and trees. The native forest cover was chiefly white pine with some hardwoods. The present second growth consists of white birch, aspen and minor species.

PROFILE OF ORIENTA FINE SAND

A_{00}—Very thin covering of loose leaves and forest debris.
A_0—Dark brown, dry, peaty organic matter (trockentorf), about 1 to 2 inches thick.
A_1—'Salt-and-pepper' colored loamy fine sand, high in humus. This layer is about ¼ to 1 inch in thickness.
A_2—Pale whitish-gray, loose fine sand. Often the sand has a faint lavender tinge. The lower limit of this horizon is very irregular. Long tongues often penetrate to a depth of nearly 24 inches below the surface. The change to the lower horizon is very abrupt and generally is encountered at about 5 to 12 inches.
B_2—Brown loamy fine sand irregularly cemented into a coffee-brown hardpan or ortstein. This layer is roughly parallel to the A_2 horizon so that long tongues often extend downward a considerable distance below the average depth which varies from 14 to 24 inches below the surface.
C —Yellowish fine sand. The upper part is often stained with brown, while the lower part immediately above the clay may be whitish in color. The sand is generally quite compact, particularly in the lower part which is usually moist. This material extends to depths ranging from 40 to 72 inches.
D —Heavy, impervious clay. The clay has a pink or reddish color with gray and yellow mottling.

TABLE 30.—*Clay Content, Base Exchange Capacity and Acidity of Orienta Fine Sand*

Horizon	A_2	B_2	C	D
Depth in inches	2—9	9—24	24—44	44—60
Per cent clay	7.2	11.1	4.7	31.4
Base exchange capacity	1.12	3.16	1.00	6.32
Reaction toward Soiltex	V.St.A	V.St.A	St.A	M.A*

* This clay is frequently alkaline but not consistently so.

From this description and the results in Table 30 it is evident that this soil is a strong Podsol. The presence of the clay beneath seems to have a tremendous influence on the profile development. For this reason it may be that the Orienta is related to the Saugatuck and has developed partly as a Ground Water Podsol. This soil is found much further south than any of the other Podsols.

SAUGATUCK SERIES

The Saugatuck soils do not comprise a very large area in Wisconsin, although a few areas are scattered about in the Podsol and transitional zones. The soils are developed on the lower lying, nearly level, sandy plains and benches. In drainage they are intermediate between Plainfield on the one hand and the marsh border soils on the other. Marbut (31) has identified the Saugatuck in Michigan as a Ground Water Podsol. The profile of the Saugatuck, as recognized in this state, is identical with that in Michigan. No laboratory investigations were conducted, but the profile character is nearly equivalent to the solum of the Orienta Fine Sand, the chief difference between the two being the heavy clay substratum of the latter.

PROFILE OF SAUGATUCK SAND

A_{00}—Thin covering of loose leaves and forest debris, ½ to 2 inches thick.

A_0—Nearly black, leaf mold and peaty organic accumulation varying from 1 to 4 inches in thickness. In summer this appears as a dry turf or trockentorf.

A_1—A very thin transition layer of sandy humus soil. It has a 'salt-and-pepper' appearance. This layer is about ½ to 1 inch in thickness.

A_2—Whitish-gray sand containing only a very small amount of organic matter. The soil is loose and incoherent. Often it has a 'fluffy' appearance. The lower limit of this horizon is very irregular but usually is encountered at 5 to 12 inches. The line of demarcation between this layer and the next is very sharp.

B_2—Brown sand, irregularly cemented into a sandy hardpan or ortstein. The cemented portion is generally a coffee-brown color. At 18 to 24 inches the soil grades into

B_3—Yellowish sand with spots and streaks of brown. The soil is quite loose and incoherent. From 24 to 36 inches this layer gives way to

C—Grayish-yellow, loose sand. The material is usually saturated or moist except during the dry seasons of the year.

Marsh Border Soils

Several series of these soils have been mapped under various conditions in the state but only three will be discussed, as they represent the general profile condition which obtains with this group of soils.

Dunning Series

The Dunning soils are developed on sandy material under conditions of poor drainage. In profile character they consist merely of 6 to 12 inches of nearly black organic matter over wet sand. This surface organic matter is usually in a fair state of decomposition and also has some mineral matter mixed with it. Under natural conditions the soils are wet and too poorly drained for most crops. Where drainage has been effected they are very much inclined to be droughty during the drier seasons of the year.

Poygan Series

The Poygan soils are developed from the red lacustrine clay under poorly drained conditions. As much of the lacustrine clay is nearly level and has poor external drainage there are considerable areas of these soils. Their typical development, as represented by the profile described below, is found in the northern part of the state. In the eastern area of the glacial lake deposits, the Clyde series tends to replace the Poygan, particularly in the southern portion. But as the red clay was held to be the determining factor in the Poygan series, much of the Clyde, developed from red clay, was identified as Poygan.

Profile of Poygan Clay Loam

A_0 and A_1 —Nearly black silty muck. This material is formed from the organic remains of low land forest vegetation and is in a fair state of decomposition. In thickness it usually varies from 5 to 10 inches. (If over one foot in depth the soil is classified with the peats.)

A_2 —Dark gray silt loam. The Glei horizon. This layer is about 2 inches thick.

A_{21}—Dark gray plastic clay. At about 12 to 18 inches this grades into

A_3 —Heavy plastic clay, pinkish-brown mottled with gray. This layer forms a transitional zone of about 8 inches to

C —Reddish or pinkish-brown heavy, impervious clay.

It is to be particularly noted that this soil is developed under a forest vegetation, whereas, as will be subsequently shown, the Clyde soils are developed under grasses.

Clyde Series

The Clyde series includes the principal marsh border soils of southern Wisconsin, occurring associated with the Miami and Carrington families of soils. The native vegetation consisted chiefly of coarse grasses and sedges.

Profile of the Clyde Silt Loam

A_1—Dark gray to black silt loam, very high in organic matter. When dry the soil has an angular pea structure. This layer varies from about 10 to 14 inches in depth.

A_2—Dark gray silt loam. The Glei horizon. This layer is about 2 inches thick and grades into

C —Heavy silt loam, mottled with gray, yellow and light rusty brown. The material is usually calcareous.

From this profile it is quite clear that there is an important distinction between the Poygan and the Clyde. The latter is probably equivalent to the European Wiesenboden, while the former is a Bog soil. This difference, however, has not been generally recognized by field men so that some areas of soil having the general profile of the Clyde, except for a reddish C horizon, have been classified with the Poygan. It is interesting to note that the lowlands of the Gray-Brown Forest zone in Wisconsin were largely covered with prairie grasses. It has been pointed out that of the upland formations those having the highest water holding capacity more commonly gave rise to Prairie soils. Whereas in the Great Plains it is felt that the grasses won out from the trees in the competition for water, in Wisconsin the grasses evidently won out in the competition with the trees in the more moist situations.

DISCUSSION OF SOILS

The descriptions presented, together with the study of the base exchange capacity and the clay content, indicate important differences between the soil series as to their profile development. The investigations have shown all of the mineral soils to be podsolic. On the basis of these results and observations the soil series have been arranged as follows:

SERIES CLASSIFIED ACCORDING TO PROFILE

Gray-Brown Forest:

Miami	Bellefontaine
Lindley	Fox
Knox	Baxter

Plainfield (Southern) }
Boone } Not strictly Gray-Brown Forest soils but found in that soil zone.

Intra-zonal: Gray-Brown Forest to Podsol (In approximate order)

Colby	Vilas
Vesper	Plainfield Sand (Northern)
Kewaunee	Antigo
Superior (Southern)	Mason
Miami Loam (Door County)	Plainfield Light Sandy Loam
Kennan	

Podsol:

Saugatuck	Cornucopia
Orienta	Superior (Northern)

Intra-zonal: Gray-Brown Forest to Prairie

Thurston

Prairie

Carrington	Marshall
Waukesha	Dodgeville

Half-Bog:

Poygan	Dunning

Wiesenboden:

Clyde

These studies have shown that the podsolization process brings about a change in the soil of tremendous importance. Neustrev (37), in reviewing the Russian work on Podsol soils, points out this fact; and the work of Tamm

(42) to which we have already referred, leads to the same conclusion. In many cases where other data did not show a great difference in total content of fine material, there was a marked difference in the absorbing complex portion. That part of the fine material which has base exchange properties is the most mobile. In the case of the Superior Silty Clay Loam the B horizon only has 1.25 times as great a content of clay as the A_2 horizon but 3.32 times as much base exchange capacity. A similar comparison is true with Orienta Fine Sand.

Truog and his co-workers (44) find that the inorganic material concerned in the base exchange reaction is of quite definite chemical nature. They are led to believe that the same substance, or very similar substances, in the soil are concerned; and that it is a chemical reaction. Organic matter in soils also possesses a high base exchange capacity and they find that it likewise appears to be a single weathering product, but differing from the inorganic substance. After depletion of the exchangeable bases subsequent leaching brings out these materials. Podsolization brings about a sorting of the colloidal material with the result that the soil finally becomes impoverished of the greatest element in its fertility.

Truog is of the opinion that the base exchange material arises from the weathering of felspar minerals. The silica content of the original mineral is reduced so that the base exchange material has a silica sesquioxide ratio of four. This material might then be considered as an intermediate product between felspar and kaolin. It would seem that its formation could only proceed in an alkaline solution. The entire soil may not be alkaline, but only that small film in contact with the mineral. Any action which tends to maintain a neutral or alkaline reaction will tend to create conditions for its formation. A vegetation which brings to the surface of the soil a high amount of bases will have this effect.

In defining the calcium cycle the influence of the bases in preventing the colloids from becoming mobile was pointed out. Consequently the vegetation has three particular relations to the base exchange colloids: (1) the effect on the soil reaction in conditioning the formation of inorganic base exchange material; (2) the formation of organic base exchange colloids (this occurs especially in the prairie and in the mull type of forest mold); and (3) the bases furnished in relation to the cations absorbed by both kinds of colloid and their subsequent mobility.

In the regions of highly developed Podsol soils such as Latvia (52), Sweden (42)—in fact much of northern Europe and Asiatic Russia—there has been found to be a decided decrease in fertility. These well developed soils may not be much older, in point of years,[1] than those of northern Wisconsin. However, it is not time in the sense of years but the stage of development of the soil in relation to its environment which constitutes "soil age". Thus from the standpoint of the podsolization process the profiles in northern Wisconsin are young as compared to many of those described in northern Europe. But assuming no change in climate it can not be doubted that at some future time they will reach the same stage of development, or even a more advanced stage.

The Prairie soils still have a large amount of base exchange material in the surface horizons, both organic and inorganic, which probably accounts for their present high fertility. The results have distinctly shown that these soils are being influenced by the same soil-building forces which have given rise to the Miami profile. A system of management which tends to deplete the soil of bases will naturally hasten the process. How rapid this degradation may be is not known—but its utlimate end will be a soil similar to the Miami. It may be mentioned that sufficient applications of calcium compounds to render the colloids immobile will prevent the podsolization process.

If the soils of each zone were mature and had all reached a definite state of equilibrium we would expect a rather constant relation between the amount of base exchange material and the percentage of clay in the B_2 horizon as compared to the A_2 horizon. The data in Table 31 are interesting in this connection. All of these soils belong to the Miami family. The portion of these data showing the re-

---

[1] Many of the Podsol soils in northern Europe and Asiatic Russia are developed on glacial deposits of approximately the same age as the glacial deposits of America.

TABLE 31.—*Some Relationships between the Primary Horizons of the Profiles of the Miami Family*

Soil	A_2		B_2		B_2/A_2		Per cent clay / Base exchange capacity	
	Base exchange capacity	Per cent clay	Base exchange capacity	Per cent clay	Base exchange capacity	Per cent clay	A_2	B_2
Miami Silt Loam	8.71	41.0	19.38	47.2	2.34	1.15	4.71	2.43
Lindley Silt Loam	8.87	41.3	19.14	48.5	2.16	1.17	4.65	2.53
Bellefontaine Silt Loam	6.62	32.6	15.06	39.0	2.28	1.19	4.92	2.58
Bellefontaine Fine Sandy Loam	6.71	18.3	10.66	26.7	1.59	1.46	2.72	2.50
Knox Silt Loam (Deep Phase)	6.36	38.8	15.64	40.6	2.46	1.04	6.10	2.59
Knox Silt Loam (Shallow Phase)	9.98	41.5	22.60	49.0	2.06	1.18	4.15	2.25
Averages					2.15	1.19	4.54	2.48

Note: In cases where there was more than one part to any primary horizon the several parts were averaged according to the depth of each.

TABLE 32.—*Some Relationships between the Primary Horizons of the Profiles of the Podsols*

Soil	A_2		B_2		B_2/A_2		Per cent clay / Base exchange capacity	
	Base exchange capacity	Per cent clay	Base exchange capacity	Per cent clay	Base exchange capacity	Per cent clay	A_2	B_2
Cornucopia Loamy Sand	1.26	4.9	4.16	8.2	3.31	1.67	3.89	1.97
Orienta Fine Sand	1.12	7.2	3.16	11.1	2.82	1.54	6.43	3.51
Superior Silty Clay Loam (Northern)	10.62	68.3	35.34	86.0	3.31	1.11	6.43	2.43

lation between the clay content and the base exchange capacity are presented in Figure 11. It would appear that within rather close limits for the B_2 horizon and somewhat wider limits for the A_2 horizon[1] there is a definite relation

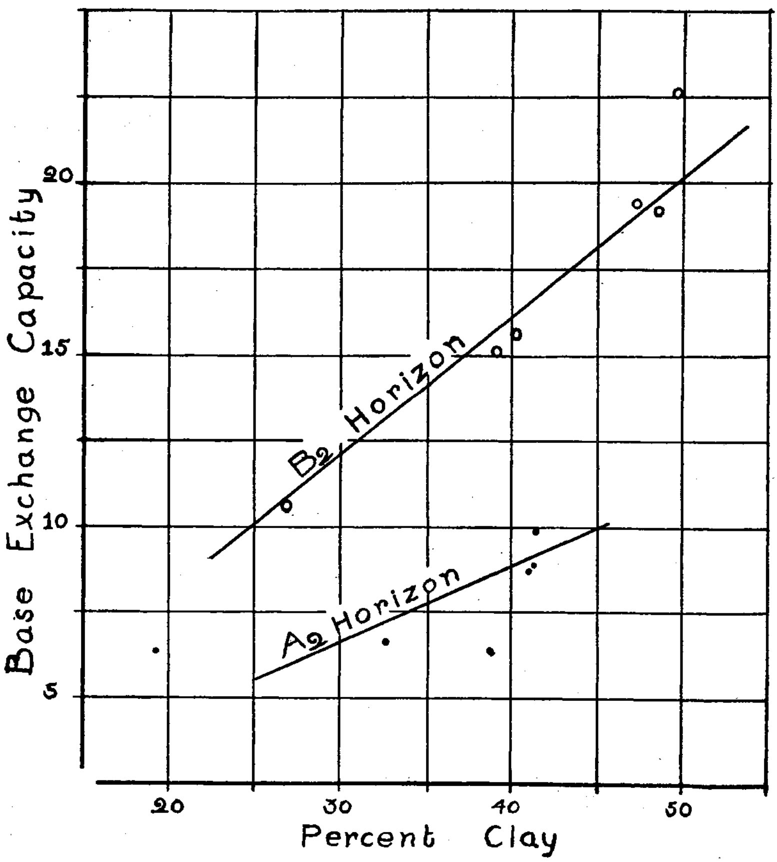


FIGURE 11. *Diagram showing the relation between the base exchange capacity and the clay contant of the Miami Family (Gray-Brown Forest Soils).*

The point to the right and above the upper curve is for the B horizon of the Shallow Knox profile.

between the amount of base exchange material and the texture *for the same genetic horizon* of a mature soil. Thus the B_2 horizons of the members of the Miami family have a re-

[1] The difficulty of obtaining an absolutely uncontaminated sample of the A horizon has been pointed out.

markably uniform proportion of base exchange colloid for each textural grade.

There is no other group of soils sufficiently comparable to make this compilation. If we take the data for the three true Podsols (Table 32) we see a very similar result; and it is especially striking considering the great differences in the geological nature of the parent material.

After a soil has developed a mature profile the horizons have come into equilibrium with the environment and the only change is one of depth unless there is a change of the environment.

The Prairie soils and the large number of soils in the transitional area are not strictly mature soils. So few profiles of the Prairie soils were examined that no significant relationships could be established.

It will be recalled that the normal Gray-Brown Forest profile has well developed A_1 and A_2 horizons, while the Podsols have a very thin A_1 horizon and a strongly leached A_2. In the transitional area between these two zones there appears to be a merging of the A_1 and the A_2 horizons. If a method could be devised to determine accurately the relative amounts of organic and inorganic base exchange material, more reliable information concerning the nature of these profiles possibly could be obtained. The presence of a large quantity of organic colloid throughout the A portion of the solum of these transitional soils masks the movements of the inorganic portion.

All of the conditions necessary for the development of a Podsol may be present but one, and this one can greatly limit its formation. This thought is perfectly analagous to nutrition studies. In northern Wisconsin this one principal condition appears to be the summer temperature. The narrow belt near Lake Superior which has its temperature ameliorated by that body of water has much stronger Podsols than areas only a few miles distant, other factors being the same. This condition is admirably shown in the comparison between the profiles of the Vilas and the Cornucopia.

From the descriptions of the profile conditions it is evident that the base exchange capacity correlates closely with the weathering conditions as expressed by the character of the horizons. This portion of the colloidal material is evidently the most active part of the soil. That this material is of extreme importance in determining soil fertility need not be emphasized here. Both from the point of view of practical application of the information and from that of giving quantitative interpretation to the formation of the profile, the writer feels that the base exchange capacity gives the best results. A total chemical analysis is concerned with the entire mass of soil so much of which is inactive that accurate comparisons are only made with difficulty. Any factor which will have an influence upon the amount of bases in the soil, especially calcium, and upon the water relations will be reflected in the disposition of this finer colloidal material.

RELATION TO GROWING PLANTS

A great deal of emphasis has been placed on the importance of the vegetation in conditioning the formation of the soil profile. Of course the relationship is reciprocal. In agricultural practice the interest is more primarily concerned with the influence of soil on the character of the growing vegetation, as to both yield and quality. There are two general methods of approach to this problem used by agricultural people: (1) an attempt to change the soil to produce definite plants; and (2) the selection of plants to suit the soil and other environmental factors. Ordinarily people use both methods. The advantage of the latter method over the former is obvious. Nevertheless agronomists have found that the introduction of lime and fertilizers often prove profitable. Further it has been found that the kinds and amounts of these materials to be used vary with different soil types. It is well known that tillage operations are necessarily at variance from one soil condition to another.

These matters are to be determined by experiment. Their application can only be made through a knowledge of the conditions under which the experiments were conducted as compared to those where the applications are to be made. One needs only to scan the literature and consider the great variance of experimental results to realize that investigations concerning one type of soil may not have any application to other conditions. Each soil is an individual; it has certain potential capabilities; and when placed under suitable conditions is able to achieve certain ends.

Research in agriculture advanced a considerable distance by empirical methods. Further advance in this way is hardly to be realized. It is not enough to apply fertilizers and observe crop yields. The reaction with the soil must be known and its relation to the plant brought under observation. Great interest has been taken during the past few years in the root systems of plants. But even so, many agronomists are yet content to sample and study only the surface soil, or at best the "soil and subsoil", when investigations have shown quite conclusively that ordinary crop plants have root systems which are by no means included in any such arbitrary concept. Nor do the roots of the same plant grow similarly on every soil. Consider, for example, alfalfa growing on Superior Silty Clay Loam and on Plainfield Sand. The writer's observations lead him to believe that in the former case the roots are largely confined to the upper two feet of soil, at the most three feet; while in Plainfield Sand alfalfa roots to depths of ten feet are not uncommon. If the chemical nature of the upper 8 inches, or even of the upper 24 inches, of soil in the two cases is compared it is quite obvious that the comparisons are faulty in relation to the alfalfa plant.

Suppose we consider the same plants to be growing on Carrington Silt Loam having a high content of base exchange material in the surface, as compared to Superior or Miami where the greatest concentration is in a well developed B horizon. It is obvious here that comparisons of the surface soil cannot be made logically.

Until the manner in which plants take in water and nutrients from the soil is better understood, investigators must be content with data to a certain extent empirical. But the importance of considering the *entire soil* needs to be emphasized. If the investigations herein presented will serve to point out the nature of the soil entities and will be of service in studying the relations between plant and soil the efforts will be amply justified.

SUMMARY

This investigation was undertaken for the purpose of describing the principal soil profiles in Wisconsin and for determining if a relation exists between the base exchange capacity and the morphology of the soil profile. The general nature of the original geological formations and the environmental factors of importance in soil-building in Wisconsin are outlined. The more important soil profiles in the state have been examined in the field and their characteristics noted. The base exchange capacity and the clay content of the various horizons of the soil profiles have been determined. The influence of climate and vegetation in producing different profiles is discussed. Conclusions from these studies may be summarized as follows:

1. The principal soil-building process is one of podsolization, varying in intensity under different conditions.
2. A classification of the soil series according to their relationship to the great soil zones is presented. The soil series fall into the Gray-Brown Forest, Podsol and Prairie zones with numerous intra-zonal soils lying between the Podsol and Gray-Brown Forest zones.
3. A close correlation between the base exchange capacity of the various horizons of the soil profile and the mode of formation of the profile has been found. Base exchange data are very useful for giving quantitative expression to profile studies.
4. A similar but much less valuable and striking correlation is to be seen in the case of the clay content.
5. That each genetic horizon of a mature soil comes into equilibrium with its environment at a definite ratio of base exchange capacity to clay content is suggested.
6. Weathering of a mature profile leads to a deepening of the soil horizons rather than to a change in the above relationship.
7. The importance of the soil profile in reference to the relationship between soil and plant is emphasized.

TABLE 33.—*Locations from which Samples were Taken*

Soil Name	County	Section	Township	Range
Antigo Fine Sandy Loam	Bayfield	36	45 N	8 W
Baxter Silt Loam	Monroe	29	15 N	3 W
Bellefontaine Fine Sandy Loam	Jefferson	29	5 N	14 E
Bellefontaine Silt Loam	Waukesha	4	8 N	17 E
Boone Fine Sand	Monroe	19	18 N	1 W
Carrington Silt Loam (On Wisconsin Drift)	Columbia	18	10 N	10 E
Carrington Silt Loam (On Illinoisian Drift)	Rock	20	1 N	14 E
Colby Silt Loam	Clark	14	26 N	1 E
Cornucopia Loamy Sand	Bayfield	22	50 N	8 W
Dodgeville Silt Loam	Iowa	17	6 N	5 E
Fox Silt Loam	Waukesha	23	8 N	17 E
Kennan Loam	Bayfield	32	45 N	7 W
Kewaunee Silty Clay Loam	Manitowoc	36	19 N	23 E
Knox Silt Loam (Shallow Phase)	Dane	10	6 N	6 E
Knox Silt Loam (Deep Phase)	Crawford	--------	9 N	3 W
Lindley Silt Loam	Rock	24	1 N	13 E
Marshall Silt Loam	Iowa	30	6 N	2 E
Mason Sandy Loam	Bayfield	25	46 N	6 W
Miami Silt Lóam	Jefferson	11	8 N	11 E
Miami Loam (Door County)	Door	15	28 N	26 E
Orienta Fine Sand	Bayfield	4	50 N	6 W
Plainfield Sand (Southern)	Wood	--------	21 N	6 E
Plainfield Sand (Northern)	Bayfield	26	46 N	9 W
Plainfield Light Sandy Loam	Bayfield	25	50 N	6 W
Saugatuck Sand	Bayfield	35	51 N	7 W
Superior Silty Clay Loam (Southern)	Outagamie	33	22 N	18 E
Superior Silty Clay Loam (Northern)	Bayfield	5	48 N	8 W
Superior Fine Sandy Loam (Northern)	Bayfield	15	50 N	6 W
Thurston Silt Loam	Sauk	--------	10 N	7 E
Vesper Fine Sandy Loam	Jackson	16	22 N	2 W
Vilas Sand	Bayfield	13	47 N	7 W
Waukesha Silt Loam	Rock	36	3 N	13 E

LITERATURE CITED

1. **ALDEN, W. C.** 1918. Quarternary geology of southeastern Wisconsin. *U. S. Geol. Surv. Porf. P.* 106.

2. **BALDWIN, MARK.** 1926. Some characteristic soil profiles in the North Central United States. *Amer. Soil Surv. Assn. Bul.* 7:1:122.

3. —— 1928. The Gray-Brown podsolic soils of the Eastern United States. *Proc. First Int. Cong. Soil Sc.* 4:276–282.

4. **BJORLYKKEE, K. O.** 1928. Soil types and soil profiles of Norway. *Proc. First Int. Cong. Soil Sc.* 4:223–269.

5. —— 1928. Die Klimatischen Bodenregionen in Norwegen. *Proc. First Int. Cong. Soil Sc.* 1:285–300.

6. **BOUYOUCOS, G. J.** 1927. The hydrometer as a new and rapid method for determining the colloid content of soils. *Soil Sc.* 23:319.

7. —— 1928. The hydrometer method for studying soils. *Soil Sc.* 25:365–369.

8. **CHAMBERLIN, T. C.** 1880. Geology of Wisconsin. 1:273.

9. **CLAYTON, H. H.** 1927. World weather records. *Smithsonian Msc. Collections.* 79:484–488.

10. **EBERMAYER, E.** 1876. Lehre der Waldstreu. 44–49. Berlin. (Quoted by B. Aarnio in *Proc. Int. Soc. Soil Sc. N. S.* 1:76–77. 1925)

11. **EKHOLM, N.** 1914. Climate. (In *Sweden, historical and statistical handbook.* Ed. by Guinchard) Stockholm.

12. **FROSTERUS, B.** 1924. Die Klassification der Böden und Bodenarten Finnlands. Memoires sur la nomenclature at la classification des sols. *Geol. Surv. of Finnland.* 143–176.

13. **GEDROIZ, K. K.** 1925. Soil absorbing complex and the absorbed soil cations as a basis of genetic soil classification. *Pub. of Nosovka Agr. Exp. Sta. No.* 38. Translation into English from the Russian by Waksman, S. A.

14. **GEIB, W. J.** et al. 1918. Soil survey of Door County, Wisconsin. *Field Operations of the Bureau of Soils. 1916.*

15. —— 1929. Soil survey of Monroe County, Wisconsin. *Soil Surv. Rept.* No. 40. *Series 1923. U. S. Bur. of Chem. and Soils.*

16. **GLINKA, K.** 1914. Die Typen der Bodenbildung. Berlin 77–87.

17. —— *Ibid.* 104.

18. **HANN, JULIUS.** 1911 Handbuch der Klimatologe. Stuttgart.

19. **HOTCHKISS, W. O.** et al. 1915. Mineral land classification. *Wis. Geol. and Natl. Hist. Surv. Bul.* 44.

20. **JENNY, HANS.** 1929. Klima and Klimabodentypen in Europe und in den Vereinigten Staaten von Nordamerika. *Soil Research.* 1:139–189.

21. **JOSEPH, A. F.** 1927. The determination of soil colloids. *Soil Sc.* 24:271–274.

22. **KAY, G. F.** and **APFEL, E. T.** 1929. The Pre-Illinoisian Pleisticene Geology of Iowa. *Iowa Geol. Surv. Vol.* 24. See page 109 *et seq.*

23. **KEEN, B. A.** 1928. Soil mechanics and physics. *Soil Sc.* 25:9.

24. **KENDREW, W. G.** 1927. The climates of the continents. Oxford. *Second edition.*

25. **KERR, H. W.** 1928. The nature of base exchange and soil acidity. *Jour. Amer. Soc. Agron.* 20:309–335.

26. **KRAUS, I.** 1926. Ueber die Schwankungen des Kalkgehaltes in Rotbuchenlaub auf verschiedenem Standort. *Forstw. Zentbl.* 48:401. Berlin.

27. **KRISCHE, PAUL.** 1928. Bodenkarten und andere kartographische Darstellungen der Faktoren der landwirtschaftlichen produktion verschiedener Länder. Paul Parey. Berlin.

28. **KVAPIL, K. and NEMEC, A. 1926.** Contributions to the question of the influence of pure spruce and beech stands, as well as the mixed stocks formed from both kinds of trees on some qualities of forest soils. *Ztschr. Forst. u. Jagdw.* 57:193. (Abstract in *Proc. Int. Soc. Soil Sc. N. S.* 2:348)

29. **LUNDBLAD, K.** 1924. A contribution to the knowledge of the properties and degeneration of the soils of the Brown-Earth type in southern Sweden. *Meddel. Statens Skogaförsöksanst* 21. (Abstract in *Proc. Int. Soc. Soil Sc. N. S.* 2:179. 1926)

30. **MARBUT, C. F.** 1928. A scheme for soil classification. *Proc. First Int. Cong. Soil Sc.* 4:1.

31. —— 1928. Notes covering lectures on soil genesis and classification presented to the graduate school of the U. S. Dept. of Agriculture. Washington.

32. **MARTIN, LAWRENCE.** 1916. The physical geography of Wisconsin. *Wis. Geol. and Natl. Hist. Surv. Bul.* 36.

33. **McCOOL, M. M.** and **VEATCH, J. O.** The sandy soils of the southern peninsula of Michigan. *Mich. Agr. Exp. Sta. Spec. Bul.* 128.

34. **McCOOL, M. M., VEATCH, J. O.,** and **SPURWAY, C. H.** 1923. Soil profile studies in Michigan. *Soil Sc.* 16:95–106.

35. **Meyer, A. 1926.** Ueber einige Zusammenhänge zwischen Klima und Boden in Europa. *Chem. der Erde.* 209–347.

36. **MULLER, P. E.** 1887. Studien uber die natürlichen Humusformen. Berlin.

37. **NEUSTRUEV, S. S.** 1927. Genesis of soils. *Russian Pedological Investigations* 3. (Published for the *First Int. Cong. of Soil Sc.)* Leningrad.

38. **RAMANN, E.** 1928. The evolution and classification of soils. Eng. Trans. by Whittles, M. A. Heffer. p. 43.

39. **VON SIGMOND, ALEXIUS A. J.** 1927. Hungarian alkali soils and methods of their reclamation. *Univ. of Calif. Special Pub. of the Agr. Exp. Sta.*

40. **SPURWAY, C. H.** 1924. Soiltex method for soil reaction. *Mich. Agr. Exp. Sta., Quar. Bul.* 6:93.

41. **SWEET, E. T.** 1880. Geology of the western Lake Superior District. *Geology of Wisconsin.* 3:310–362.

42. **TAMM, O.** 1920. Markstudier i det nordsvenska bassakogsomradet. *Medd. fr. Statens Skogsförs. Anst.* 17:49–276.

43. —— 1927. Die Klimatischen Bodenregionen in Schweden. *Proc. First Int. Cong. Soil Sc.* 1:269–285. 1928.

44. **TRUOG, E.** and **CHUCKA, J. A.** 1930. The origin, nature and isolation of the inorganic base exchange compound of mineral soils. *Jour. Amer. Soc. of Agr.* 22:553.

45. **ULRICH, E. O.** 1924. Notes on new names in table of formation and on physical evidence of breaks between Palozoic systems in Wisconsin. *Trans. Wis. Acad. of Science, Arts and Letters.* 21:83.

46. **VEATCH, J. O.** 1928. Profiles of the soils in the Great Lakes region of the United States. *First Int. Cong. Soil Sc.* 4:350.

47. —— et al. 1923. Reconnaissance soil survey of Ontonagon County, Michigan. *U. S. Dept. of Agr., Adv. Sheets Oper. Bur. Soils. 1921.*

48. —— 1928. Soil survey of Ogemaw County, Michigan. *Ibid. 1923.*

49. **WHITSON, A. R.** 1927. Soils of Wisconsin. *Wis. Geol. and Natl. Hist. Surv. Bul.* 68.

50. —— and **BAKER, O. E.** 1921. (Revised in 1928) The climate of Wisconsin and its relation to agriculture. *Wis. Agr. Exp. Sta. Bul.* 223.

51. **WHEETING, L. C.** 1924. Some physical and chemical properties of several soil profiles. *Mich. Agr. Exp. Sta. Tech. Bul.* 62.

52. **WITYN, J.** 1927. A brief survey of soil investigations in Latvia, Riga.

PLATE 6

DRAWINGS OF THE PRINCIPAL SOIL PROFILES IN WISCONSIN

The drawings are made to scale and include a section six feet in depth. All depths are referred to the surface of the A_1 horizon. The boundary lines between horizons are shown obliquely in order to illustrate the general variance in thickness and depth which may be expected. A brief description, summarizing the detailed one in the text, is given for each horizon. Differences in texture are shown by the variation in shading. The content of organic matter is roughly indicated by the depth of shading in the surface. Compactness is represented by cross shading.

N-O-T-E-S

1. This series is very similar to the Miami except that it is developed from older drift than that giving rise to the Miami. The soil is shown as Miami on the maps of the State Soil Survey.
2. The Bellefontaine series is included with the Miami on the maps of the State Soil Survey.
3. The Knox series has been variously named by the Bureau of Chemistry and Soils: on some of the older maps it appears as Knox, on others as Union, while now the accepted term is Clinton.
4. The Baxter series is now known as Dubuque by the Bureau of Chemistry and Soils in order to differentiate it from the Baxter developed in the Ozark region.
5. Thurston is a local name, not yet recognized as official.
6. The Carrington series is now mapped as Parr by the Bureau of Chemistry and Soils.
7. This name is no longer used in Wisconsin by the Bureau of Chemistry and Soils.
8. This series is recognized as Spencer by the Bureau of Chemistry and Soils.
9. This soil was mapped in Door County in 1916. At present it would probably be divided between the Onoway series and the Posen series as recognized by the Bureau of Chemistry and Soils.
10. A local name given to soils developed from material identical with that giving rise to the Vilas, but having a definite Podsol profile.
11. Orienta is a local name used by the State Soil Survey for a soil very similar to the Ogemaw of the Bureau of Chemistry and Soils.