



**AgEcon** SEARCH  
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search  
<http://ageconsearch.umn.edu>  
[aesearch@umn.edu](mailto:aesearch@umn.edu)

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

TB 399 (1933)

USDA TECHNICAL BULLETINS

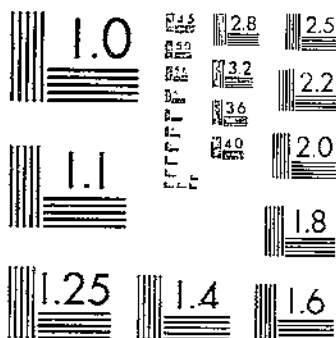
UPDATA

A STUDY OF CLAYPAN SOILS

BROWN, I. C. ; RICE, T. D. ; BYERS, H. G.

1 OF 1

# START



# LA STUDY OF CLAYPAN SOILS

BY

**IRVIN C. BROWN**

*Associate Chemist*

**T. D. RICE**

*Senior Soil Scientist*

and

**HORACE G. BYERS**

*Principal Chemist*

*Soil Investigations, Bureau of Chemistry and Soils*



UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE  
WASHINGTON, D.C.

## A STUDY OF CLAYPAN SOILS

By IRVIN C. BROWN, *associate chemist*, T. D. RICE, *senior soil scientist*, and  
HORACE G. BYERS, *principal chemist*, *Soil Investigations, Bureau of Chemistry  
and Soils*

### CONTENTS

	Page		Page
Introduction.....	1	Analytical results—Continued.....	
Description of soils.....	2	The Crete profile.....	13
Fillmore soils.....	2	The Hastings profile.....	18
Crete soils.....	4	The Holdrege profile.....	18
Hastings soils.....	5	The Keith profile.....	21
Holdrege soils.....	6	The Phillips profile.....	23
Keith soils.....	6	The Fargo profile.....	26
Phillips soils.....	7	The McLeansboro profile.....	30
Fargo soils.....	8	Hygroscopic relations.....	32
McLeansboro soils.....	8	General discussion.....	36
Methods of examination.....	9	Summary.....	40
Analytical results.....	10	Literature cited.....	41
The Fillmore profile.....	10		

### INTRODUCTION

The work of Holmes (14)<sup>1</sup> and that of Holmes and Edgington (15) present a careful investigation of the chemical characteristics of colloids of given soil types which occur in the humid region. These studies bring out the fact that the colloid of a given soil series, as defined by the Division of Soil Survey, is of essential constancy of composition, while the soil colloids derived from different series differ to a marked degree. The work of Denison (12) and that of Anderson and Byers (3, 4) show that although the soils of the great soil groups have within each group a generally similar character, the different great groups are markedly dissimilar. These groups of data, with other data collected from various sources, have been made the basis for a general treatment of the subject of the relation between the colloids of the great soil groups, as developed and defined by Marbut (18) and his associates, by Byers and Anderson (9), and a discussion of the genesis of soil colloids by Byers (8).

At the suggestion of one of the authors (Rice), the present investigation of chemical and physical properties of groups of soils which have been intensively studied in the field by the representatives of the Division of Soil Survey was undertaken as a continuing study of the relation between the chemical characteristics of soils and their classification. It was also expected that light might be thrown on the processes of production of claypans. It was at first intended to limit the study to the claypan soils of Nebraska, but as the work developed it seemed wise to include three profiles from other sources.

<sup>1</sup> Italic numbers in parentheses refer to Literature Cited, p. 41.

In southern Nebraska is an area which affords an excellent field for the study of changes in soils brought about by climatic conditions. This area, which extends east-west across the southern part of the State, is about 325 miles long. The greater part of it is mantled with Peorian loess. From about the longitude of Lincoln to the west State line the loessial mantle is almost continuous. East of this longitude it has been removed rather extensively but still caps many of the divides to within a few miles of Missouri River. Aside from some variations in its lime content the loessial material over this area is remarkably uniform in composition. Its surface, as a rule, is nearly level or very gently rolling, although it is modified here and there by shallow basinlike depressions and is crossed by narrow strips of steeply sloping or rough and broken land along drainageways. There is a gradual slope eastward from about 3,200 feet above sea level in the western part to about 1,200 feet in the eastern part.

The natural vegetation, prior to the use of the land for cultivated crops, consisted of tall prairie grasses in the eastern part, mixed tall and short grasses in the central part, and short grasses in the western part of the area. Patches of virgin grassland of varying sizes still remain in practically every township. Throughout most of the area, native forest occurs only in narrow strips along drainage channels.

The mean annual precipitation ranges from about 18 inches in Dundy County to about 32 inches in Richardson County. The mean annual temperature is almost uniform throughout the area, being 50° F. in the eastern part. Local relief nowhere exceeds 200 feet.

The importance of this area as a field for soil study is owing to its large extent, to the uniformity of the parent soil material, and to the fact that comparable successions of drainage condition occur throughout. Obviously, differences in the soils developed over this area are the result of changes in the factors of environment, which determine the nature and intensity of the soil-forming processes. It is believed that differences in the amount of soil moisture, whether directly derived from precipitation or increased or diminished locally by topographic features, account for the major soil features in a given locality. The region selected for study lies south of Platte River, extending from about the longitude of Lincoln to the western State line. Throughout this region differences in temperature, owing to differences in elevation or latitude, are not believed to be significant factors in soil formation. The character of the vegetation, a very important factor in soil development, is controlled by the amount and distribution of the rainfall.

In any given precipitation belt the soil on the smooth but well-drained upland receives the whole precipitation and develops a profile that may be regarded as the regional or zonal profile. In depressions, however, soils developed under more humid conditions may resemble soils that occur in belts of heavier rainfall farther east, and on sloping areas the soils are like the more arid soils to the west. For this reason the soil map of any country may show that soils zonal in other regions occur in association with each other, depending on the relief.

The local soil-forming processes acting on the uniform parent material have produced soils that differ in several respects. In the soils of the region under consideration an especially obvious characteristic is the development of a more or less dense upper subsoil layer. In some of them this is a true claypan. On the basis mainly of the

color, thickness, and density of the dense layer, these soils have been grouped in soil mapping into several series. This report is concerned with five series; namely, Fillmore, Crete, Hastings, Holdrege, and Keith, all of which lie west of the north-south line which separates the soils of the United States into two broad groups—pedocals and pedalfers—and they belong to the former group.

Soils of the first four series named have developed in that part of the United States where the surface soils, as a result of moderate rainfall and a heavy grass cover, have attained a very dark, in many places almost black, color. They are classed as chernozems. The intensity of darkness in the surface layers diminishes westward toward the region of lower rainfall and lighter grass cover, except in the Fillmore soils. Aside from the Fillmore soils, which may be regarded as intrazonal in their distribution, all the soils mentioned occur in more or less well-defined north-south belts across the southern part of Nebraska. The Keith soils, which have developed in the region of lightest precipitation and grass cover, have the lightest-colored surface layers and are definitely classed with the chestnut-brown group of soils. All the soil samples from Nebraska were collected by F. A. Hayes of the Soil Survey.

One of the three other profiles introduced is a solonetz from Phillips sandy loam from Montana. This soil is developed under a scanty rainfall and grass cover but has a very distinct claypan. Another is a solonetz from Fargo clay from Minnesota, developed from the lacustrine deposit of the ancient Lake Agassiz, and having a well-developed claypan and very distinct development of podzollike characteristics. The third is a silt loam which has not yet been named, since it is in an unsurveyed area. It is, however, a prairie soil, occurring 6 miles west of McLeansboro, Ill. It has a well-defined claypan, and the rounded tops of the columnar subsoil show evidence of incipient podzolization. Detailed descriptions of each of these profiles are given. The field observations of the Soil Survey indicate a wide distribution of claypan throughout the Mississippi Valley. These soils are also similar in physical characteristics to the pleistocene gumbotil, which has been summarized by Kay and Apfel (16). Lack of detailed information concerning the colloid of the gumbotil and of its physical properties makes comparison difficult, but it is possible that this material was produced by the same processes which produce claypans in the present soils. Also, dense subsoils, resembling claypans, are developed in certain areas as a result of irrigation, according to McGeorge, Breazeale, and Burgess (17), and are also found in the lateritic soils of the humid east. The relation of these to the claypans is close. It would appear, then, that laboratory investigations of a definite type of claypan should be of general interest and have a direct bearing on soil genesis and colloid constitution.

## DESCRIPTION OF SOILS

### FILLMORE SOILS

The Fillmore soils are typically developed in shallow poorly drained depressions or basins. These soils may occur in any part of the loess-covered uplands where conditions of moderately excessive moisture prevail, but they are most abundant and cover a greater proportion of the area in the eastern part of the region under consideration.

The Fillmore soils represent the most extreme development of the dense black claypan. The topsoil in few places exceeds 9 or 10 inches in thickness. It is very dark in the upper part but in many places is leached and almost white in the lower part. The upper part of the subsoil is a true claypan consisting of dense black clay from 14 to 30 inches thick. The clay in most places gives way rather abruptly at a depth of about 40 inches to light-gray limy and floury silt. This light-colored layer, or the lime zone, ranges from about 8 to 14 inches in thickness. It rests on Peorian loess. The loess contains less lime than the layer above. The profile studied is a silt loam, a description of which follows:

Location: On west side of road, 1,050 feet south of the northeast corner of sec. 15, T. 8 N., R. 9 W., Adams County, Nebr.

Topography: Nearly level area about 12 feet below the surrounding uplands.

Drainage: Water does not remain long on the surface but drains slowly to a slightly lower lying area. The claypan subsoil is nearly impervious to underdrainage.

Vegetation: Virgin-hay meadow covered mainly by western wheatgrass and a small sedge, with some bluegrass.

A<sub>1</sub>. 0 to 2 inches, very dark grayish-brown silt loam. The upper half inch is structureless, and the remainder is laminated.

A<sub>2</sub>. 2 to 6½ inches, the upper 2 inches of which is light grayish-brown laminated silt loam. In the lower part gray material coats the hard granular particles of the degrading upper part of the claypan.

B<sub>1</sub>. 6½ to 16 inches, upper part of claypan. Black dense structureless clay which contains round hard ferruginous pellets from one eighth to one fourth inch in diameter.

B<sub>2</sub>. 16 to 38 inches, same as layer above, except that the color is slightly lighter, passing into grayish brown in the lower 3 inches.

B<sub>3</sub>. 38 to 42 inches, upper part of zone of lime accumulation. Grayish-brown friable structureless silt loam containing an abundance of lime carbonate. The lime occurs in finely divided form and as a coating in root cavities. Streaks and spots of iron are also plentiful.

B<sub>4</sub>. 42 to 60 inches, appears to be the zone of maximum lime accumulation. The material is lighter in color than that in the layer above and contains lime concretions, some of which attain a diameter of three eighths of an inch.

B<sub>5</sub>. 60 to 84 inches, a transitional layer, in which the material is grading downward to unleached loess. Lime is present but is less visible than in the layer above. Iron is abundant, and ferruginous tubes occur usually in a vertical position.

C. 84 to 96 inches, the parent material consisting of Peorian loess. Pale grayish-yellow structureless silt. Contains an abundance of lime, but there is no visible concentration.

#### CRETE SOILS

As we pass from the friable loess soils in eastern Nebraska and cross the vaguely defined belt of predominantly black claypan soils, we come to the first belt in which the claypans have developed under the influence of the normal precipitation without the addition of runoff from higher lands. The precipitation in the region where the Crete soils attain their maximum and most extensive development ranges from about 26.5 to 28 inches. The soils of this belt have a brown claypan layer, slightly less dense than that of the Fillmore soils, but usually as thick. A typical profile of Crete silt loam observed on the level uplands near Hastings, Nebr., is described. A sample of this soil was collected and used in the laboratory investigations.

Location: 350 yards south of the northeast corner of sec. 8, T. 6 N., R. 9 W., Adams County, Nebr. Pit dug to a depth of 7 feet on west side of road.

Topography: Nearly level area on a smooth plain.



Vegetation: Western wheatgrass and June grass, with some big bluestem.

Drainage: Surface drainage slow but good. Underdrainage poor on account of claypanlike subsoil.

A<sub>1</sub>. 0 to 1½ inches, very dark grayish-brown structureless silt loam mulch.

A<sub>2</sub>. 1½ to 4 inches, a laminated layer. Very dark grayish-brown friable laminated silt loam. Crushes no lighter than broken surface.

A<sub>3</sub>. 4 to 20 inches, very dark grayish-brown faintly granular or structureless friable silt loam. Crushes dark grayish brown.

B<sub>1</sub>. 20 to 38 inches, a claypan layer. Brown or dark grayish-brown dense clay with a prismatic structure. The structural aggregates are slightly longer vertically than horizontally but do not exceed one half inch in any dimension. This layer becomes light grayish brown and a little more friable in its lower 3-inch part which rests directly on the lime zone.

B<sub>2</sub>. 38 to 60 inches, the lime zone. Very light grayish-brown structureless silt. Lime is abundant in disseminated form, as soft spots and splotches, as coatings on the surfaces of cracks, and as occasional small hard concretions.

C. 60 to 84 inches, raw Peorian loess. Very light grayish-yellow structureless silt. Lime is abundant, but there is no layer in which it appears to have accumulated.

#### HASTINGS SOILS

West of the belt of dense brown claypan soils is the belt of Hastings soils. These soils have developed under less moisture than those of the Crete belt. Throughout the area of their distribution in Adams, Kearney, Franklin, and Webster Counties, Nebr., the annual precipitation ranges from about 25 to 26.5 inches.

In other areas, as in those around the northern edge of the Crete belt, the precipitation is equal to that in the Crete belt, but the land surface is more rolling and less of the moisture has penetrated the ground. Aside from the eastward-extending spur of the Hastings soils, where the vegetation is of the tall-grass type, the Hastings belt is in the eastern part of the mixed-grass prairies. Here the moisture supply is not quite sufficient to support the purely tall-grass type of vegetation so common in the soil belts farther east. Tall grasses dominate, but short grasses are beginning to appear.

Owing to decreased moisture, the upper part of the subsoil in the Hastings soils is not so dark, thick, or dense as the corresponding layer in the Crete soils. However, it is by no means friable and is usually regarded as semiclaypanlike in character.

The following profile of Hastings silt loam was observed in Sherman County. This is outside the principal belt of Hastings soil but is typical of the series.

Location: 300 yards north of the southwest corner of sec. 4, T. 14 N., R. 13 W., Sherman County, Nebr. Pit dug to a depth of 9 feet on east side of road.

Topography: Tabular spur on nearly level plain.

Vegetation: Big bluestem and western wheatgrass.

Drainage: Surface drainage and underdrainage well established. No erosion.

A<sub>1</sub>. 0 to 6 inches, very dark grayish-brown structureless silt loam. Thickly matted with grass roots. No color change when crushed.

A<sub>2</sub>. 6 to 20 inches, very dark grayish-brown structureless or very faintly granular silt loam. Crushes grayish brown.

B<sub>1</sub>. 20 to 30 inches, upper part of zone of maximum compaction. Very dark grayish-brown moderately compact silty clay loam. Cloddy. The material crushes light grayish brown but is crushed with difficulty between the finger and thumb.

B<sub>2</sub>. 30 to 43 inches, lower part of zone of maximum compaction. Same as B<sub>1</sub>, except that the material is slightly lighter in color and a little more compact.

- B<sub>2</sub>. 43 to 57 inches, a transitional layer between zone of maximum compaction and lime zone. Very light grayish-brown structureless friable silt loam. Crushes no lighter than a broken surface. This layer contains scattered rust-brown ferruginous spots and splotches. The material shows no effervescence when acid is applied.
- B<sub>4</sub>. 57 to 78 inches, the zone of maximum carbonate enrichment. Very light grayish-brown structureless silt. Lime is abundant, occurring as filmlike coatings on the surfaces of cracks, in myceliumlike arrangement, and in disseminated form. The layer also contains a few filled rodent burrows, in which the material is dark colored and free from lime.
- C. 78 to 108 inches, the parent Peorian loess. Pale yellowish-brown structureless silt. This material is rich in disseminated lime and also contains scattered lime concretions from one sixteenth to one eighth inch in diameter, but there is no layer in which the carbonates appear to be concentrated.

#### HOLDREGE SOILS

West of the Hastings belt are the Holdrege soils. They have developed under a precipitation ranging from about 20 to 25 inches per annum and occupy the central and western parts of the mixed-grass prairie region. In the eastern part of the Holdrege belt, where the precipitation is greatest, tall and short grasses are about equally abundant, but in the western part short grasses dominate. These soils differ from those of the Hastings series only in degree of claypan development. A thin, rather tight layer is developed in the upper part of the subsoil in nearly all of the more nearly level areas of the Holdrege soils. This layer, although thinner and less compact than the corresponding layer in the Hastings soils to the east, otherwise has most of the characteristics common to that layer. On the more rolling areas the tight layer almost disappears in the Holdrege soils. Following is a description of a typical profile of Holdrege silt loam:

Location: 2,400 feet west of the northeast corner of sec. 20, T. 6 N., R. 19 W., Phelps County, Nebr.

- A<sub>1</sub>. 0 to 4 inches, dark grayish-brown structureless or laminated silt loam.
- A<sub>2</sub>. 4 to 7 inches, very dark grayish-brown laminated silt loam. Crushes to dark grayish brown.
- A<sub>3</sub>. 7 to 18 inches, very dark grayish-brown mealy silt loam. Crushes to a slightly lighter color than crushed material from the layer above. Horizon has imperfectly developed columnar form. It corresponds, in its profile position, to the granular layer of soils farther east.
- B<sub>1</sub>. 18 to 30 inches, the zone of maximum compaction. Grayish-brown moderately compact silty clay loam. Material seems to be made up almost entirely of worm and insect borings. It is cloddy.
- B<sub>2</sub>. 30 to 49 inches, light grayish-brown friable silt loam which is somewhat cloddy and contains very little lime. Borings are as numerous as in layer above. This is a transitional layer between the zone of maximum compaction and the lime zone.
- B<sub>3</sub>. 49 to 72 inches, light grayish-brown structureless silt. Carbonates are abundant, occurring chiefly as filmlike coatings on the surfaces of clods or of cracks and also in dendritic filaments.
- C. 72 to 96 inches, parent loess of light grayish-brown color. Lime is abundant, but carbonate segregations are rare.

#### KEITH SOILS

A little west of 100° west longitude, where the precipitation drops to less than 20 inches per annum, soils of the Keith series are developed. These soils are definitely in the short-grass prairie region. The decreased organic content has resulted in dark grayish-brown or chestnut-brown surface soils which contrast rather sharply with the darker surface layers of the Holdrege and Crete soils, especially if typical samples are compared. The Keith soils have been less thoroughly leached than any of the well-drained loess-derived soils farther

east. They have a barely perceptible compaction in the upper part of their subsoils. The profile of Keith silt loam collected is described as follows:

Location: 1,628 feet north of the southwest corner of sec. 34, T. 14 N., R. 36 W., Dundy County, Nebr.

Topography: Very gentle slope in gently undulating plain.

Drainage: Good surface drainage and underdrainage. No erosion.

Vegetation: Western wheatgrass and grama grass.

A<sub>1</sub>. 0 to ½ inch, grayish-brown structureless silt loam.

A<sub>2</sub>. ½ to 3½ inches, chestnut-brown laminated silt loam.

B<sub>1</sub>. 3½ to 14 inches, dark grayish-brown friable structureless or mealy silt loam. Worm and insect borings and casts rather numerous. Material breaks into soft clods of irregular sizes and shapes.

B<sub>2</sub>. 14 to 21 inches, upper part of lime zone. Grayish-brown cloddy friable silt loam. Limy. Carbonates occur in small soft spots, in blotches, and as filmlike coatings on the surfaces of clods. Borings very abundant.

5.<sup>1</sup> 21 to 33 inches, the zone of maximum lime accumulation. Light grayish-brown structureless silt loam. Lime very abundant, occurring both in disseminated form and as coatings on clods. Material breaks into irregular-shaped clods which are moderately hard to crush between fingers and thumb.

6.<sup>1</sup> 33 to 40 inches, very light grayish-brown structureless silt. Very limy. Material breaks into rather definite clods of various sizes and shapes, but they are softer than in layer above.

7.<sup>2</sup> 40 to 48 inches, same as layer above, except it has a floury consistence. In this horizon very little of the lime is visible, most of it being in disseminated form.

8.<sup>2</sup> 48 to 72 inches, the parent loess. Light grayish-brown floury silt. Limy.

9.<sup>2</sup> 72 to 96 inches, same as layer above.

#### PHILLIPS SOILS

The Phillips soils of northern Montana represent a group of soils which have developed a claypan layer. The sample under investigation was taken in an extensive area in northern Montana. The Phillips soils in this area have their most eastern extension in the southern part of Phillips County and stretch as an irregular belt in a northwesterly direction across the northern part of Blaine County and the northeastern corner of Hill County, and thence for an unknown distance into Canada. The elevation of the area ranges from 2,240 to 2,500 feet above sea level.

The mean annual precipitation is slightly more than 13 inches, and the mean annual temperature is about 45° F. The surface relief is flat or very gently undulating, and over the greater part of the area the precipitation is retained by the soil upon which it falls. The surface covering, which is the parent material of the soils, is glacial drift. The area covered by this soil is well within the plains grassland with its short-grass vegetation. The normal soil developed under the climatic and vegetative environment has a moderately dark grayish-brown surface layer, a slightly heavier upper subsoil layer, and a carbonate accumulation at a slight depth below the surface. The development in the Phillips belt of an extremely compact layer would indicate a difference in the composition of the parent material from that of the normal soils of the area. The location and description are as follows:

Location: 20 miles south of Malta, Mont.

A<sub>1</sub>. 0 to 1½ inches, a dust mulch.

A<sub>2</sub>. 1½ to 4 inches, a dark grayish-brown laminated layer, with blocky breakage, not columnar; laminations distinct when the material is broken out.

<sup>1</sup> C horizons not distinguishable in the field.

- B<sub>1</sub>. 4 to 9 inches, grayish-brown columnar fine sandy loam, somewhat compact in position. Apparently segmented hardpan columns.
- B<sub>2</sub>. 9 to 19 inches, dense claypan layer, dark grayish brown, distinctly columnar; columns one half to 1 inch in diameter; material very compact in position but breaks into small blocks when dug out.
- B<sub>3</sub>. 19 to 36 inches, the layer of greatest apparent lime accumulation. Material white and olive brown, firm in position, breaks out in finely compact clods.
- B<sub>4</sub>. 36 to 54 inches, similar to layer above, except there is more olive brown and less white, apparently less lime; clods slightly softer.
- C. 54 to 64 inches, grayish-yellow or olive-yellow friable clay loam. Structureless glacial drift. This sample carefully taken with post-hole digger.

## FARGO SOILS

The Fargo soils represent the profile development of the lacustrine deposit in the region of the former Lake Agassiz in Minnesota and North Dakota. The normal development is without a distinct claypan, although the subsoil is very heavy clay. In the Fargo soils, the claypan occurs in localized spots ranging from 10 to 60 feet in diameter. In some areas these spots make up more than half the total surface. The prevalent natural vegetation is that of the long-grass prairie region. The claypan spots occur in slight depressions in a generally flat surface. The mean annual rainfall is about 21.5 inches. The profile development is of the solonetz type and is strikingly uniform wherever developed. The field evidence of podzolization is in the light color of the A<sub>2</sub> horizon and the very great contrast with the texture of the B horizon. The sample studied was collected by C. C. Nikiforoff at a point about 30 miles south of Moorehead, Minn. The profile is described as follows:

- A<sub>1</sub>. 0 to 6 inches, very dark grayish-brown or black material. Structure usually finely granular. This surface soil is not noticeably different from the surface layer of the surrounding areas.
- A<sub>2</sub>. 6 to 10 inches, light-gray or ash-colored material. Loose with laminated structure, the laminae being very fragile. Material crumbles easily into a loose light-gray powder.
- B. 12 to 20 inches. This horizon begins abruptly. Black material, extremely hard and compact when dry, plastic when wet. Most of the columns range from 1 to 2 inches in diameter, and the dense upper part is usually from 4 to 6 inches in length. When degradation has proceeded to any depth the columns are rounded and have a white coating over their rounded tops. Below the dense part the columnar form is gradually lost and the material breaks up into irregular blocks.
- C. 32 to 48 inches, the parent material of lacustrine clay.

## MCLEANSBORO SOILS

A considerable area of southern Illinois is covered by a soil characterized according to an older nomenclature as a gray silt loam over light clay. A profile of this soil was collected at a point 6 miles west of McLeansboro, Hamilton County, on route 15. The county has not been surveyed, but the soil is, apparently, soil no. 1, according to the new State nomenclature. It is the characteristic soil of the flat areas of the district. The hardpan is very dense and nearly impervious to water, but it dries out, leaving large cracks through which some drainage takes place. The mean annual rainfall of the area is high, 40 to 45 inches, and the removal of colloid from the A horizons is very marked. The description of the profile follows:

- A<sub>1</sub>. 0 to 8 inches, dull-brown silt loam, somewhat dark.
- A<sub>2</sub>. 8 to 12 inches, pale-yellow silt loam.

- B<sub>1</sub>. 12 to 16 inches, heavier than A<sub>2</sub>. Consists of or contains well-defined small structure particles, each of which is coated on the outside with bluish or bluish-yellow material. The insides of the particles are reddish. Mass is of loose consistence.
- B<sub>2</sub>. 16 to 19 inches, a gray layer consisting, like B<sub>1</sub>, of small structure particles, each of which is covered with a coating of gray powdery material, the inside of each particle being reddish brown or yellowish brown in color.
- B<sub>3</sub>. 19 to 26 inches, claypan made up mainly of angular structure particles ranging up to an inch or less in diameter. Each particle is coated with dense black material, and the insides of the particles are of rust-yellow color traversed with small black streaks.
- C. 28+ inches, moderately heavy parent material breaking into irregular clods. The material in most places is rust yellow or pale grayish yellow and contains many small black spots and streaks.

### METHODS OF EXAMINATION

The mechanical analyses were made by the pipette method described by Olmstead, Alexander, and Middleton (21). Included with the mechanical analyses are determinations of organic matter by hydrogen peroxide. This method as used is not one of precision; and when but small quantities of organic matter are present with considerable soluble inorganic matter, the inorganic matter is not reported. The chemical analyses of the soils were made according to the procedure described by Robinson (26). The colloids were extracted from the soils with the aid of the supercentrifuge and essentially as described by Brown and Byers (7). In none of the horizons extracted was it found desirable to use any agent to assist the dispersion in water. Five hundred grams of the soil were kneaded to a plastic mass and dispersed by hand rubbing in 10 gallons of distilled water. The resulting suspension was centrifuged at a rate of 17 seconds per liter at a speed of 17,000 revolutions per minute (diameter of bowl, 4 inches). The colloidal particles remaining suspended were certainly less than  $1\ \mu$  in diameter and probably few exceeded  $0.3\ \mu$ . The dispersion in the same water, after filtration, was repeated four times. The resulting colloid was collected on Pasteur-Chamberland filters by suction and amounted to 30 to 80 percent of the quantity of colloid shown by mechanical analysis. The final drying of the colloid was effected on a steam bath.

The colloids were analyzed by the same methods employed for the soils. In calculating the "water of hydration" the carbon dioxide content, as well as that of the organic matter, was subtracted from the loss on ignition.

The pH values of the soils were determined by the use of the hydrogen electrode as described by Bailey (6). The approximate salt content was determined by use of the electrolytic bridge, as described by Davis (11). All samples were air-dried.

The water-vapor absorption of the colloid was determined by the method described by Robinson (25) and Middleton (19).

Because of the large quantity of analytical data, it is presented in separate tables for each soil examined, together with a brief discussion of each table. These tables are followed by a series of tables which present certain data which are derived from the analytical results. Finally a résumé of the more pertinent features is presented.

## ANALYTICAL RESULTS

## THE FILLMORE PROFILE

Fillmore silt loam is the most highly weathered of the group of Nebraska soils examined. The data obtained by mechanical analyses are presented in table 1. The chemical analyses of the whole soil are presented in table 2, and the analyses of the extracted colloid are given in table 3.

TABLE 1.—Mechanical analyses of Fillmore silt loam<sup>1</sup>

Sample no.	Horizon	Depth	Fine gravel (2-1 mm)	Coarse sand (1-0.5 mm)	Medium sand (0.5- 0.25 mm)	Fine sand (0.25-0.1 mm)	Very fine sand (0.1- 0.05 mm)	Silt (0.05-0.005 mm)	Clay (0.005-0 mm)	Colloid (0.002-0 mm)	Organic matter by H <sub>2</sub> O <sub>4</sub>
		Inches	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent
8088	A <sub>1</sub>	0-2	0.0	0.1	0.1	0.2	6.6	59.3	28.3	20.2	5.4
8089	A <sub>2</sub>	2-6½	.0	.1	.1	.2	8.1	60.2	27.6	19.8	2.9
8090	B <sub>1</sub>	6½-16	.0	.0	.1	.1	4.3	41.6	52.0	48.2	1.2
8091	B <sub>2</sub>	16-38	.0	.1	.1	.1	4.1	40.0	54.7	50.2	.5
8092	B <sub>3</sub>	38-42	.1	.1	.1	.2	4.5	54.2	30.8	29.8	.4
8093	B <sub>4</sub>	42-60	.2	.3	.2	.4	5.4	60.0	31.8	22.9	1.1
8094	B <sub>5</sub>	60-84	.1	.1	.1	.3	5.7	64.3	28.9	23.3	1.0
8095	C	84-88	.0	.2	.1	.1	4.2	63.3	31.6	25.4	1.0

<sup>1</sup> Analyses by H. W. Lakin and T. M. Shaw.

<sup>2</sup> Organic matter not present in excess of 0.4 percent.

The mechanical analyses indicate a very striking case of uniformity of texture throughout the profile so far as the sands are concerned. The chief difference between the horizons is in the relative amounts of silt and clay, which together make up from 87.8 to 94.9 percent of the total soil. In the claypan zone, the B<sub>1</sub> and B<sub>2</sub> horizons, the clay content is nearly 100 percent greater than in A<sub>1</sub> and A<sub>2</sub> and is also greater than in the lower horizons. It is to be noted that the colloid content is greater, relative to the total clay, in all horizons than in the A<sub>1</sub> and A<sub>2</sub> horizons. These facts when taken in conjunction with the additional fact of higher organic content of the A<sub>1</sub> and A<sub>2</sub> horizons are indications of enrichment of the lower strata by illuviation. These values are to be noted particularly since translocation of colloid particles, as so indicated, is less marked in certain of the other profiles.

Table 2, showing the chemical analyses of the whole soil, likewise indicates eluviation of the upper horizons. The high silt content is reflected in the high silica of the A<sub>1</sub> and A<sub>2</sub> horizons. The lower silica and higher iron and alumina content of B<sub>1</sub> and B<sub>2</sub> are due to increased colloid present in the hardpan, while in B<sub>3</sub> and B<sub>4</sub> the presence of the carbonate accentuates the decrease in silica content. The transfer of material indicated by the silica relations and by the increase of calcium carbonate is also indicated by the hydrogen-ion concentrations of the horizons which gradually decrease, with increase of pH, until the value corresponds to that of calcium carbonate. The same relation is also indicated by the soluble salts which reach a maximum value in the layers immediately beneath the hardpan. The high values of the potassium and sodium content of the soil and their relations to the content of the same elements in the colloid indicate the presence of approximately 20 percent undecom-

posed feldspars in the silt. This indication from the analyses was confirmed by petrographic examination (24).

The relative constancy of the content of the alkalis and, indeed, of all the minor constituents of the soil, other than of magnesium and calcium, are further indications of uniformity of the parent material and that the translocation which occurred is essentially of colloid only.

TABLE 2.—Chemical analyses of Fillmore silt loam<sup>1</sup>

Sample no.	Horizon	Depth	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8088	A <sub>1</sub>	0 - 2	71.93	2.74	9.46	0.95	1.25	2.31	1.45	0.53
8089	A <sub>2</sub>	2 - 6½	75.00	2.40	10.04	.88	1.18	2.46	1.55	.56
8090	B <sub>1</sub>	6½-16	67.64	4.99	14.32	1.53	1.20	2.58	1.22	.63
8091	B <sub>2</sub>	16 - 38	68.70	5.13	15.05	1.08	1.32	2.57	1.24	.63
8092	B <sub>3</sub>	38 - 42	57.68	3.85	11.51	2.03	2.87	2.24	1.16	.52
8093	B <sub>4</sub>	42 - 60	62.56	3.20	11.64	2.07	7.28	2.27	1.51	.54
8094	B <sub>5</sub>	60 - 84	66.10	3.52	11.40	2.00	5.10	2.39	1.59	.55
8095	C	84 - 96	67.20	3.36	12.00	2.08	4.76	2.37	1.43	.57

Sample no.	Horizon	Depth	MnO	P <sub>2</sub> O <sub>5</sub>	Ignition loss	SO <sub>3</sub>	Total	CO <sub>2</sub> <sup>1</sup>	N	pH	Soluble salts <sup>1</sup>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>			<i>Parts per million</i>
8088	A <sub>1</sub>	0 - 2	0.55	0.30	8.88	0.16	100.01	( <sup>2</sup> )	0.33	5.1	300
8089	A <sub>2</sub>	2 - 6½	.04	.21	5.61	.15	100.08	( <sup>2</sup> )	.12	5.4	540
8090	B <sub>1</sub>	6½-16	.04	.18	5.59	.14	100.06	( <sup>2</sup> )	.12	6.7	540
8091	B <sub>2</sub>	16 - 38	.07	.24	5.31	.12	100.11	( <sup>2</sup> )	.01	7.1	800
8092	B <sub>3</sub>	38 - 42	.05	.31	10.70	.11	100.08	5.85	.01	8.6	1,180
8093	B <sub>4</sub>	42 - 60	.16	.16	8.95	.16	100.29	4.15	.03	8.6	1,180
8094	B <sub>5</sub>	60 - 84	.05	.13	7.16	.12	100.11	1.79	.04	8.6	1,040
8095	C	84 - 96	.05	.10	5.50	.12	99.60	1.47	.03	8.6	1,060

<sup>1</sup> Determinations (except pH and soluble salts) by J. G. Smith.

<sup>2</sup> CO<sub>2</sub> of the carbonates.

<sup>3</sup> Determined by bridge method.

<sup>4</sup> Trace.

The colloid analyses (table 3) represent the composition of the colloid extracted from the various horizons by identical treatment. The quantity ranges from 37 percent of the total colloid present to 79 percent, reckoning the quantity of colloid found by mechanical analyses as 100 percent. The distinctly acid horizons are less easily dispersed than those approaching the alkaline range. The more difficultly dispersible material is also highest in organic matter. The colloid throughout is characterized by its uniformity of chemical composition when due allowance is made for the organic matter of A<sub>1</sub> and A<sub>2</sub> and for the presence of carbonates in the B<sub>3</sub> and B<sub>4</sub> horizons. The parallelism between the organic matter and the content of manganese, phosphorus, and sulphur is usual. The deficiency of magnesium in the A<sub>1</sub> horizon and the larger quantities of calcium and potassium, as compared with the A<sub>2</sub> horizon, may be noted, since this peculiarity is confined to this soil type among the chernozems reported in this investigation. Though it is more frequently encountered in the colloids from humid soils, it is by no means general (9).

The degree of uniformity of the colloid composition is more readily revealed by the set of derived data given in table 4.

TABLE 3.—Chemical analyses of Fillmore silt loam colloid

Sample no.	Horizon	Depth	Colloid extracted	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8088	A <sub>1</sub>	0 - 2	38	49.51	7.20	17.59	1.97	1.87	2.35
8089	A <sub>2</sub>	2 - 6½	37	51.35	8.30	18.53	2.78	1.25	2.52
8090	B <sub>1</sub>	6½-16	79	52.95	8.94	21.62	2.73	1.37	2.44
8091	B <sub>2</sub>	16 - 38	73	53.80	9.28	21.00	2.00	1.78	2.44
8092	B <sub>3</sub>	38 - 42	69	51.40	8.31	18.13	2.48	5.54	2.03
8093	B <sub>4</sub>	42 - 60	71	52.03	7.76	18.01	2.75	5.50	2.07
8094	B <sub>5</sub>	60 - 84	69	54.55	7.43	20.60	2.72	8.04	2.27
8095	C	84 - 96	71	54.68	7.80	20.26	2.68	2.84	2.20

Sample no.	Horizon	Depth	Na <sub>2</sub> O	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	Ignition loss	Total	Organic matter <sup>1</sup>	CO <sub>2</sub> <sup>1</sup>	N
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8088	A <sub>1</sub>	0 - 2	0.42	0.65	0.13	0.34	0.28	18.62	100.63	12.73	(3)	0.70
8089	A <sub>2</sub>	2 - 6½	.45	.74	.11	.25	.19	14.20	100.07	7.62	(3)	.33
8090	B <sub>1</sub>	6½-16	.39	.67	.09	.22	.10	9.03	100.58	2.05	(3)	.14
8091	B <sub>2</sub>	16 - 38	.22	.68	.09	.20	.09	9.53	101.61	1.84	(4)	.12
8092	B <sub>3</sub>	38 - 42	.50	.68	.08	.38	.14	10.63	100.30	1.46	2.33	.12
8093	B <sub>4</sub>	42 - 60	.40	.68	.08	.20	.12	10.47	100.07	1.11	2.40	.13
8094	B <sub>5</sub>	60 - 84	.45	.67	.05	.30	.11	8.20	100.33	.94	.81	.08
8095	C	84 - 96	.41	.55	.05	.19	.08	8.46	100.19	.53	.06	.07

<sup>1</sup>Determined by combustion method (CO<sub>2</sub>×0.471).CO<sub>2</sub> of the carbonates.<sup>1</sup>Trace.

TABLE 4.—Derived data: Fillmore silt loam colloid

Sample no.	Horizon	Depth	Molecular ratio					Water of hydration	Combined water of the soil acid <sup>2</sup>
			SiO <sub>2</sub>	SiO <sub>2</sub>	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub> <sup>1</sup>		
			Fe <sub>2</sub> O <sub>3</sub> .Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Total bases		
		<i>Inches</i>						<i>Percent</i>	<i>Percent</i>
8088	A <sub>1</sub>	0 - 2	3.76	13.20	4.75	0.262	7.44	5.79	9.00
8089	A <sub>2</sub>	2 - 6½	3.65	16.37	4.69	.287	6.80	4.58	9.55
8090	B <sub>1</sub>	6½-16	3.22	15.52	4.05	.259	7.02	6.98	9.15
8091	B <sub>2</sub>	16 - 38	3.52	15.36	4.34	.283	7.05	7.49	9.82
8092	B <sub>3</sub>	38 - 42	3.73	16.39	4.80	.293	6.28	6.84	9.09
8093	B <sub>4</sub>	42 - 60	3.84	17.75	4.90	.276	6.47	6.96	9.98
8094	B <sub>5</sub>	60 - 84	3.05	10.40	4.21	.231	6.72	6.45	9.15
8095	C	84 - 96	3.67	18.60	4.57	.246	7.00	7.27	8.90

<sup>1</sup>Carbonates deducted.<sup>2</sup>Water of hydration plus the water equivalent of the bases, corrected for organic matter and carbonate content.

The uniformity of the ratios is remarkable and, indeed, seems to indicate that we are dealing with the same substance throughout the profile. There are, however, differences which may be noted. The silica-sesquioxide ratio is higher in the A<sub>1</sub> and A<sub>2</sub> than in the claypan horizons. There is a minor alteration in the silica-ferric oxide ratios, and of the ferric oxide-alumina ratios, which indicates a very slight amount of fractionation of the colloid which is so marked in podzol soils (3, 7). The colloid of these soils, when the organic matter is removed by hydrogen peroxide, is grayish white, and this would seem to indicate that but a very small quantity of ferric oxide or hydroxide can be present as such. The silica-alumina ratio indicates, as does also the presence of feldspars in the soil, a comparatively low



degree of weathering or of removal of silica by leaching. The silica-total base ratio is fairly uniform throughout the profile, though despite the supposedly strong base-holding power of organic matter, the total bases present are least in the A<sub>1</sub> horizon. The water of hydration is somewhat variable, but within a narrow range.

The total combined water of the soil acid given in the last column of table 4 is the sum of the water of hydration (the ignition loss less the carbon dioxide and organic matter) and of the water equivalent of the bases and corrected for the organic matter and carbonate content. The quantities so arrived at indicate the amount of water which will result from the ignition of acids of the types assumed to exist in colloids, as discussed by Brown and Byers (7) and more fully discussed by Byers (8). If the colloid were a pure acid, which of course it is not, and were of the montmorillonitic type (see General Discussion), the water loss indicated should be 10.6 percent, and if of the pyrophyllitic type it should be 13.6 percent.

Too much reliance on the validity of these calculations is to be guarded against since, as will be more fully discussed after all the data are presented, they are affected by a number of sources of error of unknown magnitude. These include uncertainty of quantity of organic matter, the probable presence in the colloid of undecomposed mineral particles of colloidal size, and the lack of evidence that "combined water" is limited to that present at 105° C. It must also be observed that the water equivalent of the bases includes any bases present in the organic matter. The remarkable uniformity of composition indicated by the corrected water values in the last column may, however, be regarded as a final bit of evidence that the colloid of the Fillmore profile is, so far as its inorganic material is concerned, essentially a definite chemical substance.

#### THE CRETE PROFILE

As mentioned in the introduction, the Crete soils are associated with the Fillmore soils in the same area but occur where drainage is good. Farther west, with lower rainfall, they occur under nearly the same conditions as do the Fillmore soils lying to the east of them. The particular profile for which analytical data are given in tables 5, 6, and 7 is from an area only a few miles distant from the Fillmore profile given in tables 1, 2, and 3. It has therefore developed under practically identical conditions, except for better drainage and as a consequence with probably decreased hydrolysis and less leaching.

TABLE 5.—Mechanical analyses of Crete silt loam<sup>1</sup>

Sample no.	Horizon	Depth	Fine gravel (2-1 mm)	Coarse sand (1-0.5 mm)	Medium sand (0.5-0.25 mm)	Fine sand (0.25-0.1 mm)	Very fine sand (0.1-0.05 mm)	Silt (0.05- 0.005 mm)	Clay (0.005-0 mm)	Colloid (0.002-0 mm)	Organic matter by H <sub>2</sub> O <sub>2</sub>
		Inches	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent
8099	A <sub>1</sub>	0 - 1½	0.1	0.1	0.1	0.2	7.9	70.5	18.5	15.9	2.0
8100	A <sub>1</sub>	1½ - 4	.0	.1	.1	.2	7.9	60.0	23.5	20.3	2.4
8101	A <sub>1</sub>	4 - 20	.0	.0	.1	.1	5.5	63.6	28.3	24.0	2.2
8102	B <sub>1</sub>	20 - 38	.0	.0	.0	.1	4.3	43.3	51.0	46.2	.9
8103	B <sub>2</sub>	38 - 60	.0	.0	.1	.3	7.0	62.0	30.0	23.7	1.0
8104	C	60 - 84	.0	.0	.0	.1	8.3	66.7	28.7	20.1	4.0

<sup>1</sup> Analyses by H. W. Lakin and T. M. Shaw.

\* Organic matter not present in excess of 0.4 percent.

In mechanical composition (table 5) the lesser degree of weathering, as compared with the Fillmore silt loam, is indicated by the somewhat larger percentage of silt and smaller percentage of clay in the A<sub>1</sub>, A<sub>2</sub>, and A<sub>3</sub> horizons and by a less marked translocation of colloid to the B horizon. Perhaps these differences may be ascribed to better surface drainage on slopes, or less rain on flats, and in part to better underdrainage which gives rise to a deeper penetration of translocated colloid before an impervious layer is developed. To better drainage is to be ascribed, also, the almost complete removal of carbonates from the profile, as shown in tables 6 and 7.

TABLE 6.—Chemical analyses of Crete silt loam soil<sup>1</sup>

Sample no.	Horizon	Depth	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8099	A <sub>1</sub>	0 - 1½	74.88	1.36	11.40	0.87	1.30	2.19	1.79	0.62
8100	A <sub>2</sub>	1½ - 4	74.22	2.01	10.26	.95	1.32	2.31	1.68	.61
8101	A <sub>3</sub>	4 - 20	73.78	3.12	10.98	1.05	1.38	2.29	1.68	.62
8102	B <sub>1</sub>	20 - 38	67.24	5.28	13.26	2.07	1.40	2.04	1.10	.63
8103	B <sub>2</sub>	38 - 60	69.00	4.72	13.04	1.64	2.40	2.69	1.43	.60
8104	C	60 - 84	71.50	4.24	12.30	1.85	1.50	2.74	1.41	.68

Sample no.	Horizon	Depth	MnO	P <sub>2</sub> O <sub>5</sub>	Igni- tion loss	SO <sub>4</sub>	Total	CO <sub>2</sub> <sup>2</sup>	N	pH	Solu- ble salts <sup>3</sup>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>		<i>Parts per mil- lion</i>
8099	A <sub>1</sub>	0 - 1½	(0)	0.14	5.41	0.12	100.08	0.00	0.13	7.2	<293
8100	A <sub>2</sub>	1½ - 4	0.02	.13	5.27	.13	99.79	.00	.15	6.3	<293
8101	A <sub>3</sub>	4 - 20	.05	.12	5.53	.14	100.04	.00	.17	6.6	<293
8102	B <sub>1</sub>	20 - 38	.06	.21	5.78	.16	99.82	.00	.10	7.1	340
8103	B <sub>2</sub>	38 - 60	.06	.21	4.11	.12	100.02	.32	.04	8.6	1,440
8104	C	60 - 84	.08	.21	8.14	.10	99.65	.04	.03	8.6	800

<sup>1</sup> Determinations (except pH and soluble salts) by J. G. Smith.

<sup>2</sup> CO<sub>2</sub> of the carbonates.

<sup>3</sup> Determined by bridge method.

<sup>4</sup> Trace.

The effect of improved drainage is also shown in table 6 by the low soluble salt content of the A horizons and the, by contrast, high content of the layer immediately beneath the claypan. The drier average state of the Crete soil, as compared with the Fillmore, is indicated by the higher pH values of the A horizons and again by the lower content of organic matter as measured by hydrogen peroxide treatment. In other respects the general relations shown by table 6 indicate a close similarity of the Crete and Fillmore profiles. If proper allowance be made for the potassium and sodium in the colloid, the results indicate very clearly the presence of undecomposed feldspars in the silt and very fine sand. The analysis of the whole soil (table 6) indicates essential constancy of composition except for translocation of colloid.

The analyses of the colloid (table 7) likewise indicate a greater degree of permeability and relative dryness of the Crete soil, which may be assumed to be the reason for the marked uniformity of the colloid. The quantity extracted by identical treatment without dispersing agent is not widely different in the different horizons, the range being from 49 percent in the A<sub>1</sub> horizon to 78 percent in the B<sub>2</sub>. The colloid differs most markedly from the Fillmore colloid in the low content of calcium carbonate in the lower strata and in the organic-matter content of the A horizons.

TABLE 7.—Chemical analyses of Crete silt loam colloid

Sample no.	Horizon	Depth	Colloid extracted	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O
		Inches	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
8099	A <sub>1</sub>	0 - 1½	49	50.30	7.31	20.88	2.14	1.41	2.65	0.39
8100	A <sub>2</sub>	1½ - 4	55	50.00	7.36	20.47	2.08	1.51	2.55	.40
8101	A <sub>3</sub>	4 - 20	85	50.11	7.68	20.18	2.23	1.45	2.47	.40
8102	B <sub>1</sub>	20 - 38	78	52.20	7.79	22.14	2.75	1.85	2.40	.32
8103	B <sub>2</sub>	38 - 60	78	53.60	8.36	20.03	3.27	1.90	2.18	.31
8104	C	60 - 84	70	53.95	8.42	20.25	3.14	1.49	2.28	.25

Sample no.	Horizon	Depth	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	SO <sub>2</sub>	Ignition loss	Total	Organic matter <sup>1</sup>	CO <sub>2</sub> <sup>2</sup>	N
		Inches	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
8099	A <sub>1</sub>	0 - 1½	0.68	0.16	0.33	0.25	14.13	100.88	6.59	0.09	0.42
8100	A <sub>2</sub>	1½ - 4	.75	.11	.34	.21	14.69	100.44	7.16	.00	.44
8101	A <sub>3</sub>	4 - 20	.76	.16	.39	.23	14.28	100.23	6.65	.00	.44
8102	B <sub>1</sub>	20 - 38	.72	.07	.26	.28	10.60	100.77	2.28	.00	.18
8103	B <sub>2</sub>	38 - 60	.77	.10	.19	.20	8.74	99.74	1.11	.37	.14
8104	C	60 - 84	.75	.10	.14	.24	9.15	100.20	.91	.39	.13

<sup>1</sup> Determined by combustion method (CO<sub>2</sub> × 0.471).<sup>2</sup> CO<sub>2</sub> of the carbonates.

The average content of potassium oxide in the Crete colloid is 2.42 percent and in the Fillmore is exactly the same, while the same constituent is 2.40 percent in the soil of both. This apparent identity is more fortuitous than real, since the content of organic matter and of carbonates are both greater in the Fillmore soil and colloid. The figures, however, do indicate an essentially like degree of saturation of the two colloids by this not readily exchangeable base and lends emphasis to the assumption that both colloids contain the same soil acid. This assumption is best established by a consideration of the data derived from the colloid analyses and given in table 8.

TABLE 8.—Derived data: Crete silt loam colloid

Sample no.	Horizon	Depth	Molecular ratio					Wt. % of hydration	Combined water of the soil acid <sup>2</sup>
			SiO <sub>2</sub>	SiO <sub>2</sub>	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub> <sup>1</sup>		
			Fe <sub>2</sub> O <sub>3</sub> Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Total bases		
8099	A <sub>1</sub>	0 - 1½	2.34	18.20	4.09	0.224	7.41	Percent	Percent
8100	A <sub>2</sub>	1½ - 4	3.37	18.00	4.14	.230	7.40	7.59	10.28
8101	A <sub>3</sub>	4 - 20	3.59	17.30	4.21	.243	6.72	7.48	10.23
8102	B <sub>1</sub>	20 - 38	3.20	17.70	4.00	.225	7.04	7.58	10.52
8103	B <sub>2</sub>	38 - 60	3.58	16.93	4.53	.267	6.59	8.22	10.07
8104	C	60 - 84	2.57	16.95	4.51	.266	7.07	7.25	9.88
								7.95	10.43

<sup>1</sup> Carbonates deducted.<sup>2</sup> Water of hydration plus the water equivalent of the bases, corrected for organic matter and carbonate content.

The silica sesquioxide ratios shown by the Crete colloid average 3.42, and those of the Fillmore average 3.63. The corresponding averages for the silica-alumina ratios are 4.25 and 4.50, respectively. Taken by themselves, these values seem to indicate a greater degree of hydrolysis in the Crete. It is probable, however, that the relatively small differences noted are due to the removal of silicic acid by better

drainage in the Crete. Some translocation of iron oxide downward, i.e., fractionation of the colloid, is indicated by the decreasing silica-ferrous oxide ratios and increasing ferric oxide-alumina ratios. This indicates that podzolization is slight.

More important is the silica-total base ratio, which is nearly uniform in the Crete profile, while it is less constant in the Fillmore. In both soils, however, if the organic content of the colloid is taken into account, the evidence of definite composition is strong. This definiteness is still more strongly emphasized by the combined water of the soil acids. The mean value of this quantity for the whole profile is 10.33 percent. When one considers the known sources of error in computing this component, aside from the unavoidable analytical errors, the constancy is surprising.

#### THE HASTINGS PROFILE

The Hastings silt loam sample, the analytical data of which are given in tables 9, 10, and 11, is from Sherman County, Nebr., a little to the northwest of the Fillmore and Crete samples, but it is representative of the soils lying directly west of the Crete area and which are developed under lower rainfall than are the soils previously discussed.

TABLE 9.—Mechanical analyses of Hastings silt loam<sup>1</sup>

Sample no.	Horizon	Depth Inches	Fine gravel (2-1 mm)	Coarse sand (1-0.5 mm)	Medium sand (0.5-0.25 mm)	Fine sand (0.25-0.1 mm)	Very fine sand (0.1-0.05 mm)	Silt (0.05-0.005 mm)	Clay (0.005-0 mm)	Colloid (0.002-0 mm)	Organic matter by H <sub>2</sub> O <sub>2</sub>
			Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent
8379	A <sub>1</sub>	0-6	0.0	0.1	0.1	0.3	12.9	58.4	24.3	21.9	3.5
8380	A <sub>2</sub>	6-20	0.0	.1	.0	.2	6.1	57.1	30.8	27.0	2.2
8381	B <sub>1</sub>	20-30	.0	.0	.0	.1	6.3	49.1	40.9	35.8	.6
8382	B <sub>2</sub>	30-43	.0	.0	.1	.1	11.1	48.1	39.9	34.0	.0
8383	B <sub>3</sub>	43-57	.3	.0	.1	.1	15.1	54.6	29.5	23.0	.5
8384	B <sub>4</sub>	57-78	.1	.1	.1	.3	19.5	57.1	22.5	14.8	.4
8385	C	78-108	.0	.1	.1	.1	18.0	57.0	23.0	16.6	.6

<sup>1</sup> Analyses by H. W. Lakin and T. M. Shaw.

The data given in table 9 indicate that the lower rainfall and consequent lessened percolation have produced less differentiation between silt and clay in the A and B horizons than in the Fillmore and Crete soils and may be responsible for the greater quantities of very fine sand. This condition results in greater permeability, more complete drying between rains, and deeper penetration of the smaller quantity of water available. These characteristics of the soil are also shown by the data given in table 10 by the less sharp concentration of carbonates and at a greater depth, by the mild acidity of the upper four horizons, by the uniformity of the distribution of the silica, and by the increased sodium content of the soil. As in the previous profiles, the presence of unweathered feldspars is indicated.

TABLE 10.—Chemical analyses of Hastings silt loam soil<sup>1</sup>

Sample no.	Horizon	Depth	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8079	A <sub>1</sub>	0-6	71.48	2.99	12.20	0.97	1.60	2.47	1.62	0.59
8080	A <sub>2</sub>	6-20	70.98	3.43	12.41	1.05	1.44	2.38	1.53	.80
8081	B <sub>1</sub>	20-30	69.92	4.24	14.06	1.34	1.33	2.42	1.38	.80
8082	B <sub>2</sub>	30-43	69.34	4.43	14.32	1.80	1.57	2.62	1.09	.61
8083	B <sub>3</sub>	43-57	70.46	4.13	14.01	1.52	1.75	2.51	1.54	.59
8084	B <sub>4</sub>	57-78	70.69	8.84	13.59	1.41	2.41	2.45	1.47	.61
8085	C	78-108	70.95	3.62	12.80	1.59	1.88	3.07	1.49	.88

Sample no.	Horizon	Depth	MnO	P <sub>2</sub> O <sub>5</sub>	Ignition loss	SO <sub>3</sub>	Total	CO <sub>2</sub> <sup>2</sup>	N	pH	Soluble salts <sup>3</sup>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>		<i>Parts per million</i>
8079	A <sub>1</sub>	0-6	0.05	0.18	6.05	0.19	100.34	0.00	0.22	6.3	<298
8080	A <sub>2</sub>	6-20	.06	.14	5.28	.19	100.48	.00	.15	6.1	<288
8081	B <sub>1</sub>	20-30	.05	.13	4.72	.15	100.28	.00	.08	6.7	<288
8082	B <sub>2</sub>	30-43	.05	.14	4.38	.10	100.19	.14	.07	6.8	<298
8083	B <sub>3</sub>	43-57	.08	.22	3.65	.14	100.58	.13	.03	7.2	920
8084	B <sub>4</sub>	57-78	.06	.15	3.79	.15	100.63	.46	.03	8.3	990
8085	C	78-108	.06	.25	3.47	.10	100.17	.25	.01	6.3	680

<sup>1</sup> Determinations (except pH and soluble salts) by J. G. Smith.<sup>2</sup> CO<sub>2</sub> of the carbonates.<sup>3</sup> Determined by bridge method.

In the colloid analyses of table 11 may be noted the high organic content of the A horizons, which is associated with increased sulphur and phosphorus, although the organic content is lower than that of the Fillmore profile. A point of considerable interest is that colloidal calcium carbonate exists throughout the profile in small quantity, though the quantity in the soil itself is so small that it was not reported for the upper three layers of the soil. An interesting, though not surprising, result of the increased permeability of the soil is that though the weathering is less, as indicated by the colloid content (table 9), the leaching of that which is produced is greater, as indicated by base content shown in table 11, as compared with tables 3 and 7.

TABLE 11.—Chemical analyses of Hastings silt loam colloids

Sample no.	Horizon	Depth	Colloid extracted	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8079	A <sub>1</sub>	0-6	65	48.81	7.50	20.28	2.37	1.09	1.77
8080	A <sub>2</sub>	6-20	60	49.90	7.50	21.42	2.33	1.02	2.24
8081	B <sub>1</sub>	20-30	84	51.75	7.82	22.40	2.61	1.04	2.26
8082	B <sub>2</sub>	30-43	78	53.41	7.33	22.19	2.87	1.21	2.04
8083	B <sub>3</sub>	43-57	63	54.52	8.21	19.90	3.18	2.00	2.22
8084	B <sub>4</sub>	57-78	65	55.10	8.18	19.51	3.15	2.68	2.30
8085	C	78-108	66	54.79	8.81	19.92	3.10	2.07	2.16

Sample no.	Horizon	Depth	Na <sub>2</sub> O	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	Ignition loss	Total	Organic matter <sup>1</sup>	CO <sub>2</sub> <sup>2</sup>	N
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8079	A <sub>1</sub>	0-6	0.24	0.71	0.09	0.26	0.26	17.25	100.63	7.10	0.58	0.45
8080	A <sub>2</sub>	6-20	.21	.61	.07	.17	.31	14.09	100.47	5.91	.12	.38
8081	B <sub>1</sub>	20-30	.19	.62	.07	.11	.20	11.55	100.62	2.35	.05	.18
8082	B <sub>2</sub>	30-43	.17	.66	.06	.12	.16	10.21	100.43	1.48	.08	.12
8083	B <sub>3</sub>	43-57	.81	1.04	.07	.25	.17	8.95	100.84	1.02	.34	.05
8084	B <sub>4</sub>	57-78	.26	.75	.07	.23	.19	8.68	100.92	.88	.25	.06
8085	C	78-108	.23	.67	.06	.21	.17	8.76	100.68	1.08	.28	.07

<sup>1</sup> Determined by combustion method (CO<sub>2</sub>×0.471).<sup>2</sup> CO<sub>2</sub> of the carbonates.

The essential characteristics of the colloids of the profile are indicated by the derived data shown in table 12.

TABLE 12.—*Derived data: Hastings silt loam colloid*

Sample no.	Horizon	Depth	Molecular ratio					Water of hydration	Combined water of the soil acid <sup>2</sup>
			$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3 \cdot \text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	$\frac{\text{Fe}_2\text{O}_3}{\text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2^1}{\text{Total bases}}$		
		<i>Inches</i>						<i>Percent</i>	<i>Percent</i>
8079	A <sub>1</sub>	0-6	3.30	17.22	4.08	0.237	9.23	9.43	11.98
8080	A <sub>2</sub>	6-20	3.23	17.63	4.17	.224	8.19	8.67	11.20
8081	B <sub>1</sub>	20-30	3.05	17.52	3.92	.223	7.83	9.15	11.40
8082	B <sub>2</sub>	30-43	3.37	19.30	4.08	.212	7.58	8.65	10.92
8083	B <sub>3</sub>	43-57	3.66	17.55	4.62	.263	6.70	7.59	10.23
8084	B <sub>4</sub>	57-78	3.78	17.85	4.79	.268	6.35	7.57	10.55
8085	C	78-108	3.68	17.45	4.66	.267	6.39	7.40	10.06

<sup>1</sup> Carbonates deducted.

<sup>2</sup> Water of hydration plus water equivalent of the bases, corrected for organic matter and carbonate content.

The silica-sesquioxide, silica-alumina, and silica-total base ratios all indicate a sharp transition to colloid characteristic of the C horizon at a depth of 43 inches. This may be taken to mean that the zone of carbonate accumulation has been weathered to practically the same extent as has the C horizon. The increased leaching of the colloid, heretofore mentioned, is shown by the lower silica-sesquioxide and silica-alumina ratios of the Hastings colloid, as compared with the Fillmore (table 4). The leaching effect is accompanied by incipient fractionation of the colloid, as shown by slight alterations in the silica-iron oxide and iron oxide-alumina ratios. On the whole, however, the composition of the colloid is essentially the same throughout the profile, so far as its inorganic negative complex is concerned, and the differences are due to the translocation of colloid as a whole. The silica-total base ratios indicate the slightly more extensive leaching of the bases from the upper horizons. The attention of the reader is again directed to the water relations. The greater leaching of the colloid, despite less water, is shown by the magnitude of the water of hydration, as compared with the corresponding quantities shown by the Fillmore and Crete soils, and corresponds to the assumed existence of a definite soil acid. The water of hydration decreases as the ratio of silica to total base decreases; i.e., with increase of base saturation. When to the water of hydration is added the water equivalent of the bases and these values are corrected for organic matter and calcium carbonate content, the quantities listed in the last column of table 12 are shown. While these quantities are not so constant as those for the Fillmore and Crete soils, they are very important as exceeding by a small margin the maximum content to be expected for montmorillonitic acid (?), though short of the quantities required for pyrophyllitic acid (?). (See General Discussion, p. 37.)

#### THE HOLDREGE PROFILE

The Holdrege silt loam profile reported in tables 13, 14, and 15 was collected in Phelps County, Nebr., still farther west, in a drier area and at a greater elevation than those previously discussed.

TABLE 13.—Mechanical analyses of Holdrege silt loam<sup>1</sup>

Sample no.	Horizon	Depth	Fine gravel (2-1 mm)	Coarse sand (1-0.5 mm)	Medium sand (0.5-0.25 mm)	Fine sand (0.25-0.1 mm)	Very fine sand (0.1-0.05 mm)	Silt (0.05-0.005 mm)	Clay (0.005-0 mm)	Colloid (0.002-0 mm)	Organic matter by H <sub>2</sub> O <sub>2</sub>
		Inches	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
9215	A <sub>1</sub>	0-4	0.0	0.1	0.1	0.2	15.0	59.5	20.7	18.3	3.5
9216	A <sub>1</sub>	4-7	.1	.1	.1	.1	12.0	59.4	24.2	20.5	3.4
9217	A <sub>1</sub>	7-18	.0	.1	.0	.1	10.2	57.2	29.5	26.1	2.4
9218	B <sub>1</sub>	18-30	.1	.1	.1	.1	10.8	50.1	37.4	31.5	.3
9219	B <sub>1</sub>	30-49	.1	.1	.1	.1	13.9	57.7	27.7	22.1	.0
9220	B <sub>2</sub>	49-72	.0	.1	.1	.1	13.8	62.0	23.5	16.7	.0
9221	C	72-95	.1	.1	.1	.2	12.8	64.3	22.1	17.0	.0

<sup>1</sup> Analyses by H. W. Lakin and T. M. Shaw.<sup>2</sup> Organic matter not present in excess of 0.4 percent.

This soil is different from those previously discussed in that it can scarcely be said to have either a distinct hardpan or a zone of carbonate accumulation, though developed from the same parent material.

The mechanical analyses (table 13) indicate a very marked uniformity of texture throughout the profile, the maximum difference in clay content being between the A<sub>1</sub> horizon and the B<sub>1</sub>, and this difference but 11 percent of the whole soil. The decrease in weathering is most sharply indicated by the higher values of the very fine sand content as compared with the soils previously discussed. This relative coarseness is most marked in the A<sub>1</sub> horizon and may have been effected by wind erosion. It would appear that the translocation of the colloid is less, by reason of the lesser rainfall. At the same time, the soil is more permeable and less weathered.

TABLE 14.—Chemical analyses of Holdrege silt loam soil<sup>1</sup>

Sample no.	Horizon	Depth	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
		Inches	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
9215	A <sub>1</sub>	0-4	72.46	1.92	11.58	0.95	1.52	2.46	1.88	0.52
9216	A <sub>1</sub>	4-7	72.52	2.72	10.88	1.03	1.54	2.47	1.76	.55
9217	A <sub>1</sub>	7-18	72.40	3.28	11.76	1.06	1.50	1.92	1.89	.58
9218	B <sub>1</sub>	18-30	68.34	3.54	15.38	1.51	1.69	2.34	1.50	.62
9219	B <sub>1</sub>	30-49	70.76	3.28	13.34	1.57	1.64	2.67	2.68	.52
9220	B <sub>2</sub>	49-72	71.84	3.52	12.90	1.47	2.22	2.27	1.43	.55
9221	C	72-95	70.00	3.68	13.02	1.73	2.40	2.40	2.40	.62

Sample no.	Horizon	Depth	MnO	P <sub>2</sub> O <sub>5</sub>	Ignition loss	SO <sub>3</sub>	Total	CO <sub>2</sub> <sup>2</sup>	N	pH	Soluble salts <sup>3</sup>
		Inches	Percent	Percent	Percent	Percent	Percent	Percent	Percent		Parts per million
9215	A <sub>1</sub>	0-4	0.04	0.18	0.43	0.19	100.13	0.00	0.22	6.8	569
9216	A <sub>1</sub>	4-7	.06	.18	0.13	.18	100.32	.00	.18	7.2	700
9217	A <sub>1</sub>	7-18	.00	.10	5.62	.23	100.46	.00	.15	6.9	440
9218	B <sub>1</sub>	18-30	.05	.17	4.75	.16	100.26	.00	.08	7.1	560
9219	B <sub>1</sub>	30-49	.05	.19	3.55	.15	100.30	.00	.04	7.8	420
9220	B <sub>2</sub>	49-72	.04	.19	3.75	.16	100.34	.22	.03	8.5	1,306
9221	C	72-95	.03	.13	3.61	.15	100.17	.33	.03	8.5	1,200

<sup>1</sup> Determinations (except pH and soluble salts) by J. G. Smith.<sup>2</sup> CO<sub>2</sub> of the carbonates.<sup>3</sup> Determined by bridge method.

The data in table 14 indicate that, while the permeability of the soil has allowed the practically complete removal of calcium carbonate from the profile to a depth of 50 inches and has not resulted in a marked accumulation of carbonate, at least to a depth of 96 inches, the colloid is not excessively leached. The zone of accumulation of soluble salts, as shown by the bridge reading, is, however, immediately beneath the layer which, in an area of greater rainfall, would constitute the claypan. In this soil, as in all the others, the presence of undecomposed feldspars is sharply evident.

TABLE 15.—Chemical analyses of Holdrege silt loam colloid

Sample no.	Horizon	Depth	Colloid extracted	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
9215	A <sub>1</sub>	0-4	59	49.91	7.25	19.32	2.57	1.29	2.69
9216	A <sub>2</sub>	4-7	60	49.55	7.15	19.11	2.33	1.48	2.56
9217	A <sub>3</sub>	7-18	60	50.20	7.61	19.93	2.58	1.45	2.27
9218	B <sub>1</sub>	18-30	75	52.75	7.60	21.45	2.94	1.49	2.39
9219	B <sub>2</sub>	30-49	72	54.10	7.90	19.30	3.19	2.09	2.16
9220	B <sub>3</sub>	49-72	78	54.42	8.20	19.60	3.11	2.54	2.28
9221	C	72-96	64	54.35	8.54	19.45	3.09	2.44	2.37

Sample no.	Horizon	Depth	Na <sub>2</sub> O	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	Ignition loss	Total	Organic matter <sup>1</sup>	CO <sub>2</sub> <sup>2</sup>	N
		<i>Inches</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>
9215	A <sub>1</sub>	0-4	0.18	0.70	0.21	0.28	0.29	15.18	99.93	7.46	0.21	0.51
9216	A <sub>2</sub>	4-7	.25	.54	.14	.16	.33	16.57	100.17	9.11	.10	.55
9217	A <sub>3</sub>	7-18	.24	.64	.16	.29	.27	14.55	100.19	6.33	.00	.41
9218	B <sub>1</sub>	18-30	.21	.69	.12	.20	.21	10.66	100.71	2.37	.18	.16
9219	B <sub>2</sub>	30-49	.50	.73	.11	.26	.34	9.67	100.30	1.62	.23	.17
9220	B <sub>3</sub>	49-72	.34	.75	.10	.24	.24	8.81	100.69	.77	.18	.12
9221	C	72-96	.37	.73	.13	.28	.21	8.93	100.88	1.21	.14	.13

<sup>1</sup> Determined by combustion method (CO<sub>2</sub> × 0.471).

<sup>2</sup> CO<sub>2</sub> of the carbonates.

The data presented in table 15 indicate that considerably more organic matter exists in colloidal form than is the case with either the Hastings or Crete soils. Whether this be a result of the lessened activities of bacteria in a drier area or a result of the differences in grass cover is not to be determined from the data at hand. In almost all other respects the analyses of the Holdrege colloid are strikingly similar to those of the Hastings colloid. The differences which exist are more clearly revealed by the derived data assembled in table 16.

TABLE 16.—Derived data: Holdrege silt loam colloid

Sample no.	Horizon	Depth	Molecular ratio					Water of hydration	Combined water of the soil acid
			SiO <sub>2</sub> Fe <sub>2</sub> O <sub>3</sub> :Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub> Fe:O <sub>3</sub>	SiO <sub>2</sub> Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub> Al <sub>2</sub> O <sub>3</sub>	SiO <sub>3</sub> <sup>1</sup> Total bases		
		<i>Inches</i>						<i>Percent</i>	<i>Percent</i>
9215	A <sub>1</sub>	0-4	3.52	18.24	4.36	0.239	7.37	7.48	10.16
9216	A <sub>2</sub>	4-7	3.55	18.41	4.39	.239	7.26	7.36	10.36
9217	A <sub>3</sub>	7-18	3.43	17.45	4.27	.245	7.06	8.22	11.04
9218	B <sub>1</sub>	18-30	3.39	18.35	4.10	.227	7.04	8.11	10.65
9219	B <sub>2</sub>	30-49	3.77	18.25	4.76	.261	6.31	7.82	10.58
9220	B <sub>3</sub>	49-72	3.70	17.55	4.68	.267	6.10	7.86	10.66
9221	C	72-96	3.70	16.85	4.71	.281	6.10	7.58	10.40

<sup>1</sup> Carbonates deducted.

<sup>2</sup> Water of hydration plus water equivalent of the bases, corrected for organic matter and carbonate content.



The mean value of the silica-sesquioxide ratio in the Holdrege colloid is 3.58, in the Hastings 3.44. The corresponding values for the silica-iron oxide ratios are 17.87 and 17.80, respectively, and for the silica-alumina ratios 4.76 and 4.33, respectively. These all indicate less leaching of the Holdrege profile. This indication is also furnished by smaller numerical values of the silica-total base ratios of the upper layers of the profile. The silica-iron oxide ratios and the iron oxide-alumina ratios of the three A horizons compared with those for the B<sub>1</sub> horizon show but the faintest trace of fractionation of the colloid. The translocation of colloid from the surface downward is of the colloid as a whole. The combined water of the soil acid indicates essentially constant composition of the colloid.

## THE KEITH PROFILE

The analyses of the Keith profile are given in tables 17, 18, and 19. These samples were collected in Dundy County, Nebr., where the annual rainfall is approximately 18 inches. The chestnut-brown soil which develops is essentially free from claypan but has a normal development of a zone of carbonate accumulation, whereas the Fillmore soil, under a rainfall of 32 inches, develops a very marked claypan and carbonate layer. The intermediate soils show claypan development and less marked carbonate accumulations.

TABLE 17.—Mechanical analyses of Keith silt loam<sup>1</sup>

Sample no.	Horizon <sup>1</sup>	Depth	Fine gravel (3-1 mm)	Coarse sand (1-0.5 mm)	Medium sand (0.5-0.25 mm)	Fine sand (0.25-0.1 mm)	Very fine sand (0.1-0.05 mm)	Silt (0.05-0.005 mm)	Clay (0.005-0 mm)	Colloid (0.002-0 mm)	Organic matter by H <sub>2</sub> O <sub>3</sub>
		Inches	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
9222	A <sub>1</sub>	0 - 3½	0.1	0.1	0.1	0.4	31.2	47.4	18.4	18.2	1.8
9223	A <sub>2</sub>	3½ - 3½	.1	.2	.1	.4	26.6	47.8	22.8	20.0	1.2
9224	B <sub>1</sub>	3½ - 14	.1	.1	.0	.3	24.9	46.4	26.4	22.2	1.3
9225	B <sub>2</sub>	14 - 21	.1	.1	.1	.3	23.5	48.2	26.8	23.7	.5
9226	5	21 - 33	.0	.1	.1	.3	25.4	44.5	28.8	24.4	.1
9227	6	33 - 40	.0	.0	.0	.3	26.7	47.6	24.8	18.1	.0
9228	7	40 - 48	.0	.0	.0	.3	29.3	48.6	21.2	16.1	.0
9229	8	48 - 72	.0	.0	.1	.2	30.5	50.4	18.3	13.2	.0
9230	9	72 - 96	.0	.0	.1	.2	31.6	49.8	17.6	13.2	.0

<sup>1</sup> Determinations by H. W. Lakin and T. M. Shaw.

<sup>2</sup> C horizons not distinguishable in the field.

<sup>3</sup> Organic matter not present in excess of 0.4 percent.

In this soil the horizontal development is indistinct, even in the upper part, and quite markedly so at lower depths. However, the samples are marked A<sub>1</sub>, A<sub>2</sub>, B<sub>1</sub>, and B<sub>2</sub> for the upper part, and the lower samples are simply numbered. Table 17, when compared with table 13, reveals definite differences between the Keith and Holdrege soils. The Keith has a much higher very fine sand fraction and definite quantities of fine sand. The silt and clay together make up only about two thirds of the surface layer, and the colloid content is low. Surface removal of colloid is indicated, and wind erosion is a possible cause. Certainly only a relatively small concentration of colloid in the lower strata is to be noted.

TABLE 18.—Chemical analyses of Keith silt loam soil<sup>1</sup>

Sample no.	Horizon <sup>2</sup>	Depth	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
9222	A <sub>1</sub>	0 - 1½	72.82	3.04	19.86	1.06	1.86	2.48	2.35	0.60
9223	A <sub>2</sub>	1½ - 3½	71.00	3.44	11.66	1.17	1.88	2.34	2.23	.60
9224	B <sub>1</sub>	3½ - 14	71.10	3.60	12.02	1.26	1.88	2.32	2.10	.64
9225	B <sub>2</sub>	14 - 21	71.46	3.92	11.88	1.44	2.08	2.28	2.15	.64
9226	5	21 - 33	68.22	3.60	12.00	1.85	3.94	2.62	1.92	.58
9227	6	33 - 40	64.80	3.68	11.84	1.66	6.14	2.45	1.42	.60
9228	7	40 - 48	65.82	3.36	11.84	1.63	5.44	2.48	1.89	.58
9229	8	48 - 72	68.68	3.36	11.88	1.67	4.30	1.98	1.06	.57
9230	9	72 - 96	69.36	3.36	11.42	1.63	4.46	2.51	1.38	.58

Sample no.	Horizon <sup>2</sup>	Depth	MnO	P <sub>2</sub> O <sub>5</sub>	Ignition loss	SO <sub>3</sub>	Total	CO <sub>2</sub> <sup>3</sup>	N	pH	Soluble salts <sup>4</sup>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>		<i>Parts per million</i>
9222	A <sub>1</sub>	0 - 1½	0.02	0.10	4.63	0.16	99.98	0.05	0.14	7.4	580
9223	A <sub>2</sub>	1½ - 3½	.03	.11	5.55	.14	100.15	.03	.17	7.4	500
9224	B <sub>1</sub>	3½ - 14	.03	.09	4.70	.18	99.92	.03	.12	7.0	400
9225	B <sub>2</sub>	14 - 21	.04	.09	3.90	.20	100.06	.10	.09	8.2	1,160
9226	5	21 - 33	.03	.08	4.94	.24	100.02	1.48	.09	8.5	1,400
9227	6	33 - 40	.05	.19	6.98	.15	99.95	3.83	.05	8.4	1,480
9228	7	40 - 48	.05	.18	6.33	.30	100.00	3.04	.04	8.5	1,460
9229	8	48 - 72	.07	.16	5.34	.23	100.27	2.42	.03	8.8	1,460
9230	9	72 - 96	.05	.16	5.08	.16	100.15	2.24	.03	8.8	1,400

<sup>1</sup> Determinations (except pH and soluble salts) by J. G. Smith.<sup>2</sup> C horizons not distinguishable in the field.<sup>3</sup> CO<sub>2</sub> of the carbonates.<sup>4</sup> Determined by bridge method.

TABLE 19.—Chemical analyses of Keith silt loam colloid

Sample no.	Horizon <sup>1</sup>	Depth	Colloid extracted	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
9222	A <sub>1</sub>	0 - 1½	46	51.92	6.92	19.13	3.00	2.12	2.42
9223	A <sub>2</sub>	1½ - 3½	46	51.45	6.92	18.61	2.84	2.21	2.41
9224	B <sub>1</sub>	3½ - 14	79	51.80	7.13	19.67	3.07	2.70	2.38
9225	B <sub>2</sub>	14 - 21	76	53.00	7.22	20.40	3.37	1.93	2.34
9226	5	21 - 33	87	47.80	6.19	17.88	3.51	7.69	2.16
9227	6	33 - 40	89	43.60	8.38	18.62	4.31	11.92	1.82
9228	7	40 - 48	68	46.00	5.77	17.58	3.39	9.72	1.91
9229	8	48 - 72	92	40.50	6.45	19.09	3.48	6.54	2.12
9230	9	72 - 96	90	52.61	6.98	19.75	3.52	3.93	2.21

Sample no.	Horizon <sup>1</sup>	Depth	Na <sub>2</sub> O	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	Ignition loss	Total	Organic matter <sup>2</sup>	CO <sub>2</sub> <sup>3</sup>	N
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
9222	A <sub>1</sub>	0 - 1½	0.14	0.66	0.19	0.29	0.28	13.43	100.60	5.32	0.66	0.37
9223	A <sub>2</sub>	1½ - 3½	.29	.71	.22	.36	.25	14.38	100.45	6.32	.69	.48
9224	B <sub>1</sub>	3½ - 14	.28	.72	.13	.22	.24	13.65	101.34	5.68	.69	.31
9225	B <sub>2</sub>	14 - 21	.15	.67	.08	.11	.16	11.69	100.91	2.98	.22	.23
9226	5	21 - 33	.43	.54	.09	.27	.17	13.94	100.57	1.67	4.71	.16
9227	6	33 - 40	.37	.51	.11	.26	.15	16.70	100.70	1.75	8.34	.14
9228	7	40 - 48	.39	.52	.12	.23	.13	15.03	100.79	1.86	6.46	.08
9229	8	48 - 72	.38	.50	.11	.20	.13	12.33	100.89	1.21	3.58	.13
9230	9	72 - 96	.34	.66	.09	.21	.14	10.71	100.85	.89	1.32	.10

<sup>1</sup> C horizons not distinguishable in the field.<sup>2</sup> Determined by combustion method (CO<sub>2</sub>×0.471).<sup>3</sup> CO<sub>2</sub> of the carbonates.

The data given in table 17 show in the layer, 3½ to 14 inches, incipient claypan structure, and there is a corresponding increase of the water-soluble salts in the next lower stratum (table 18). In the fifth and sixth layers is found the zone of carbonate accumulation. The whole profile indicates a very low degree of weathering and also of leaching. The high pH values and low loss on ignition are both indicative of these facts. The relatively unweathered state is also indicated by the mechanical analyses and by the high potassium and sodium content. Abundant feldspar content is evident.

The organic-matter content of the colloid (table 19) is less in the Keith soil than in its neighbor, the Holdrege, but to what extent this is due to better oxidation or less abundant vegetation is not evident. Low organic content is characteristic of chestnut-brown soils. The colloid composition is uniform throughout the profile except for the increased content of organic matter and sulphur in the upper strata and of carbonate in the lower part. It is again evident that translocation of colloid is as a whole to whatever extent it has occurred. The derived data on this profile are given in table 20.

TABLE 20.—Derived data: Keith silt loam colloid

Sample no.	Horizon <sup>1</sup>	Depth	Molecular ratio					Water of hydration	Combined water of the soil acid <sup>3</sup>
			$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	$\frac{\text{Fe}_2\text{O}_3}{\text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2^2}{\text{Total bases}}$		
		Inches						Percent	Percent
9222	A <sub>1</sub>	0 - 2½	3.74	19.91	4.61	0.229	5.14	8.07	11.22
9223	A <sub>2</sub>	2½ - 3½	3.78	19.70	4.08	.235	6.41	7.97	11.08
9224	B <sub>1</sub>	3½ - 14	2.62	19.21	4.46	.232	5.59	7.37	10.74
9225	B <sub>2</sub>	14 - 21	3.58	19.44	4.58	.225	6.06	7.89	10.74
9226	5	21 - 33	3.71	20.44	4.53	.222	5.51	7.55	11.57
9227	6	33 - 40	3.69	21.52	4.48	.207	5.53	6.61	11.41
9228	7	40 - 48	3.67	21.13	4.43	.210	5.55	6.73	11.05
9229	8	48 - 72	3.61	20.32	4.40	.216	5.45	7.56	11.43
9230	9	72 - 96	3.72	21.02	4.52	.215	5.77	8.50	11.57

<sup>1</sup> C horizons not well defined.

<sup>2</sup> Carbonates deducted.

<sup>3</sup> Water of hydration plus water equivalent of the bases, corrected for organic matter and carbonate content.

The somewhat high silica-sesquioxide and silica-alumina ratios of the first two layers give ground for suspicion of the presence of silica or feldspathic silicates of colloidal size, but even if present the remaining data indicate that the quantity is small. The silica-iron oxide and ferric oxide-alumina ratios of the first and second layers, compared with the corresponding values for the third and fourth, indicate but a faint trace of fractionation. The silica-total base ratios average 5.78 for the entire profile and are the lowest for any of the soils examined. These values, as well as the pH values for the whole soil, indicate that leaching has not been extensive. The combined water of the soil acids, when corrected for organic matter and carbonates present, is so nearly a constant value for all horizons as to leave little reason for doubt that a soil inorganic acid of essentially constant composition is present.

#### THE PHILLIPS PROFILE

As mentioned in the description of the samples, the Phillips profile has a well-developed claypan, and yet the mean annual rainfall is less and the temperature lower than in the Keith area where the claypan

is absent. There is an essential difference in the parent material which, under the Phillips soils, is glacial drift. Moreover, the soil is a sandy loam, whereas the others reported are silt loams. In this area the high winds produce sufficient erosion on the sparsely grassed areas to remove the surface soils and produce so-called "slick spots." The analytical data on this profile are given in tables 21, 22, and 23.

TABLE 21.—Mechanical analyses of Phillips sandy loam<sup>1</sup>

Sample no.	Horizon	Depth	Fine gravel (2-1 mm)	Coarse sand (1-0.5 mm)	Medium sand (0.5-0.25 mm)	Fine sand (0.25-0.1 mm)	Very fine sand (0.1-0.05 mm)	Silt (0.05-0.005 mm)	Clay (0.005-0 mm)	Colloid (0.002-0 mm)	Organic matter by H <sub>2</sub> O <sub>2</sub>
		Inches	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
8749	A <sub>1</sub>	0-1½	1.4	3.5	4.1	10.2	17.8	38.9	18.6	12.9	4.9
8750	A <sub>2</sub>	1½-4	1.3	3.2	4.2	10.9	19.5	39.4	19.5	13.2	1.3
8751	B <sub>1</sub>	4-9	1.4	2.8	3.0	11.1	18.2	34.8	28.8	19.7	1.5
8752	B <sub>2</sub>	9-19	1.4	1.5	2.1	5.4	12.3	40.7	36.5	31.0	1.5
8753	B <sub>3</sub>	19-30	.6	1.2	2.3	8.1	19.1	33.2	35.0	27.2	1.0
8754	B <sub>4</sub>	30-54	1.0	2.5	3.9	13.9	20.4	27.4	30.2	24.1	1.0
8754-A	C	54-64	1.3	3.7	5.8	13.4	15.4	31.0	28.9	21.6	1.0

<sup>1</sup> Determinations by H. W. Lakin and T. M. Shaw.

<sup>2</sup> Organic matter not present in excess of 0.4 percent.

Table 21, the mechanical analyses, shows that the sandy character of the surface layer persists throughout the profile and indeed becomes somewhat coarser, colloid content being considered, as the depth increases. The silt and clay content nowhere exceeds 60 percent. Marked eluviation of colloid from the A horizons and concentration in the B horizons is apparent. The B horizon in which the greatest concentration of colloid appears (B<sub>2</sub>) is the point at which the soil becomes alkaline (table 22). Immediately beneath this layer the content of soluble salts, as determined by the bridge reading, becomes considerable, and the pH values rise sharply, becoming the highest of any of the profiles examined. If the original soil material at the surface had the same composition aside from the colloid, the cause of the deposition of the hardpan would appear to be the flocculation and consequent deposition of colloid, which ultimately by filtration of finer colloid, as the surface became leached, resulted in a practically impervious layer. That this original material contained sulphates is not indicated by the analyses, but an examination of the water-soluble material from the B<sub>2</sub> horizon shows the presence of 39 parts per million of sulphur trioxide and 339 parts per million of chlorine. The C horizon shows 159 parts per million of soluble sulphur trioxide and but 85 parts per million of chlorine. It would appear, therefore, that small as is this alkali-salt content, to it is to be ascribed the claypan deposition. The part played by alkali in the "freezing up" of soils under irrigation has been described by McGeorge, Breazeale, and Burgess (17). It does not follow that their conclusions concerning the role of aluminum hydroxide in the process are valid. The soil analyses indicate by their high potassium and sodium content the presence of much undecomposed feldspars. The high silica content of the profile indicates the presence of free quartz.

TABLE 22.—Chemical analyses of Phillips sandy loam soil

Sample no.	Horizon	Depth	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8749 <sup>1</sup>	A <sub>1</sub>	0 - 1½	73.60	2.80	9.44	0.63	1.18	1.80	1.80	0.45
8750 <sup>1</sup>	A <sub>2</sub>	1½ - 4	75.54	2.80	10.24	.72	1.12	1.94	2.48	.48
8751 <sup>1</sup>	B <sub>1</sub>	4 - 9	74.64	3.34	11.54	.91	1.06	2.06	1.84	.50
8752 <sup>1</sup>	B <sub>2</sub>	9 - 19	70.12	4.41	12.85	2.23	1.15	2.14	1.87	.54
8753 <sup>1</sup>	B <sub>3</sub>	19 - 36	64.66	8.84	11.70	1.48	6.98	1.84	1.81	.46
8754 <sup>1</sup>	B <sub>4</sub>	36 - 54	65.34	4.32	11.50	2.20	6.14	1.83	2.00	.45
8754A <sup>1</sup>	C	54 - 64	69.49	3.31	10.38	2.08	4.27	1.77	1.30	.50

Sample no.	Horizon	Depth	MnO	P <sub>2</sub> O <sub>5</sub>	Ignition loss	SO <sub>2</sub>	Total	CO <sub>2</sub> <sup>1</sup>	N	pH	Soluble salts <sup>2</sup>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>			<i>Parts per million</i>
8749 <sup>1</sup>	A <sub>1</sub>	0 - 1½	0.05	0.16	8.15	0.16	100.27	6.00	0.25	6.1	340
8750 <sup>1</sup>	A <sub>2</sub>	1½ - 4	.05	.15	4.50	.17	100.17	.00	.15	6.2	<298
8751 <sup>1</sup>	B <sub>1</sub>	4 - 9	.03	.11	3.85	.20	100.08	.00	.10	6.5	<298
8752 <sup>1</sup>	B <sub>2</sub>	9 - 19	.08	.13	4.62	.18	100.31	.00	.09	7.4	<298
8753 <sup>1</sup>	B <sub>3</sub>	19 - 36	.04	.17	8.04	.16	100.18	4.00	.04	9.4	1,460
8754 <sup>1</sup>	B <sub>4</sub>	36 - 54	.04	.16	6.10	.14	100.23	2.73	.03	9.1	1,520
8754A <sup>1</sup>	C	54 - 64	.08	.13	6.40	.13	99.84	3.60	.03	10.0	1,980

<sup>1</sup> Determinations (except pH and soluble salts) by J. G. Smith.<sup>2</sup> Determinations (except pH and soluble salts) by G. Edgington.<sup>3</sup> CO<sub>2</sub> of the carbonates.<sup>4</sup> Determined by bridge method.

TABLE 23.—Chemical analyses of Phillips sandy loam colloid

Sample no.	Horizon	Depth	Colloid extracted	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8746	A <sub>1</sub>	0 - 1½	51	49.45	8.02	18.82	2.06	1.09	2.45	0.29
8750	A <sub>2</sub>	1½ - 4	60	50.05	8.24	19.22	2.20	.94	2.69	.17
8751	B <sub>1</sub>	4 - 9	63	51.31	8.88	21.03	1.93	.84	2.15	.64
8752	B <sub>2</sub>	9 - 19	84	51.95	9.18	20.91	3.16	.82	2.30	.23
8753	B <sub>3</sub>	19 - 36	95	51.10	9.20	20.97	3.21	2.30	1.57	.73
8754	B <sub>4</sub>	36 - 54	74	52.45	8.32	20.21	3.38	2.95	1.74	.15
8754A	C	54 - 64	75	51.42	8.31	20.80	3.24	2.59	1.83	.48

Sample no.	Horizon	Depth	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	SO <sub>2</sub>	Ignition loss	Total	Organic matter <sup>1</sup>	CO <sub>2</sub> <sup>1</sup>	N
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
8749	A <sub>1</sub>	0 - 1½	0.80	0.15	0.61	0.40	16.69	100.76	10.30	0.12	0.80
8750	A <sub>2</sub>	1½ - 4	.80	.14	.43	.31	14.83	100.11	7.46	.06	.69
8751	B <sub>1</sub>	4 - 9	.82	.09	.26	.22	11.96	100.13	4.10	.12	.35
8752	B <sub>2</sub>	9 - 19	.63	.00	.17	.21	10.83	100.45	2.59	.04	.21
8753	B <sub>3</sub>	19 - 36	.73	.07	.15	.19	10.76	100.98	2.65	.88	.20
8754	B <sub>4</sub>	36 - 54	.73	.06	.19	.14	10.15	100.48	1.37	1.48	.11
8754A	C	54 - 64	.69	.05	.08	.18	10.20	100.56	1.56	1.49	.11

<sup>1</sup> Determined by the combustion method (CO<sub>2</sub>×0.471).<sup>2</sup> CO<sub>2</sub> of the carbonates.

The analyses of the colloid (table 23) indicates the association of the sulphur and phosphorus content with the organic matter, and the persistence of organic matter throughout the profile is an indication of the slow development of the claypan. The high content of carbonates shown by the soil analyses in horizons B<sub>3</sub>, B<sub>4</sub>, and C, when contrasted with the low relative carbonate content of the extracted colloid, indicates coarse carbonates, as compared with the Nebraska silt loam soils. The organic and carbonate content being considered,

the gross analyses themselves indicate a very uniform type of colloid and that its concentration in the B horizon has been without serious fractionation, so far as the inorganic part, at least, is concerned. These relations are more clearly presented by the derived data given in table 24.

TABLE 24.—*Derived data: Phillips sandy loam colloid*

Sample no.	Horizon	Depth	Molecular ratio					Water of hydration	Combined water of the soil acid <sup>2</sup>
			$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3 \cdot \text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	$\frac{\text{Fe}_2\text{O}_3}{\text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2^1}{\text{Total bases}}$		
		<i>Inches</i>						<i>Percent</i>	<i>Percent</i>
8749	A	0 - 1½	3.59	16.34	4.58	0.282	8.12	6.27	9.05
8750	A	1½ - 4	3.46	16.08	4.41	.274	7.46	7.31	10.09
8751	B <sub>1</sub>	4 - 9	3.28	15.32	4.14	.275	8.94	7.74	9.91
8752	B <sub>2</sub>	9 - 19	3.28	14.90	4.21	.281	7.16	8.20	10.60
8753	B <sub>3</sub>	19 - 36	3.24	14.71	4.13	.281	6.64	7.25	10.60
8754	B <sub>4</sub>	36 - 54	3.70	16.70	4.40	.264	7.02	7.30	10.00
8754-A	C	54 - 64	3.29	15.27	4.19	.274	7.12	7.24	10.13

<sup>1</sup> Carbonates deducted.

<sup>2</sup> Water of hydration plus water equivalent of the bases, corrected for organic matter and carbonate content.

The silica-sesquioxide and silica-alumina ratios, when considered in the light of the possible presence of secondary quartz and undecomposed minerals, are fairly uniform and average for the profile 3.41 and 4.30, respectively. The silica-iron oxide ratios, taken alone, might be considered as indicating incipient podzolization, but even this degree of fractionation is not wholly confirmed by the iron oxide-alumina ratios. One might, by using sufficient imagination, visualize the process as producing after a sufficiently long interval, a kind of gray layer in place of the A<sub>2</sub> and B<sub>1</sub> layers. If so, the process must be very slow. The silica-total base ratio indicates considerable leaching of the upper three horizons. The combined water of the soil acid has an average value of 9.87 percent, which is essentially the same as for the Fillmore profile.

#### THE FARGO PROFILE

The profile of Fargo clay, which is detailed in tables 25, 26, and 27, was collected in Wilkin County, Minn., across the Red River from Wahpeton, N.Dak. It is not a continuous profile. The transitional zones between A<sub>2</sub> and B and between B and C were omitted by the collector. The Fargo soils contain a larger soluble-salt content in the whole profile than the Phillips soils of Montana. The dominant soils of the area are, in general, not strictly claypan soils, but in the slight depressions below the general level a pronounced dense claypan appears. The annual rainfall of the area is 21.5 inches, and in the depressions the water available for weathering and profile development is in excess of this amount. The soil parent material, being a lacustrine deposit, was doubtless much weathered before profile development began. Also, as the glacial Lake Agassiz disappeared the soil material was doubtless impregnated with soluble salts. The present condition is thus, perhaps, analagous to the result of long-continued irrigation. There is no certainty that the parent material was uniform in character; but, since deep lake deposits are usually uniform in texture, it may be assumed that they were so in this case.

TABLE 25.—*Mechanical analyses of Fargo clay*<sup>1</sup>

Sample no.	Horizon	Depth	Fine gravel (2-1 mm)	Coarse sand (1-0.5 mm)	Medium sand (0.5-0.25 mm)	Fine sand (0.25 -0.1 mm)	Very fine sand (0.1-0.05 mm)	Silt (0.05-0.005 mm)	Clay (0.005-0 mm)	Colloid (0.002-0 mm)	Organic matter by H <sub>2</sub> O <sub>4</sub>
			Inches 0-6 6-10 12-20 32-48	Pct. 0.4 1.7 .6 .4	Pct. 1.6 2.8 1.5 1.1	Pct. 2.5 3.5 2.1 1.2	Pct. 9.7 13.8 7.8 5.8	Pct. 4.7 6.5 3.6 1.8	Pct. 29.1 31.2 10.7 15.2	Pct. 42.2 38.7 72.3 74.2	
106	A <sub>1</sub>	0-6									0.2
107	A <sub>2</sub>	6-10									1.4
108	B	12-20									7
109	C	32-48									9

<sup>1</sup> Determinations by H. W. Lakin and T. M. Shaw.

The process of soil formation, if the profile was originally uniform, has resulted in tremendous differentiation. The sands and silt are very much higher in the A horizons than in the B and C, and there is a sharp difference between A<sub>1</sub> and A<sub>2</sub>. This relation is characteristic of podzol soils. The thick and very dense claypan shows, however, no tendency toward the production of a true hardpan, or ortstein, layer, and the clay and colloid content of the B layer are essentially the same as in the parent material. This condition is not normal for podzol soils. The organic content of the A<sub>1</sub> horizon is high; that of the A<sub>2</sub> is much lower. This is a podzol characteristic. The B horizon is also low in organic matter. This is not true of the normal humid podzols.

TABLE 26.—*Chemical analyses of Fargo clay soil*

Sample no.	Horizon	Depth	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
		Inches	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
106	A <sub>1</sub>	0-6	69.92	2.37	9.22	1.05	0.97	1.63	0.93	0.80
107	A <sub>2</sub>	6-10	79.59	2.91	8.04	.74	.81	1.93	1.37	.83
108	B	12-20	66.70	5.28	14.74	2.38	.72	1.85	.76	.81
109	C	32-48	57.30	4.55	13.72	3.00	6.83	2.04	.83	.78

Sample no.	Horizon	Depth	MnO	P <sub>2</sub> O <sub>5</sub>	Ignition loss	SO <sub>2</sub>	Total	CO <sub>2</sub> <sup>1</sup>	N	pH	Soluble salts <sup>1</sup>
		Inches	Percent	Percent	Percent	Percent	Percent	Percent	Percent		Parts per million
106	A <sub>1</sub>	0-6	0.09	0.15	12.49	0.17	99.79	0.16	(2)	6.3	1,060
107	A <sub>2</sub>	6-10	.11	.05	3.28	.06	99.72	.08	(2)	7.5	460
108	B	12-20	.10	.07	6.09	.13	99.61	.19	(2)	7.9	600
109	C	32-48	.13	.12	8.97	1.79	100.06	4.64	(2)	8.3	12,060

<sup>1</sup> CO<sub>2</sub> of the carbonates.<sup>2</sup> Determined by bridge method.<sup>3</sup> Not determined.

The chemical examination of the whole soil (table 26) reveals some important facts. The silica content, allowance being made for the high ignition loss, is tremendously higher in the A horizons than in the B horizon; whereas, when account is taken of the carbonates and sulphates in the C horizon, the silica contents in the B and C horizons are of similar magnitude, being 71.2 percent for the B horizon and 71.5 percent for the C. The eluviation of carbonates from the A and B horizons is essentially complete. The high magnesium content of the B and C horizons may be taken to indicate that the carbonates are somewhat dolomitic. The limitation of the leaching of the soil is

definitely marked. The exceedingly sudden and enormous increase of soluble salts in the C horizon may be taken to mean that the B horizon is essentially impermeable to water and that, therefore, drainage must be either from the surface of the soil or from the surface of the B horizon. The soluble salts were examined and shown to consist almost wholly of calcium and magnesium sulphates, about 10,000 parts per million of the dry soil. The chloride content does not exceed 400 parts per million.

TABLE 27.—Chemical analyses of Fargo clay colloid

Sample no.	Horizon	Depth	Colloid extracted	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
106	A <sub>1</sub>	0-6	75	49.25	11.38	11.40	2.61	1.95	1.97	0.33
107	A <sub>2</sub>	6-10	41	61.20	4.74	16.66	2.13	1.07	2.61	.71
108	B	12-20	75	54.69	7.07	21.73	3.52	.76	1.82	.40
109	C	32-48	61	54.50	8.88	19.02	3.13	2.95	1.93	.34

Sample no.	Horizon	Depth	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	Ignition loss	Total	Organic matter <sup>1</sup>	CO <sub>2</sub> <sup>2</sup>	N
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
106	A <sub>1</sub>	0-6	0.97	0.05	0.33	0.32	20.61	101.17	14.41	0.07	0.81
107	A <sub>2</sub>	6-10	1.04	.04	.12	.23	10.32	100.87	6.95	.07	.74
108	B	12-20	.79	.03	.11	.16	9.58	100.56	3.02	.09	.16
109	C	32-48	.81	.05	.12	.14	8.99	100.23	2.93	.85	(?)

<sup>1</sup> By combustion method (CO<sub>2</sub>×0.471).

<sup>2</sup> CO<sub>2</sub> of the carbonates.

<sup>3</sup> Not determined.

The chemical analyses of the colloid (table 27) indicate relatively little colloidal carbonates and lead to the conclusion that the carbon dioxide of the soil of the B and C horizons is largely residual. This conclusion is in harmony with the arid soil characteristics of the C horizon. The derived data in table 28 reveal several important features of the profile.

TABLE 28.—Derived data: Fargo clay colloid

Sample no.	Horizon	Depth	Molecular ratio					Water of hydration	Combined water of the soil acid <sup>2</sup>
			SiO <sub>2</sub> Fe <sub>2</sub> O <sub>3</sub> ·Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub> Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub> Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub> Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub> <sup>1</sup> Total bases		
		<i>Inches</i>						<i>Percent</i>	<i>Percent</i>
106	A <sub>1</sub>	0-6	4.48	11.53	7.35	0.539	4.75	8.13	10.60
107	A <sub>2</sub>	6-10	5.40	34.63	6.42	.188	9.28	3.30	5.67
108	B	12-20	3.53	20.47	4.27	.208	7.01	6.52	9.12
109	C	32-48	3.73	19.73	4.84	.296	6.09	5.16	8.28

<sup>1</sup> Carbonates deducted.

<sup>2</sup> Water of hydration plus water equivalent of the bases corrected for organic matter and carbonate content.

The very high silica-sesquioxide ratio of the A<sub>1</sub> horizon, the still higher value for the A<sub>2</sub>, and the correspondingly high silica-alumina ratios clearly indicate the presence of colloidal free silica. The relatively high iron oxide content of the A<sub>1</sub> horizon, together with the high organic matter, when taken into consideration with the low iron



oxide in the  $A_2$  horizon, leads to an interesting conclusion. The removal of iron oxide and alumina has not been by transference to the B horizon but has been accomplished chiefly by lateral erosion. This conclusion is supported by the iron-alumina ratio which is very slightly greater in the B horizon than in the  $A_2$  and is still greater in the C. This relation, together with the silica-iron oxide ratio, would indicate that even the B horizon has been somewhat eluviated, so far as its iron content is concerned. This conclusion accords also with the fact that in slight depressions this soil must, during rainy periods, be swampy and therefore subject to anaerobic fermentation, as shown by Robinson (27), with consequent reduction of iron to the ferrous state and its removal by drainage above and not through the claypan. Under such circumstances the chalybeate water at the surface would be oxidized and deposited with humus material. This assumed process accounts for the relatively high iron content of the  $A_1$  horizon. The holding power of humified matter for ferric iron has been recently emphasized by Horner, Burk, and Hoover.<sup>2</sup>

The immense base-holding capacity of organic matter and the transfer of bases by grass cover are emphasized by the low silica-total base ratio of the  $A_1$  horizon. The wide difference between this value for the  $A_1$  and  $A_2$  horizons is indicative of the intermittently swampy character of these claypan spots.

The water of hydration and the total combined water of the soil acid are interesting even if not readily explicable. The low experimental value and the calculated value for the parent material are both lower than is to be expected were the colloid derived from trisilicates, as appears to be the case with the  $A_1$  horizon. There is nothing abnormal in the fact that these quantities for the B horizon are similar to those of the parent material, since the indications are that but little transfer of material downward has occurred. It must be noted, however, that in the  $A_1$  horizon the calculated value of the combined water of the soil acid includes the water equivalent of the bases which are associated with the organic matter. This introduces a considerable degree of possible error where the organic matter is high.

On the whole, the profile examination indicates that this soil has developed on a saline clay nearly impervious to water and that by eluviation of fine material the present B horizon has been produced with but little downward transportation of material. It seems clear that the apparent podzolization of the surface soil has been produced by lateral erosion aided by anaerobic fermentation and consequent solution and removal of the iron component of the clay. At the same time, leaching of calcium and magnesium has occurred to a marked degree. Whether there has been any actual removal of colloid as a whole by lateral translocation may not be inferred from the data. This kind of podzolization would appear to be a common process by which a light-colored layer (bleicherde) may be produced, and it may be that the so-called "sandy podzols" of the areas of low rainfall are of this character. There is not sufficient information available at present to decide the question, but it is well worth careful investigation. It appears certain from this profile and from other fragmentary and unpublished data that there is a definite distinction between a

<sup>2</sup> HORNER, C. R., BURK, D., and HOOVER, E. R. PREPARATION OF HUMATE OF IRON AND OTHER HUMATE METALS. *Plant Physiol.* (In press.)

profile of the character of this one and the podzols of the cold and humid areas to which the term is ordinarily applied. Whether a new term should be used to describe them remains to be seen.

Other than for this variation in leaching, the soil colloid developed on the Fargo parent material appears to be the same as that developed on the loess in Nebraska and on glacial drift in Montana, under the same general climatic conditions.

#### THE McLEANSBORO PROFILE

As mentioned in the introduction, a development of claypan on level areas is not confined to regions of low rainfall. It seemed desirable to include in the present study a profile developed under climatically different conditions but which otherwise is similar to the claypan soils of Nebraska. A profile from southern Illinois was selected. It is developed on level areas, with high rainfall and at a mean annual temperature much higher than in Nebraska. The analytical data are presented in tables 29, 30, and 31.

TABLE 29.—*Mechanical analyses of McLeansboro silt loam*<sup>1</sup>

Sample no.	Horizon	Depth	Fine gravel (2-1 mm)	Coarse sand (1-0.5 mm)	Medium sand (0.5-0.25 mm)	Fine sand (0.25-0.1 mm)	Very fine sand (0.1-0.05 mm)	Silt (0.05-0.005 mm)	Clay (0.005-0 mm)	Colloid (0.002-0 mm)	Organic matter by H <sub>2</sub> O <sub>2</sub>
		Inches	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
10331	A <sub>1</sub>	0-8	0.9	2.0	1.6	2.2	2.7	36.7	23.3	19.5	0.4
10332	A <sub>1</sub>	8-12	.7	1.6	1.2	1.6	2.0	32.5	29.7	21.6	
10333	B <sub>1</sub>	12-16	.2	.8	.8	1.2	1.4	52.1	43.0	35.8	.2
10334	B <sub>2</sub>	16-19	.2	.7	.8	1.4	1.6	51.5	43.4	35.3	1.0
10335	B <sub>2</sub>	19-25	.2	.6	.9	1.7	1.8	48.6	45.7	38.6	.1
10336	C	26+	.4	1.0	1.3	2.2	2.5	60.5	31.7	25.1	1.0

<sup>1</sup>Determinations by H. W. Lakin and T. M. Shaw.

<sup>2</sup>Organic matter not present in excess of 0.4 percent.

The mechanical analyses (table 29) indicate that this profile, like those in Nebraska, consists largely of silt and clay, and that the hardpan layers are very definitely developed. The B<sub>1</sub> horizon is essentially the same as B<sub>2</sub>, except that it includes the rounded tops of the columnar clay with a whitish podzolized very thin crust. The mechanical texture is the same as in B<sub>2</sub>, except for a slightly increased silt content. The high clay and colloid content of the parent material indicates either transfer of colloid into it or formation of colloid in place. Yet there is material translocation of colloid from the A horizon to the B horizons, as indicated by an alteration ranging from less than 30 percent in the A horizons to more than 40 percent in the B horizons.

The chemical analyses of the profile indicate severe leaching through the whole profile so far as it is examined. This is shown by the total absence of carbonates and by the pH values obtained (table 30), as well as by the soluble-salt content. It is therefore impossible to say, from the data, whether the material originally was saline, although the character of the claypan indicates that condition. Despite the extensive weathering, the soil still contains undecomposed feldspars, as is indicated by the contrast between the sodium content of the soil and of the colloid (table 31). The chief component of the sands and silt is obviously quartz.

TABLE 30.—Chemical analyses of McLeansboro silt loam soil<sup>1</sup>

Sample no.	Horizon	Depth	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
10331	A <sub>1</sub>	0-8	80.59	3.34	8.03	0.53	0.45	1.26	0.90	0.90
10332	A <sub>2</sub>	8-12	78.09	4.26	10.18	.61	.46	1.36	1.06	.91
10333	B <sub>1</sub>	12-16	78.27	6.14	12.56	.89	.39	1.44	1.29	.91
10334	B <sub>2</sub>	16-19	71.68	6.00	13.60	.80	.60	1.35	.88	.92
10335	B <sub>3</sub>	19-26	70.96	5.93	14.12	.96	.37	1.43	.94	.91
10336	C	26+	74.82	5.35	11.75	.80	.57	1.77	1.35	.91

Sample no.	Horizon	Depth	MnO	P <sub>2</sub> O <sub>5</sub>	Ignition loss	SO <sub>3</sub>	Total	CO <sub>2</sub> <sup>2</sup>	N	pH	Soluble salts <sup>3</sup>
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>		<i>Parts per million</i>
10331	A <sub>1</sub>	0-8	0.15	0.13	3.82	0.10	100.20	0.06	0.10	5.2	<298
10332	A <sub>2</sub>	8-12	.06	.10	3.20	.07	100.36	.06	.05	4.5	<298
10333	B <sub>1</sub>	12-16	.04	.07	4.02	.07	101.09	.06	.06	4.8	<298
10334	B <sub>2</sub>	16-19	.03	.08	4.58	.07	100.47	.06	.05	5.0	<298
10335	B <sub>3</sub>	19-26	.04	.10	4.80	.05	100.60	.06	.04	5.3	<298
10336	C	26+	.09	.16	3.10	.05	100.68	.09	.02	5.7	<298

<sup>1</sup> Determinations (except pH and soluble salts) by J. G. Hough.<sup>2</sup> CO<sub>2</sub> of the carbonates.<sup>3</sup> Determined by bridge method.

TABLE 31.—Chemical analyses of McLeansboro silt loam colloid

Sample no.	Horizon	Depth	Colloid extracted	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
10331	A <sub>1</sub>	0-8	70	46.66	8.22	23.81	1.65	0.44	1.60	0.07
10332	A <sub>2</sub>	8-12	70	48.72	9.18	24.83	1.70	.29	1.52	.08
10333	B <sub>1</sub>	12-16	75	48.43	10.84	24.67	1.77	.34	1.44	.06
10334	B <sub>2</sub>	16-19	80	48.92	11.11	24.92	1.95	.43	1.35	.33
10335	B <sub>3</sub>	19-26	79	49.25	9.48	20.09	1.98	.43	1.33	.28
10336	C	26+	79	48.21	6.09	29.11	2.20	.73	1.57	.32

Sample no.	Horizon	Depth	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	Ignition loss	Total	Organic matter <sup>1</sup>	CO <sub>2</sub> <sup>2</sup>	N
		<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
10331	A <sub>1</sub>	0-8	0.83	0.03	0.26	0.23	16.21	100.01	6.60	0.21	0.25
10332	A <sub>2</sub>	8-12	.81	.02	.18	.16	12.53	100.02	3.21	.11	.12
10333	B <sub>1</sub>	12-16	.81	.07	.16	.16	11.48	100.23	1.93	.26	.12
10334	B <sub>2</sub>	16-19	.89	.03	.13	.17	10.80	101.03	1.95	.12	.16
10335	B <sub>3</sub>	19-26	.85	.03	.14	.16	10.71	100.71	1.82	.06	.16
10336	C	26+	.92	.07	.18	.17	10.11	100.28	1.47	.11	.13

<sup>1</sup> By combustion method (CO<sub>2</sub> × 0.471).<sup>2</sup> CO<sub>2</sub> of the carbonates.

The analyses of the colloids (table 31) are normal for the prairie colloids. The high organic matter in the A<sub>1</sub> horizon is accompanied by corresponding quantities of phosphorus and sulphur and by slightly higher calcium and potassium, as compared with the A<sub>2</sub> horizon. The carbonates, which are negligible in the whole soil, become measurable in the colloid. This is particularly interesting as indicating that acid colloids (table 30) contain appreciable quantities of carbonates (1). The story of the colloid, told by the derived data in table 32, is substantially the same as that of the Nebraska soils, with the exception of a few features.

TABLE 32.—*Derived data: McLeansboro silt loam colloid*

Sample no.	Horizon	Depth	Molecular ratio					Water of hydration	Combined water of the soil acids <sup>2</sup>
			$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3 \cdot \text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	$\frac{\text{Fe}_2\text{O}_3}{\text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Total bases}}$		
		Inches						Percent	Percent
10331	A <sub>1</sub>	0-8	2.72	15.02	3.33	0.221	11.58	9.44	11.36
10332	A <sub>1</sub>	8-12	2.69	14.05	3.33	.237	12.40	9.21	10.79
10222	B <sub>1</sub>	12-16	2.60	11.84	3.33	.282	12.11	9.29	10.63
10334	B <sub>1</sub>	16-19	2.59	11.65	3.33	.285	10.56	8.73	10.27
10335	B <sub>1</sub>	19-26	2.60	13.75	3.20	.233	10.79	8.83	10.37
10336	C	26+	2.45	19.16	2.81	.147	8.47	8.53	11.14

<sup>1</sup> Carbonates deducted.<sup>2</sup> Water of hydration plus water equivalent of the bases, corrected for organic matter and carbonate content.

The silica-sesquioxide and the silica-alumina ratios are those of prairie and not of chernozem type (3). The silica-iron oxide ratios indicate that a much higher degree of podzolization, i.e., fractionation of the colloid, accompanies the translocation of the colloid downward than occurs in the chernozems. The same is also indicated by the ferric oxide-alumina ratios. The deposition of the iron oxide is much more marked in the upper 7 inches of the B horizon (B<sub>1</sub> and B<sub>2</sub>) than in the second 7 inches (B<sub>3</sub>). The silica-total base ratios are much greater than in the chernozem colloids, a feature which corresponds to the evidence of leaching already mentioned. The lower silica-total base ratio of the A<sub>1</sub> horizon and of the C horizon are indications of the high base-holding power of organic matter and of the decreased leaching of the C horizon. The water of hydration decreases as the base content increases and when converted to the water of combination of the soil acid gives an average water value of 10.76. This numerical value is a point of considerable interest, as will appear in the general discussion. The whole profile indicates translocation of colloid as a whole from the upper to the lower horizons and makes probable the presence of a soil acid of definite composition but essentially different from that of the chernozems.

#### HYGROSCOPIC RELATIONS

In a previous publication (7) the writers, Brown and Byers, have called attention to the hygroscopic character of colloidal fractions of widely different soil types and particularly to the striking differences in the ratio of the water vapor absorbed over 3.3 percent sulphuric acid, 99 percent humidity, and over 30 percent sulphuric acid, 75 percent humidity. In the colloids there reported a wide variation of this ratio was noted. For the Amarillo silty clay loam colloid, a chernozem, the ratio was found to be approximately 1.9; for the Marshall silt loam colloid, a prairie soil, about 2.5; and for the Davidson clay loam colloid, a lateritic soil, the ratio rose to as high as 6.17 for one fraction. It seemed probable, therefore, that if the colloids of the soils under consideration were as closely similar as their analyses indicate, this water-vapor relation would also indicate their similarity. The results of this examination are given in table 33.

TABLE 33.—Hygroscopic properties of the colloids of the soil profiles found in tables 1 to 32, inclusive

FILLMORE SILT LOAM						KEITH SILT LOAM					
Sample no.	Horizon	Depth	Water vapor absorbed over—		Absorption ratio	Sample no.	Horizon	Depth	Water vapor absorbed over—		Absorption ratio
			3.3 percent $H_2SO_4$	30 percent $H_2SO_4$					3.3 percent $H_2SO_4$	30 percent $H_2SO_4$	
		Inches	Percent	Percent				Inches	Percent	Percent	
8088	A <sub>1</sub>	0 - 2	27.09	12.17	2.21	9222	A <sub>1</sub>	0 - 14	32.39	15.50	2.09
8089	A <sub>2</sub>	2 - 6 <sup>1</sup> / <sub>2</sub>	27.79	13.08	2.12	9223	A <sub>2</sub>	1 <sup>1</sup> / <sub>2</sub> - 3 <sup>1</sup> / <sub>2</sub>	32.83	16.49	2.12
8090	B <sub>1</sub>	6 <sup>1</sup> / <sub>2</sub> - 16	34.14	17.61	1.95	9224	B <sub>1</sub>	3 <sup>1</sup> / <sub>2</sub> - 14	34.56	17.21	2.01
8091	B <sub>2</sub>	16 - 38	34.88	18.17	1.92	9225	B <sub>2</sub>	14 - 21	34.18	17.71	1.92
8092	B <sub>3</sub>	38 - 42	33.02	18.87	1.96	9226	B <sub>3</sub>	21 - 33	32.99	18.08	2.05
8093	B <sub>4</sub>	42 - 60	33.48	18.48	2.04	9227	B <sub>4</sub>	33 - 40	32.91	14.13	2.33
8094	B <sub>5</sub>	60 - 84	33.41	16.00	2.09	9228	B <sub>5</sub>	40 - 48	33.28	14.45	2.30
8095	O	84 - 98	32.25	16.25	1.99	9229	B <sub>6</sub>	48 - 72	32.33	15.29	2.12
						9230	B <sub>7</sub>	72 - 90	32.91	14.61	2.25
ORETE SILT LOAM						PHILLIPS SANDY LOAM					
8096	A <sub>1</sub>	0 - 1 <sup>1</sup> / <sub>2</sub>	26.18	12.42	2.11	8749	A <sub>1</sub>	0 - 1 <sup>1</sup> / <sub>2</sub>	25.75	10.53	2.42
8100	A <sub>2</sub>	1 <sup>1</sup> / <sub>2</sub> - 4	28.28	13.42	1.96	8750	A <sub>2</sub>	1 <sup>1</sup> / <sub>2</sub> - 4	25.70	11.17	2.31
8101	A <sub>3</sub>	4 - 20	27.76	12.85	2.16	8751	B <sub>1</sub>	4 - 9	20.85	14.06	2.12
8102	B <sub>1</sub>	20 - 38	32.03	15.85	2.02	8752	B <sub>2</sub>	9 - 19	34.30	16.71	2.65
8103	B <sub>2</sub>	38 - 60	35.89	17.36	2.07	8753	B <sub>3</sub>	19 - 30	33.83	16.44	2.06
8104	O	60 - 84	34.89	16.65	2.09	8754	B <sub>4</sub>	30 - 54	35.93	16.74	2.15
						8754-A	C	54 - 64	35.25	15.56	2.26
HASTINGS SILT LOAM						FARGO CLAY					
8079	A <sub>1</sub>	0 - 6	28.44	13.34	2.13	106	A <sub>1</sub>	0 - 6	25.20	13.13	2.22
8080	A <sub>2</sub>	6 - 20	30.04	14.88	2.02	107	A <sub>2</sub>	6 - 10	19.55	8.56	2.28
8081	B <sub>1</sub>	20 - 30	33.85	16.60	2.04	108	B	12 - 20	35.07	16.07	1.93
8082	B <sub>2</sub>	30 - 43	33.14	17.37	1.91	109	C	32 - 48	34.23	16.22	2.16
8083	B <sub>3</sub>	43 - 57	28.14	17.14	1.64						
8084	B <sub>4</sub>	57 - 78	28.31	17.17	1.53						
8085	O	78 - 108	27.13	16.80	1.62						
HOLDREGE SILT LOAM						McLEANSBORO SILT LOAM					
9215	A <sub>1</sub>	0 - 4	30.00	13.16	2.28	10331	A <sub>1</sub>	0 - 8	23.10	10.35	2.25
9216	A <sub>2</sub>	4 - 7	28.71	12.76	2.25	10332	A <sub>2</sub>	8 - 12	21.60	11.29	1.91
9217	A <sub>3</sub>	7 - 18	30.15	14.05	2.06	10333	B <sub>1</sub>	12 - 16	25.20	13.60	1.86
9218	B <sub>1</sub>	18 - 30	33.43	16.75	2.00	10334	B <sub>2</sub>	16 - 19	30.04	14.37	2.09
9219	B <sub>2</sub>	30 - 49	33.92	16.02	2.12	10335	B <sub>3</sub>	19 - 26	30.65	14.85	2.06
9220	B <sub>3</sub>	49 - 72	34.63	16.06	2.16	10336	C	26+	30.04	14.62	2.06
9221	O	72 - 96	34.90	15.72	2.22						

<sup>1</sup> O horizon not distinct.

These data may, at first sight, seem too satisfactory in that they show the chernozem and solonetz profiles to have a nearly uniform water-vapor ratio over 3.3 and 30 percent sulphuric acid, with a mean value for the first seven soils of 2.08 and for the prairie profile a mean value of 2.04. This relation may seem to indicate a closer similarity between the McLeansboro profile and the others than is warranted by the analytical data. However, in the general discussion which follows there will be given a possible explanation.

The data of table 33 bring out a point of great interest with reference to the hygroscopic capacity of the colloids. It is to be observed that the water-vapor absorption of the surface horizons is in every

case lower than for the B horizons. This difference is of considerable magnitude. The average for the B horizons of the eight soils is 32.96 percent, while for the A horizons it is 27.27 percent, a difference of 5.69 percent for the absorption from a nearly saturated atmosphere. At 75 percent humidity the mean values for the B horizon colloids is 17.14 percent and for the A horizon colloids 12.71 percent, a difference of 4.43 percent. These differences are too wide and too general to be accidental, despite the fact that the water-vapor absorptions are known not to be equilibrium values. The only marked differences between the A and B horizon colloids is, in general, in the organic-matter content which, in this series of colloids, averages 7.27 percent for the A horizons and 1.96 percent for the B horizons, a difference of 5.31 percent.

It would apparently seem that the inference is warranted that the hygroscopicity of the organic matter of these colloids is less than that of the inorganic part. This conclusion is in general accord with the data on water-vapor absorption of a series of colloids reported by Gile, Middleton, Robinson, Fry, and Anderson (13) in which the water-vapor absorption of the colloid of 15 surface soils over 3.3 percent sulphuric acid shows a mean value of 0.2825, whereas the subsoils of the same soils show a mean of 0.3050. These are the same soils reported by Robinson and Holmes (28) which have a mean organic content of the surface soil colloids of 6.36 percent, while the subsoil colloids have an organic content of 3.08 percent. Among these soils are three in which the surface soil colloid has higher absorptive capacity. These are the Cecil, Stockton, and Wabash soils. Of these three, the Stockton and Wabash are reported as having a lower organic content in the surface soil colloid. On the other hand, it is not in accord with the conclusions reported by Richter (23), although a careful inspection of Richter's data show that they do not well support his own deductions from them. It is also to be noted that Richter worked with soils of low silica-sesquioxide ratio. Anderson and Byers (4) have shown that the inorganic colloid of a lateritic soil of the Cecil series has an extremely low water-vapor absorption over 30 percent sulphuric acid, and that from a desert soil colloid of the Fallon series has a high absorptive capacity when the organic matter has been removed from both. They have also shown that (3) the podzol colloids, when the organic matter is removed, show lowered absorptive capacity. It is therefore not to be assumed that the water-vapor-absorption capacity of any inorganic soil colloid is greater than its organic associated material, even though this appears to be the case in the colloids of at least the chernozem and prairie soil groups.

In drawing the general conclusion that the organic colloid is of relatively low water-vapor absorption in these colloids, it should be mentioned that other possible explanations may be found. The surface soils are more subject to alterations through change of temperature and are therefore more likely to suffer irreversible dehydration. This explanation seems most probable, but no evidence is available at present. Also, no account has been taken in the above considerations of the effect of colloidal size on the hygroscopic relations. It has been shown by Brown and Byers (7) that in general the fine colloid particles, less than  $0.1 \mu$ , are capable of higher moisture absorption than those of greater dimension, and it is possible that the finer

particles of colloid eluviated from the A horizons may be the cause of the observed results. The question is of importance, and its further investigation is being pursued.

It is perhaps also worth while to call attention to the abnormally low value of the water-vapor absorption of the colloid of the A<sub>2</sub> horizon of Fargo clay. This phenomenon is also exhibited by the humid podzols reported by Anderson and Byers (8) and may, perhaps, be considered as the normal behavior of the gray layer (bleicherde).

### GENERAL DISCUSSION

In order to bring into as condensed form as possible the general information conveyed by the analytical data of tables 1 to 33, inclusive, so that this information may serve as a basis for a discussion of the topics mentioned in the introduction, table 34 has been prepared. The two points in question are with reference to claypan formation and the constitution of soil colloids.

TABLE 34.—Review of data: Colloids

Soil type	Colloids in the soil <sup>1</sup>	Molecular ratio					Com bined water of the soil acid <sup>2</sup>	Absorp- tion ratio <sup>3</sup>
		SiO <sub>2</sub>	SiO <sub>2</sub>	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub> <sup>4</sup>		
		Fe <sub>2</sub> O <sub>3</sub> .Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Total bases		
Fillmore silt loam:	Percent						Percent	
A horizon.....	20.0	3.71	17.29	4.72	0.275	7.22	9.28	2.17
Claypan <sup>5</sup> .....	49.1	3.37	15.44	4.19	.271	7.03	9.50	1.93
Entire profile.....	30.0	3.63	17.20	4.50	.267	6.84	9.56	2.03
Crete silt loam:								
A horizon.....	20.1	3.37	17.83	4.15	.232	7.17	10.38	2.08
Claypan <sup>5</sup> .....	40.2	3.42	17.33	4.26	.246	6.81	10.28	2.04
Entire profile.....	25.0	3.42	17.52	4.25	.242	7.35	10.35	2.07
Hastings silt loam:								
A horizon.....	24.5	3.25	17.43	4.13	.231	8.71	11.59	2.06
Claypan <sup>5</sup> .....	34.9	3.21	18.41	4.00	.217	7.73	11.19	1.97
Entire profile.....	24.7	3.44	17.80	4.33	.242	7.48	10.91	1.84
Holdrege silt loam:								
A horizon.....	21.6	3.50	18.03	4.34	.231	7.22	10.52	2.27
Claypan <sup>5</sup> .....	31.5	3.58	18.30	4.45	.244	6.07	10.62	2.06
Entire profile.....	21.7	3.58	17.87	4.75	.251	6.75	10.55	2.15
Keith silt loam:								
A horizon.....	18.1	3.76	19.81	4.55	.234	6.28	11.15	2.11
Claypan <sup>5</sup> .....	23.4	3.60	19.37	4.42	.228	5.82	10.74	1.97
Entire profile.....	18.5	3.68	20.30	4.60	.222	5.78	11.20	2.13
Phillips sandy loam:								
A horizon.....	13.1	3.53	16.21	4.50	.278	7.79	9.52	2.30
Claypan <sup>5</sup> .....	26.0	3.27	15.11	4.17	.278	8.00	10.28	2.08
Entire profile.....	21.4	3.41	15.61	4.30	.275	7.51	10.11	2.20
Fargo clay:								
A horizon.....	23.9	4.94	23.05	6.88	.414	7.52	8.24	2.25
Claypan <sup>5</sup> .....	58.8	3.53	20.47	4.26	.208	7.01	9.12	1.93
Entire profile.....	40.0	4.25	21.46	5.56	.316	6.94	8.72	2.04
McLeansboro silt loam:								
A horizon.....	19.1	2.71	14.53	3.33	.220	12.02	11.08	2.08
Claypan <sup>5</sup> .....	35.5	2.60	11.74	3.32	.283	11.33	10.42	1.99
Entire profile.....	28.6	2.61	14.25	3.22	.234	10.51	10.81	2.19

<sup>1</sup> Determined by mechanical analysis.

<sup>2</sup> Carbonates deducted.

<sup>3</sup> Water of hydration plus water equivalent of bases, corrected for carbonates and organic matter.

<sup>4</sup> Water absorbed over 3.3 percent H<sub>2</sub>SO<sub>4</sub> divided by water absorbed over 30 percent H<sub>2</sub>SO<sub>4</sub>.

<sup>5</sup> Includes only B<sub>1</sub> and B<sub>2</sub>, or equivalent horizons.

It would appear that, with the exception of the Fargo soil, the claypans are all produced by the same process. The colloid as a whole is translocated from the surface downward by dispersion and eluviation. The transfer is from a point of lower toward one of higher pH value. It seems probable that originally the parent material contained calcium carbonate, or calcium silicates. As a

result of leaching, calcium bicarbonate was formed and transported downward through the parent material in periods of excess precipitation. During dry periods the bicarbonate would be decomposed and precipitated as the carbonate in the stratum of maximum mean water penetration. The soluble calcium salts just above the carbonate layer would tend to flocculate dispersed colloid, and its accumulation thus tends to decrease the permeability of this layer. Where the rainfall is sufficiently high, as in the Fillmore and Crete areas, this layer may become sufficiently dense as to be practically impermeable. From the description of the soils it would appear that it is immaterial whether the water reaches the soil by rainfall or by drainage from higher areas. Where the rainfall is still higher, the layer of calcium carbonate cannot form, because of nearly constant underdrainage. The exceeding tightness of the claypan is not sufficient to stop underdrainage completely but only to impede it. This would appear to be the case with the McLeansboro profile. Where the rainfall is less, the concentration of colloid in the B horizon is not so great and the claypan not so dense or impermeable. This is the case in the Hastings and also the Holdrege profiles. Where it is sufficiently low no claypan is formed.

The chief differences between the Phillips profile and the profiles in Nebraska are apparently due to the differences in the parent material which is glacial drift in the Phillips area. The examination of the water-soluble material shows a reasonably large accumulation of soluble alkali salts beneath the B horizon (table 22 and discussion). It is reasonable to assume, therefore, that the original material of which the soil was formed contained sufficient salts to precipitate the dispersed colloid and to form a nearly impervious layer, under a smaller rainfall than in the loessial region of the Keith areas. Whether the prairie claypans developed on glacial drift have had their formation facilitated by the presence of such salts cannot be inferred from the data here presented. Also, it cannot be definitely asserted, because of lack of information, that the nonslick-spot areas adjacent to the Phillips soils were developed on different parent drift. It would be of interest to determine this point. It is not necessary to assume that fractionation of the colloids has had any part in the development of the claypans, though evidence of such fractionation is detectable in any case where a claypan is formed. Neither is it necessary to assume that free ferric hydroxide or aluminum hydroxide have played a part in the development, although the presumptive presence of small amounts of both is to be granted.

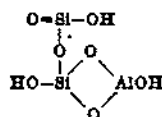
The facts presented in table 34, on which, for the most part, the conclusions just stated are based, are as follows: The silica-sesquioxide ratios of all the soils except the Fargo show essential constancy of composition throughout each profile. The same is true of their silica-alumina ratios; their silica-iron ratios; and the water of combination of the soil acids. The base content of the claypan is uniformly greater than in the A horizons, as indicated by the lower value of the silica-total base ratios. The lower degree of concentration of colloid in the B horizon in the Keith soil, which has no hardpan, is significant, and equally significant of the probable part played by the soluble salts is the relatively small concentration of colloid which produces the "tight" claypan of the Phillips soil. The existence of fractionation of the colloid is indicated strongly in the McLeansboro profile by the



decrease of the silica-ferric oxide ratio and the increase of the ferric oxide-alumina ratio in the B horizon as compared with the A horizons. This alteration is less in the Fillmore profile and still less in the Crete profile. It becomes still less definite in the Holdrege, Keith, and Phillips profiles.

As indicated in the discussion of tables 25, 26, 27, and 28, the Fargo clay presents a different picture. The colloid is not uniform, and the soil is not leached below the claypan. It would appear that the original clay deposit on which the soil developed is the claypan, and that the unquestioned leaching of the upper part is due to ground water rather than to the percolation which presumably produces the humid podzols. These conclusions are based in part on the concentrated data of table 34 and in part on the more detailed data of tables 25, 26, 27, 28, and 33. It can scarcely be conceived that leaching through the B horizon could produce a soil with smaller ferric oxide-alumina ratio in the B than in the A horizons. It would also appear from the variations of the silica-sesquioxide and silica-alumina ratios and the water of combination of the soil acids that the lacustrine deposit is itself a relatively highly weathered deposit.

The information concerning the constitution of the colloids, which is concentrated in table 34, has a very direct bearing on the views expressed by Brown and Byers (?) and more fully by Byers (8). According to this conception of soil formation there are in the different soil colloids, inorganic "acids" of definite composition,  $3\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$ , montmorillonitic acid;  $3\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$ , pyrophyllitic acid;  $3\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ , halloysitic acid; and  $3\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3$ , aluminum hydroxide. The names are derived from the clay minerals which most closely approach the soil colloids in composition. Pyrophyllite is partly dehydrated and crystallized, while montmorillonite appears to be a hydrate (10) and of rather indefinite composition. These acids are to be regarded as amphoteric and to have a definite constitution which, in the absence of synthetic evidence, may be hypothetically represented for one of them by the following formula:



Pyrophyllitic acid

The colloids are to be regarded as the salts of these acids, in which a part of the acid hydrogen is replaced by bases and of the basic hydroxyl, attached to the alumina, by acid radicals. The inorganic part of the colloid is associated with more or less organic matter, but to what degree the inorganic matter is associated chemically with organic matter is not made evident from any data at present available. It seems reasonable to assume, however, that a part of the bases present in a soil colloid are held in combination by humic acid. It should be clear, from all the considerations involved, that under normal circumstances pure samples of the compounds in question are not to be expected to occur in nature.

That a very close approximation to the hypothetical pyrophyllitic acid is found in the colloid of the first six profiles summarized in table 34 is made evident from the following considerations: The silica-ses-

quioxide ratio of these six profiles averages  $3.53 \pm 0.13$ . A sample of pyrophyllite, beautifully crystallized, which was obtained from the Smithsonian Institution and analyzed by R. S. Holmes, has a silica-sesquioxide ratio of 3.67, while the samples of this mineral reported by Dana (10) range between the limits of 3.40 and 3.88.

The iron content of these colloids is essentially wholly associated with the aluminosilicate radical, i.e., plays the part of the aluminum in a complex acid radical, as is indicated by a number of facts. These soils, when treated with hydrogen peroxide for removal of organic matter, leave a grayish-white residue with no trace of the red or yellow color of iron oxide. The silica-iron oxide and iron oxide-alumina ratios fluctuate in the different parts of the same profile within exceedingly narrow limits, as compared with most soil colloids of other great groups. The silica-alumina ratios, therefore, ought to be greater than 4, as they are, in every case. The silica-total base ratio indicates that the acid complex which is presumably a stronger acid (8) than are the acids of lower silica-sesquioxide ratio (8) holds the bases strongly. How much of this indicated high base content is to be ascribed to the strength of the acid and how much to limited leaching, under low rainfall, cannot be determined.

The most striking evidence of a definite soil acid is furnished by the water of combination of the soil acids given in table 34. The quantity in question, it may be repeated, is calculated by subtraction of the carbon dioxide and organic content from the ignition loss, adding to this value the water equivalent of the bases present and then correcting this value for the organic matter and carbonates present. This operation leaves a number of inaccuracies and uncertainties. The bases present weigh more than the water they are assumed to replace. A part of the manganese is also in manganous form and therefore replaces hydrogen, but how much of it is so held is not determined. The phosphorus pentoxide and sulphur trioxide, so far as they are a part of the inorganic complex, also replace water in the acid complex which is amphoteric. It is certain, however, that a part of each of these is associated with the organic part of the colloid.

These uncertainties are quantitatively relatively unimportant. There are, however, two other sources of inaccuracy which cannot be so dismissed. The assumption is generally made that all water given off from a soil colloid below  $105^{\circ}\text{C}$ . is not chemically associated with it. This may be true of colloids of the general type of aluminum hydroxide, but it cannot be assumed in the case of substituted silicic acid, such as are assumed to exist in these colloids. How large the error introduced by making this assumption may not be estimated. The laboratory of the Division of Soil Chemistry and Physics, Bureau of Chemistry and Soils, is at present engaged on this point, but the data are not yet available.

Another known source of error is the uncertainty in the determination of the organic matter, which has been reviewed by Alexander and Byers (1). This error is likely to be compensatory for the others, since the organic matter, as calculated from the factor  $0.471 \times \text{CO}_2$ , is probably too low, thus making the apparent water content as reported somewhat too high. All the other undetermined or neglected corrections would tend to increase the combined water values. When these items are considered, the fact that the mean value of the water of combination of the six profiles is  $10.45 \pm 0.86$  shows that the constancy is too great to be considered accidental. Pyrophyllitic acid,

$H_3AlSi_2O_7$ , should have a water content, if pure, of 13.6 percent. The trend of the evidence is that this acid, if it exists in these soils, does so as an acid salt of the general type,  $MH_3(AlSi_2O_7)_2$ . This general relation is supported by the fact that the water equivalent of the bases is on the average 2.28 and therefore a ratio with the 13.6 percent of 6.0. If then, the acid is pyrophyllic acid, approximately 1 out of 6 hydrogen ions are neutralized. It is scarcely to be expected that an acid salt of this type can be heated to  $105^\circ C$ . and not lose a part of its water. The behavior to be expected should be analagous to that of silicic acid itself. The general conclusion is therefore that a definite acid of the pyrophyllic type exists in the six profiles just considered. This statement may also be considered as being applicable to the colloids of the Barnes silt loam profile, reported by Denison (12), the Colby silty clay loam reported by Middleton, Slater, and Byers (20), and the Amarillo silty clay loam reported by Anderson and Byers (3), all of which are chernozem soils.

The relation of this colloid of essentially constant composition to climatic and other conditions requires some consideration in view of a recently published paper by Reifenberg (22). This author attempts to show that there is a direct relation between the silica-sesquioxide ratio and rainfall. He uses analyses of American soil colloids as the basis of his argument and cites the apparently conflicting evidence of Robinson and Holmes and of Crowther on the one hand and of Jenny and of Baver and Scarseth on the other. In view of the fact that the same colloid develops with a range in rainfall from 13 to 32 inches, it can scarcely be established that rainfall is the sole determining influence. Indeed, such could scarcely be true, even though colloid formation is essentially a hydrolysis. Temperature changes affect hydrolysis both as to rate and to the changes produced on the resulting hydrolytic products. It seems apparently clear also that the parent material plays a part in the process, and the resultant effect of all these on the vegetative cover is to be taken into account. It seems a useless expenditure of effort to attempt to assign to any one of these a primary role. It is probably the case that the relative importance of these fundamental factors in soil formation is variable under different conditions.

The Fargo soil colloid (table 34) presents a somewhat different case. It would seem to have a composition which indicates an intermediate condition between the montmorillonitic type of colloid and the pyrophyllic type. This is not believed to be the case, despite the high silica ratios of the A horizon. It seems more probable that the true character of the colloid is represented by the silica-sesquioxide ratio of the B horizon, and that, as previously mentioned, the A horizons, especially the  $A_2$  horizon, are affected by secondary silica of colloidal dimension. Of greater interest is the water content of the soil acid, and the evidence, previously mentioned, of the pseudopodzolic character of the profile. The data at hand allow only the conclusion that the ground water podzols of the semiarid region of the Northwest deserve a much more intensive investigation.

The McLeansboro profile is typically that of the prairie soils. The colloidal acid has characteristics of an intermediate stage between that of the pyrophyllic structure and the halloysitic. The debasing effect of the high rainfall is apparent. The water content of the soil acid is slightly higher than for the chernozems but still much below

that of halloysitic acid. The results are in harmony with those for prairie soils presented by Middleton, Slater, and Byers (20)—the Marshall soil from Iowa, the Shelby from Missouri, and the Palouse from Washington.

The absorption ratios given in the last column of table 34 require some special consideration. As already mentioned, Brown and Byers (7), in their study of the fractionation of soil colloids, have called attention to the wide variation in the water-vapor absorption of colloids of different types and different colloidal dimension. They also pointed out that surface alone is not an adequate explanation of the variations observed. In the series of colloids under present consideration, there is also found in colloids of presumably like size a rather wide variation in the water-vapor absorption; a range between the limits of 19.58 and 35.93 percent for 99 percent humidity and between 8.56 and 18.17 percent for 75 percent humidity. There is, however, no such range between the ratios observed as given in table 34. It has been pointed out that a partial explanation may exist in the behavior of organic matter, but that this alone does not account for the phenomena. It would again seem that this ratio is associated with the chemical composition of the colloid. Since, then, the general character of these colloids is the same, there should be a similar ratio. It is possible that the pyrophyllitic colloid, when exposed to water vapor, absorbs water to form a fully hydrated acid and holds this water at 75 percent humidity more tenaciously than do colloids dominantly halloysitic or lateritic. This possibility is intriguing and calls for special study.

Some unfinished investigations, at present being carried on, lend some support to the view expressed. At present, they do not furnish proof. There are also, particularly in the work of Anderson and Mattson (5) and of Anderson (2), data which show a marked influence of the presence of bases in the colloids on the water-vapor absorption at 75 percent humidity. In what degree these differences affect the absorption ratio is not apparent.

#### SUMMARY

There are presented detailed mechanical and chemical analyses of complete profiles of eight soils, together with the analyses of their colloids. Included with these analyses are determinations of the soluble salts and hydrogen-ion concentrations of each horizon and the water-vapor absorption of the colloids over 3.3 and 30 percent sulphuric acid. The analyses are preceded by a careful description of each profile and a description of the areas in which the soils occur, together with data on climatic and vegetative conditions.

From the analytical data are calculated the usual ratios of the silica to sesquioxide, iron oxide, alumina, and total bases; also the ferric oxide-alumina ratios. The data are also made the basis of calculation of what is called the total combined water of the soil acid; that is, the combined water of the soil colloid plus the water equivalent of the bases present.

The data show that the six chernozem soils contain a colloid which, though developed under a rainfall ranging from 13 to 32 inches, is essentially the same material. It varies in calcium carbonate, organic-matter, and base content, but it has a mean value of the silica-sesquioxide ratio of 3.53. The analyses of Fargo clay show it to be a

pseudopodzol, the gray layer of which may be considered as being produced by chemical action rather than colloidal translocation downward. The McLeansboro profile is chemically a typical prairie soil.

An explanation is offered for the existence of the claypans and for their absence when not found.

A general discussion of the chemical and physical properties of the colloids is made the basis for the conclusion that the dominant material in the colloid is an acid salt of the hypothetical pyrophyllic acid,  $H_4AlSi_2O_7$ . This salt is considered to have the general formula  $MH_2(AlSi_2O_7)_2$  in which the bases are chiefly magnesium, calcium, potassium, and sodium.

The examination of the moisture relations leads to the apparently unorthodox and improbable conclusion that the water-vapor absorption of the organic colloid of these chernozems, at least, is less than for the corresponding inorganic colloid, although other possible explanations are pointed out. Which of these, or some other explanation, is correct must be decided on in the light of future evidence. These data also lead to the tentative conclusion that chemical relations play an important part in determining the quantity of hygroscopic water which may be absorbed by soil colloids.

#### LITERATURE CITED

- (1) ALEXANDER, L. T., and BYERS, H. G.  
1932. A CRITICAL LABORATORY REVIEW OF METHODS OF DETERMINING ORGANIC MATTER AND CARBONATES IN SOIL. U.S. Dept. Agr. Tech. Bul. 317, 26 p., illus.
- (2) ANDERSON, M. S.  
1929. THE INFLUENCE OF SUBSTITUTED CATIONS ON THE PROPERTIES OF SOIL COLLOIDS. Jour. Agr. Research 38: 565-584.
- (3) ——— and BYERS, H. G.  
1931. CHARACTER OF THE COLLOIDAL MATERIALS IN THE PROFILES OF CERTAIN MAJOR SOIL GROUPS. U.S. Dept. Agr. Tech. Bul. 228, 24 p.
- (4) ——— and BYERS, H. G.  
1933. CHARACTER AND BEHAVIOR OF ORGANIC SOIL COLLOIDS. U.S. Dept. Agr. Tech. Bul. 377, 33 p.
- (5) ——— and MATTSON, S.  
1926. PROPERTIES OF THE COLLOIDAL SOIL MATERIAL. U.S. Dept. Agr. Bul. 1452, 47 p., illus.
- (6) BAILEY, E. H.  
1932. THE EFFECT OF AIR DRYING ON THE HYDROGEN-ION CONCENTRATION OF THE SOILS OF THE UNITED STATES AND CANADA. U.S. Dept. Agr. Tech. Bul. 291, 44 p., illus.
- (7) BROWN, I. C., and BYERS, H. G.  
1932. THE FRACTIONATION, COMPOSITION, AND HYPOTHETICAL CONSTITUTION OF CERTAIN COLLOIDS DERIVED FROM THE GREAT SOIL GROUPS. U.S. Dept. Agr. Tech. Bul. 319, 44 p.
- (8) BYERS, H. G.  
1933. THE CONSTITUTION OF THE INORGANIC SOIL COLLOIDS. Amer. Soil Survey Assoc. Bul. 14: 47-52.
- (9) ——— and ANDERSON, M. S.  
1932. THE COMPOSITION OF SOIL COLLOIDS IN RELATION TO SOIL CLASSIFICATION. Jour. Phys. Chem. 36: [348]-366.
- (10) DANA, E. S.  
1914. THE SYSTEM OF MINERALOGY OF JAMES DWIGHT DANA 1837-1893. DESCRIPTIVE MINERALOGY. Ed. 6, rewritten and enl., with appendices I and II, completing the work to 1909, 1134 p., illus. New York and London.
- (11) DAVIS, R. O. E.  
1927. THE USE OF THE ELECTROLYTIC BRIDGE FOR DETERMINING SOLUBLE SALTS. U.S. Dept. Agr. Circ. 423, 14 p., illus.

- (12) DENISON, I. A.  
1930. THE CHEMICAL COMPOSITION OF COLLOIDAL MATERIAL ISOLATED FROM THE HORIZONS OF VARIOUS SOIL PROFILES. *Jour. Agr. Research* 40: 469-483.
- (13) GILE, P. L., MIDDLETON, H. E. ROBINSON, W. O., FRY, W. H., and ANDERSON, M. S.  
1924. ESTIMATION OF COLLOIDAL MATERIAL IN SOILS BY ADSORPTION. U.S. Dept. Agr. Bul. 1193, 42 p.
- (14) HOLMES, R. S.  
1928. VARIATIONS OF THE COLLOIDAL MATERIAL IN TYPICAL AREAS OF THE LEONARDTOWN SILT LOAM SOIL. *Jour. Agr. Research* 36: 459-470.
- (15) ——— and EDGINGTON, G.  
1930. VARIATIONS OF THE COLLOIDAL MATERIAL EXTRACTED FROM THE SOILS OF THE MIAMI, CHESTER, and CECIL SERIES. U.S. Dept. Agr. Tech. Bul. 229, 24 p., illus.
- (16) KAY, G. F., and APPEL, E. T.  
1928. THE PRE-ILLINOIAN PLEISTOCENE GEOLOGY OF IOWA. *Iowa Geol. Survey Bul.* 34, 304 p., illus.
- (17) McGEORGE, W. T., BREAZEALE, J. F., and BURGESS, P. S.  
1926. ALUMINUM HYDROXIDE IN ALKALINE SOILS AND ITS EFFECT UPON PERMEABILITY. *Ariz. Expt. Sta. Tech. Bul.* 12, p. 257-305, illus.
- (18) MARBUT, C. F.  
1933. SOILS OF THE UNITED STATES. *Atlas of American Agriculture*, pt. 3, Advance Sheets no. 8, illus.
- (19) MIDDLETON, H. E.  
1928. THE ABSORPTION OF WATER VAPOR BY SOILS AND SOIL COLLOIDS. *First Internat. Cong. Soil Sci. Comn.* 1, *Proc. and Papers* 1: 446-455, illus.
- (20) ———, STATER, C. S., and BYERS, H. G.  
1932. PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS. U.S. Dept. Agr. Tech. Bul. 316, 51 p.
- (21) OLMSTEAD, L. B., ALEXANDER, L. T., and MIDDLETON, H. E.  
1930. A PIPETTE METHOD OF MECHANICAL ANALYSIS OF SOILS BASED ON IMPROVED DISPERSION PROCEDURE. U.S. Dept. Agr. Tech. Bul. 170, 23 p., illus.
- (22) REIFENBERG, A. VON.  
1933. DIE KLASSIFIKATION DER BODEN AUF GRUND DER ZUSAMMENSETZUNG IHRER KOLLOIDFRAKTION II. DIE KLASSIFIKATION AMERIKANISCHER BODEN. *Ztschr. Pflanzenernähr. Düngung u. Bodenk. (A)* 29: 155-162, illus.
- (23) RICHTER, C.  
1931. PHYSICAL PROPERTIES OF HAWAII SOILS, WITH SPECIAL REFERENCE TO THE COLLOIDAL FRACTION. *Hawaii Agr. Expt. Sta. Bul.* 62, 45 p., illus.
- (24) ROBINSON, W. O.  
1914. THE INORGANIC COMPOSITION OF SOME IMPORTANT AMERICAN SOILS. U.S. Dept. Agr. Bul. 122, 27 p.
- (25) ———  
1922. THE ABSORPTION OF WATER BY SOIL COLLOIDS. *Jour. Phys. Chem.* 26: [647]-653.
- (26) ———  
1930. METHOD AND PROCEDURE OF SOIL ANALYSIS USED IN THE DIVISION OF SOIL CHEMISTRY AND PHYSICS. U.S. Dept. Agr. Circ. 139, 20 p.
- (27) ———  
1930. SOME CHEMICAL PHASES OF SUBMERGED SOIL CONDITIONS. *Soil Sci.* 30: 197-217.
- (28) ——— and HOLMES, R. S.  
1924. THE CHEMICAL COMPOSITION OF SOIL COLLOIDS. U.S. Dept. Agr. Bul. 1311, 42 p.

**ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE  
WHEN THIS PUBLICATION WAS LAST PRINTED**

---

<i>Secretary of Agriculture</i> .....	HENRY A. WALLACE.
<i>Assistant Secretary</i> .....	REXFORD G. TUGWELL.
<i>Director of Scientific Work</i> .....	A. F. WOODS.
<i>Director of Extension Work</i> .....	C. W. WARBURTON.
<i>Director of Personnel and Business Administration.</i>	W. W. STOCKBERGER.
<i>Director of Information</i> .....	M. S. EISENHOWER.
<i>Solicitor</i> .....	SETH THOMAS.
<i>Bureau of Agricultural Economics</i> .....	NILS A. OLSEN, <i>Chief</i> .
<i>Bureau of Agricultural Engineering</i> .....	S. H. MCCRORY, <i>Chief</i> .
<i>Bureau of Animal Industry</i> .....	JOHN R. MOHLER, <i>Chief</i> .
<i>Bureau of Biological Survey</i> .....	PAUL G. REDINGTON, <i>Chief</i> .
<i>Bureau of Chemistry and Soils</i> .....	H. G. KNIGHT, <i>Chief</i> .
<i>Office of Cooperative Extension Work</i> .....	C. B. SMITH, <i>Chief</i> .
<i>Bureau of Dairy Industry</i> .....	O. E. REED, <i>Chief</i> .
<i>Bureau of Entomology</i> .....	LEE A. STRONG, <i>Chief</i> .
<i>Office of Experiment Stations</i> .....	JAMES T. JARDINE, <i>Chief</i> .
<i>Food and Drug Administration</i> .....	WALTER G. CAMBELL, <i>Chief</i> .
<i>Forest Service</i> .....	FERDINAND A. SILCOX, <i>Chief</i> .
<i>Grain Futures Administration</i> .....	J. W. T. DUVEL, <i>Chief</i> .
<i>Bureau of Home Economics</i> .....	LOUISE STANLEY, <i>Chief</i> .
<i>Library</i> .....	CLARIBEL R. BARNETT, <i>Librarian</i> .
<i>Bureau of Plant Industry</i> .....	WILLIAM A. TAYLOR, <i>Chief</i> .
<i>Bureau of Plant Quarantine</i> .....	A. S. HOYT, <i>Acting Chief</i> .
<i>Bureau of Public Roads</i> .....	THOMAS H. MACDONALD, <i>Chief</i> .
<i>Weather Bureau</i> .....	CHARLES F. MARVIN, <i>Chief</i> .

---

*Agricultural Adjustment Administration*.... GEORGE N. PEEK, *Administrator*.

This bulletin is a contribution from

*Bureau of Chemistry and Soils*..... H. G. KNIGHT, *Chief*.  
*Division of Soil Investigations*..... A. G. MCCALL, *Chief*.

**END**