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Genesis of the Soils of Lake Dakota Plain in Spink County South Dakota

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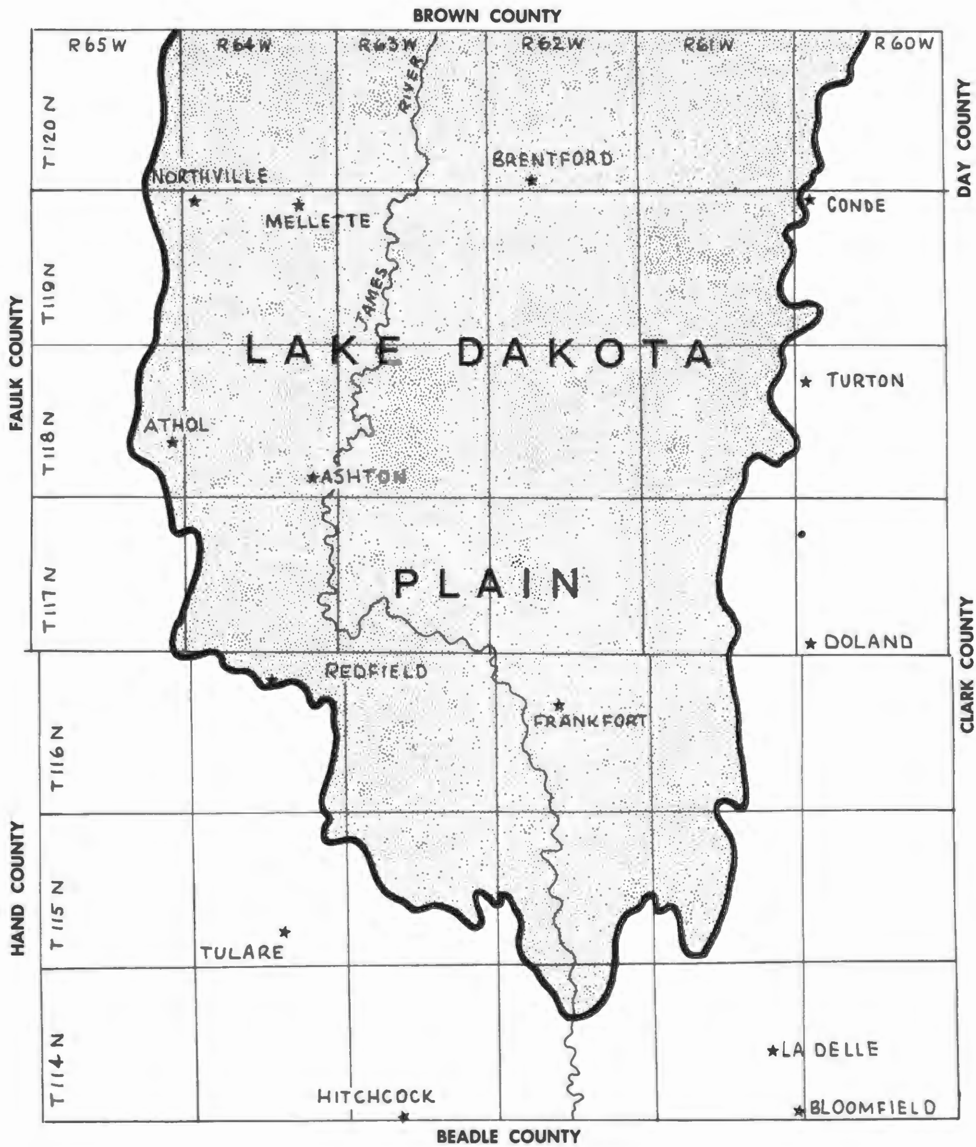

Figure 1—Location of Glacial Lake Dakota Plain in Spink County, S. D.

Genesis of the Soils of Lake Dakota Plain in Spink County South Dakota

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INTRODUCTION

The Soil Survey of Spink County (47) provided an opportunity to study the field and laboratory characteristics of soils of the Glacial Lake Dakota Plain.[1] Spink County comprises an area of 936,840 acres in east-central South Dakota. The Glacial Lake Dakota Plain makes up about 460,000 acres (49%) of Spink County (See fig. 1). Although the Lake Plain extends also into Brown, Marshall and Day counties, only the Spink County portion is considered in this bulletin.

The proposed Oahe Irrigation Project for South Dakota includes most of the area of the Glacial Lake Dakota Plain. This Plain, late in the glacial period, was the floor of a large lake. The resulting flat topography, the friability of the lake-deposited silts and clays, plus its large extent, all are factors explaining the appeal of this Glacial Lake Plain for irrigators.

Although favored by flat topography and friable soil-forming materials, much of the Lake Plain has soils characterized by a dense, hard, claypan subsoil. These soils are called Solonetz soils, and due to the character of the subsoil, their value for irrigation is less than that of the friable associated soils which are classified as Chernozem soils. Since both Solonetz and Chernozem soils are developed from the same parent materials, and since there is some basis for relating Solonetz soil formation (Solonization) to poor drainage, there is concern that irrigation may "salt out" or cause solonization to occur in the friable Chernozem soils. An understanding of the genesis of Solonetz soils can prevent this from happening. Moreover, an understanding of the solonization process may furnish clues for the successful irrigation of some of the Solonetz soils themselves.

The purpose of this publication is to describe the kinds of soils on the Glacial Lake Dakota Plain and to discuss their genesis or mode of formation. From this information some conclusions are drawn relative to the behavior of the soils under irrigation.

[1]The Spink County Soil Survey is available from the County Extension Office or SCS Office in Redfield, or may be obtained from Bulletin Room, South Dakota State University, Brookings. The published soil survey includes line maps at a scale of 1 inch=1 mile. Larger scale aerial photo soil maps also are available.

Discussion of the Terms Solonetz, Chernozem, Regosol

Solonetz Soils

The term "Solonetz" is of Russian origin and literally means "little salt." It was used along with the term Solonchak (literally "much salt") to describe the salt-affected soils of the subhumid to semiarid steppes of Russia. Vilensky (45) states that these Solonetz soils had dense, columnar-structured B horizons leached of salt while the Solonchak soils were those containing rather high concentrations of salt and no distinctive structure. This is essentially the way Glinka (12) defined Solonetz and Solonchak in his classification system.

Gedroiz (9, 10, 11) attached importance to sodium in the formation of Solonetz soils. He defined these soils as having a hard columnar structure and he believed that at one time they contained an excess of sodium salts.

Shaw and Kelly (34) credit Marbut with introducing the term Solonetz into the United States literature. Marbut stated that these soils had a heavy textured, dense, clayey, B horizon which breaks into round-topped columns when dry.

The Soil Survey staff of the USDA in the *Soil Survey Manual* (38) felt that the term had a genetic significance and defined a Solonetz as a soil having a dense, columnar B horizon formed by dispersion of clay by the sodium ion. The B horizon was considered solonetzic if 15% or more of the exchangeable ions were sodium.

Prior to publication of the *Soil Survey Manual,* soils were described which had very small amounts of exchangeable sodium, but high amounts of exchangeable magnesium. These soils had all of the morphological characteristics of Solonetz. These soils were described in Manitoba by Ellis and Caldwell (8); in the Red River Valley by Nikiforoff (27), and by Rost and Maehl (33); in California by Nikiforoff (28), Kelley (20), and Storie (41); in Alberta by MacGregor and Wyatt (24); in Saskatchewan by Mitchell and Riecken (26), and Bentley and Rost (2); in Minnesota by Rost (32); in Europe by Joffe (17); in Australia by Teakel (43); in North Dakota by Kellogg (22), and by Marbut (25). Ellis and Caldwell (8) suggested the name "magnesium Solonetz" be used for these soils.

In spite of the wide occurrence of soils having clays with high magnesium and low sodium saturation, the effect of the magnesium ion in causing dispersion is still in dispute. However, the importance of high sodium saturation in causing the dispersion of solonetzic soils has never been questioned.

In the *Comprehensive System of Soil Classification* (39) many of the Solonetz soils are placed in the system by recognition of a "natric horizon" which is defined as a special kind of argillic (claypan) horizon which has prismatic or blocky structure and a subhorizon having more than 15% sodium saturation. If an underlying C horizon has more than 15% saturation with sodium in some part, the natric horizon may have more sodium plus magnesium than calcium plus hydrogen.

The dense subsoil of Solonetz soils has low permeability for moisture, air and plant roots. Following saturation by water of the friable material above the dense subsoil, water tends to pond and waterlogged conditions prevail. Soil when worked in this condition will puddle, resulting in a poor seedbed in the plow layer while the subsoil remains dry.

Plant roots need oxygen which exists in pores normally occupying about a fourth of the soil volume. Solonetz soils are compacted and hence are low in pore space. Smaller amounts of oxygen, therefore, are available to plant roots and the essential microorganisms of soils. Poor root growth results and, in addition, growth of undesirable microorganisms, which may produce toxic substances, is encouraged.

The principal Solonetz soil series of the Glacial Lake Dakota Plain include Harmony, Aberdeen, Exline and Tetonka. Of these four, the Harmony is the least compacted and in its present condition is considered a good prospect for irrigation. The Aberdeen and Exline soils have dense compacted B horizons. In the Aberdeen soil this B horizon occurs below a friable A horizon usually about 10 inches thick. In the Exline series the B horizon is within 6 inches of the soil surface. The Tetonka soil has a deep-lying B horizon but the soil occurs in poorly drained sites.

In summary, the Solonetz is a soil having a dense subsoil horizon having, usually, a columnar or prismatic structure of rounded tops. This subsoil horizon may presently contain 15% or more of exchangeable sodium, or if low in exchangeable sodium, it usually has a high proportion of magnesium ions with an underlying horizon containing a substantial exchangeable sodium content.

Chernozem Soils

The name Chernozem is used to describe friable soils, usually of medium texture, that have developed from calcareous materials in a subhumid climate under the influence of a native vegetation of grass. The soils have dark-colored friable surface horizons of soft granular or blocky structure, high in organic matter, friable subsoils of prismatic structure which in turn overlay a horizon of carbonate enrichment. The soils occur on gently sloping topographic positions and in their present state are excellent prospects for irrigation. Great Bend and Beotia are the most extensive Chernozem soil series on the Glacial Lake Dakota Plain.

Regosols

Regosols are thin friable soils occurring on fairly sloping positions which usually are the upper slopes of valley sides of the James River and tributary streams. The soils are calcareous at or near the surface and have rather low organic matter content. Leveling operations in connection with irrigation likely would expose the raw soil-forming material. Shallow profiles and sloping positions of these soils detract from their ability to respond favorably to irrigation. These soils are of small extent on the Glacial Lake Dakota Plain and Zell is the only soil series recognized.

Soils of the Glacial Lake Dakota Plain

General Description. Seven soil series[2] make up about 90% of the soils of the Glacial Lake Dakota Plain in Spink County. These seven series are listed and classified in table 1 and their areal extent shown. A block diagram, figure 2, shows the mode of occurrence of the soils.

The Zell, Great Bend and Beotia soils were described briefly above.

The Harmony, Aberdeen and Exline soils are all classified in the solodized Solonetz group. The Harmony and Aberdeen soils are differentiated on the degree of compaction of the solonetzic or B horizon —the Harmony has slight, and the Aberdeen moderate to strong compaction. The Exline soil has strong compaction and the solonetz horizon occurs within 6 inches of the surface. In establishing the differentiating characteristics used in separating these three series, the degree of compaction of the solonetz horizon was thought to be of prime importance. From a genetic point of view, compaction of the solonetz horizon mirrors the degree of dispersion which this horizon has undergone. And from a practical point of view this easily recognizable field characteristic is an accurate index of the relative value of the soil for dry-land farming and also for irrigation.

Harmony and Aberdeen soils both have friable, dark gray, crumb-structured Al or surface horizons, 8 or 9 inches thick underlain by thin, friable, light gray, platy A2 horizons 3 to 4 inches thick. The surface horizon of Exline is less than 6 inches thick. The thin gray A2 horizons are progressively ligher colored and more distinctly platy in the Harmony than in the Aberdeen and Exline series. The solonized B horizons of these three series range from 6 to 12 or 14 inches in thickness grading rather abruptly into the horizon of lime and gypsum accumulation at about 24 inches. The B horizon of the Harmony series is blocky-structured with the medium-sized blocks yielding to moderate pressure to form hard, very fine blocks. The blocks are darker colored than the plates of the A2 horizon. The B horizon of the Aberdeen series has a subangular or cloddy structure which breaks with difficulty into smaller clods of slightly lighter color. The color of the larger clods is very dark brown. The B horizon of the Exline series is roughly columnar, black, and so hard that the dry

[2]Soil series are not equivalent to irrigation land class although a relationship between the two exists. Irrigation land class is an economic classification in which the soil physical and chemical characteristics are only one factor. Also considered in land class is accessability, slope, irrigation pattern, surface leveling, cover, and drainage factors including surface outlet and subsurface drainage.

structural units cannot be broken in the hand.

The Tetonka series is classified in the Soloth group. These soils have friable, dark gray, platy A2 horizon 8 to 15 or 20 inches thick. The A2 horizon grades gradually into a firm, black, blocky B2 horizon which extends down 50 or 60 inches. In places these soils have been weathered so deeply that there is no horizon of lime accumulation within 6 or 7 feet of the surface.

The descriptions of the seven lake bed soils given above are for the modal profiles. These are the profile models to which the soil surveyor compares the profile he is attempting to classify. Much field study preceded the decision in each case as to what set of morphological features was to be considered modal. Several sub-units of each of the solonetzic series were differentiated in the survey, based on thickness of, and depth to, the solonetz horizon. Although this variation within a soil series, which in some cases is considerable, does exist, it is felt that the sub-units within each series are genetically similar to the modal profile of its series.

Detailed descriptions of soil profiles are placed in the appendix.

Topographic relationships. Tetonka, the Soloth, always occupies the lowest topographic position in the lake plain landscape. Usually this is a small channel which is not occupied by a permanent stream, or it may be an enclosed depression. The general topographic relationships of the soils are shown in figure 3.

The many small channels of the Lake Dakota Basin as well as the channels of the James River and its tributaries are characterized by having natural levees of low relief. The relatively sharp front-slope from the levee down to the channel is the typical site for the Zell and Great Bend series. The levee itself which is the high point in the landscape is occupied by the Beotia series. Where the gentle back-slope of the levee grades into the dead flat, the Harmony soils are found. The Aberdeen soils are found on the

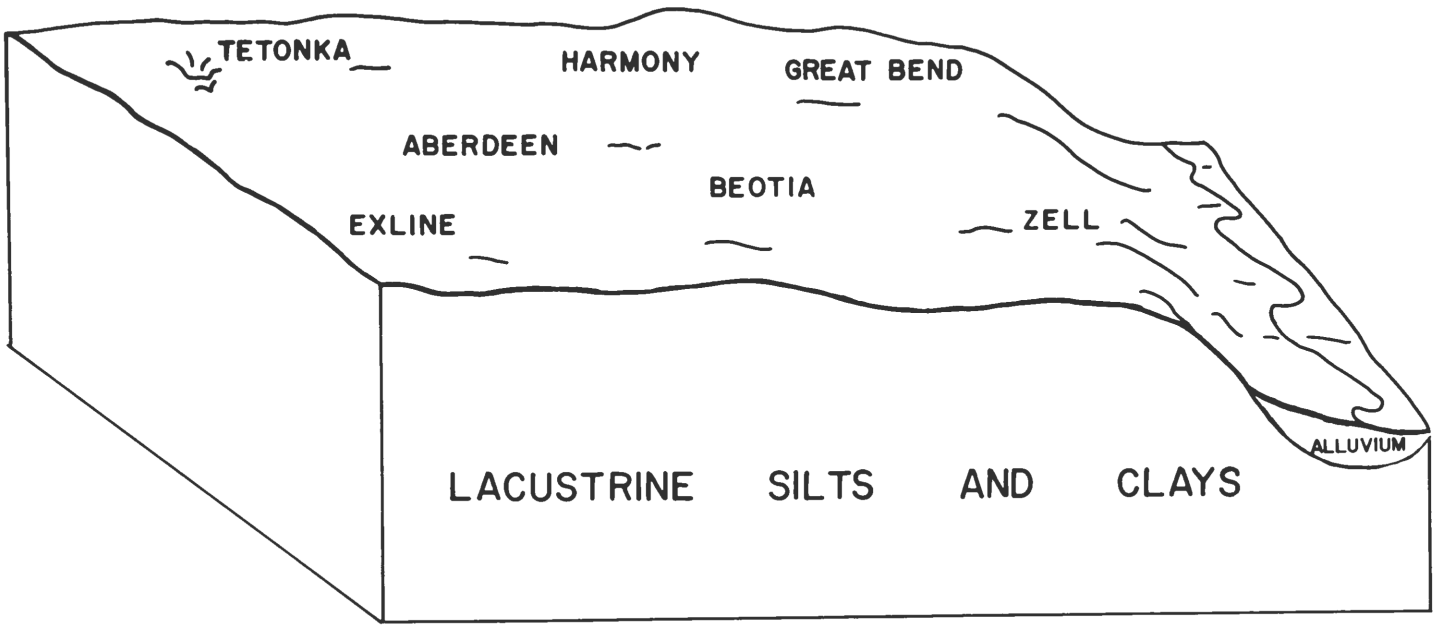
Table 1. Classification of the seven principal soil series of the Glacial Lake Dakota Plain in Spink County.

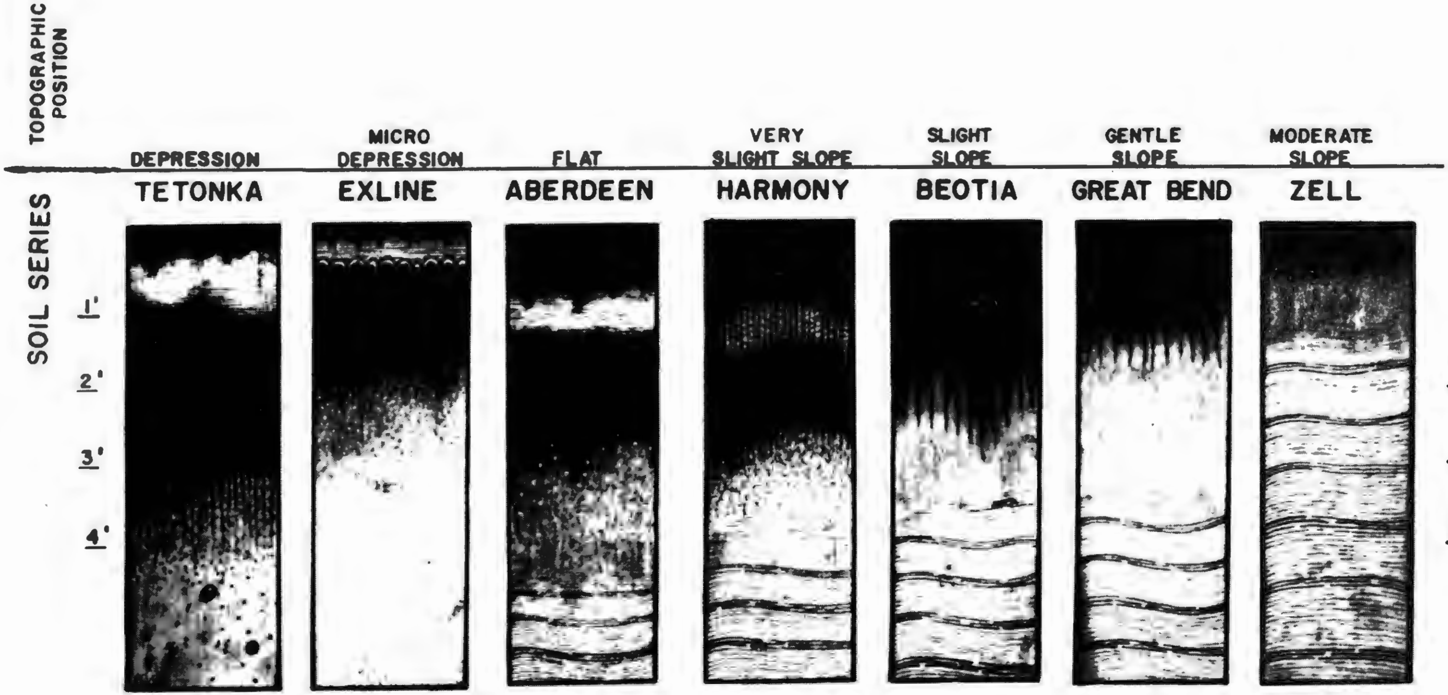
Series†	Classification	Natural drainage	Approximate acreage
Zell	Regosol	Somewhat excessive	8,901
Great Bend	Chernozem	Well	43,853
Beotia	Chernozem	Moderately well	84,884
Harmony	Solodized Solonetz	Moderately well	85,931
Aberdeen	Solodized Solonetz	Somewhat poor	145,830
Exline	Solodized Solonetz	Poor	35,032
Tetonka	Soloth	Very poor	20,000*
			424,431

*The acreage for Tetonka is difficult to obtain since this soil was mapped both on the Lake Plain and the Till Plain in Spink County.

†Soil series are not equivalent to irrigation land class although a relationship between the two exists. Irrigation land class is an economic classification in which the soil physical and chemical characteristics are only one factor. Also considered in land class is accessability, slope, irrigation pattern, surface leveling, cover, and drainage factors including surface outlet and subsurface drainage.

Figure 2. Topographic Relationships of Soils




TOPOGRAPHIC POSITION
DEPRESSION
MICRO DEPRESSION
FLAT
VERY SLIGHT SLOPE
SLIGHT SLOPE
GENTLE SLOPE
MODERATE SLOPE
SOIL SERIES
TETONKA
EXLINE
ABERDEEN
HARMONY
BEOTIA
GREAT BEND
ZELL
1'
2'
3'
4'

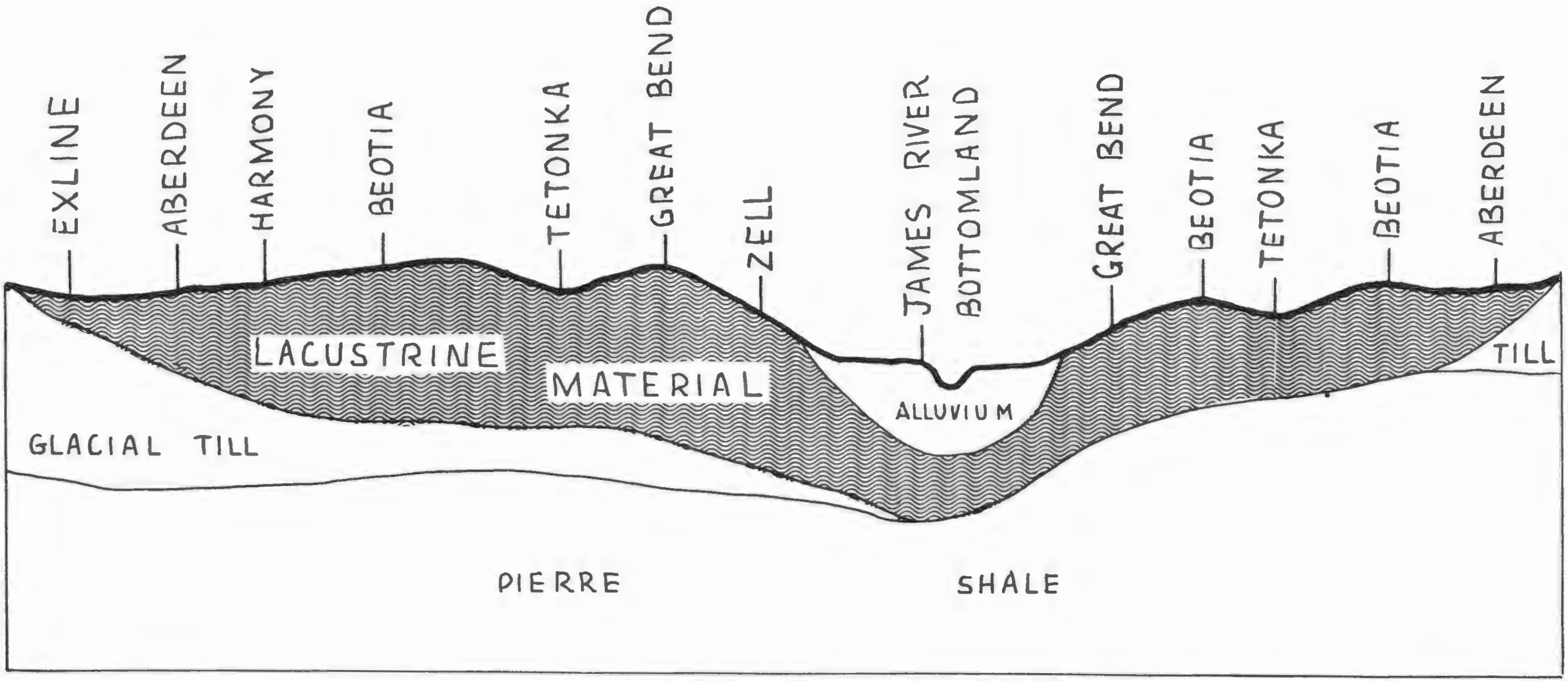


Figure 3—Slope relationships of the Lake Dakota Plain soils.

dead flats and the Exline soils occur in the slightly depressed areas; thus, under ideal conditions, these soil series occur in tracts which roughly parallel the drainage channels. In practice, however, ideal conditions do not always prevail. For example, the sequence may be broken if a slight basin occurs immediately back of a levee. In this case Exline would be found alongside Great Bend or Beotia.

Although, in general, these soils occur as fairly homogeneous belts roughly paralleling the drainage channels, it often happens that they occur in complexes with one another. That is, two or more soil series occur in such intimate association that the individual series cannot be delineated regardless of how large a scale is used on the map. This complex occurrence, which is associated with a microrelief topography, is much more typical of two or more solonetzic soils than it is of the Chernozem soils.

Genesis of Soils

As indicated in the preceding discussion, topography provides a useful tool in determining the kind of soil that will develop on the Lake Dakota Plain. Important also in this regard are the other factors of soil formation—climate, parent material, organisms and time. These factors, with the exception of time, usually are interdependent variables. The specific topographic positions of the solonetzic and Chernozem soils on the lake bed have been noted. The principal effect of topography is to control the movement of surface water. The Zell, Great Bend and Beotia soils occur on topographic positions which allow excess water to drain off the soil surface rather than into the soil profiles. On a very slight slope, Harmony, the slightly solonized member, occurs. On a dead flat where water neither runs off nor is collected, Aberdeen, the moderately solonized member occurs. In slightly depressed areas, Exline, the strongly solonized soil is found. In these low areas the soil not only must dispose of precipitation received but also of the water which flows in from higher-lying areas. In depressions which receive considerable excess runoff water and may contain temporary ponds, Tetonka, the Soloth soil, occurs.

Solonetzic soils do not form by simple leaching. If leaching alone were responsible for their formation, the Chernozem soils also would be solonized because they are leached to 2 feet or more. The difference in environment between the Chernozem and solonetzic soils is that on flat topography the slowly permeable, laminated substratum causes ponding to occur in the solonetzic positions while the slope of the Chernozem and Regosol soils causes any excess water to run off. Field observation is that solonetzic profiles nearly always contain excess water in the early part of the spring. They almost invariably dry out in late summer, however, and deep borings show that when dry there is no water table within 10 feet or more of the surface. Thus, during spring and early summer the slowly permeable substratum appears to cause a perched water table so that water, ponded by a flat or depressed topography, evaporates or escapes only slowly by percolation. Finally, in late summer, excess water is evaporated, is transpired by plants, or leaches slowly through the profile. The laminated structure of the parent material contributes toward solonization by helping to establish a wetting and drying environment.

Mechanical analyses data indicate that the parent materials of the lake bed solonetzic soils are finer textured than those of the Great Bend soils. The texture of the parent material of the Beotia series most nearly resembles that of the solonetzic soils.

Not only the structure and texture of the lake bed sediments but its chemical nature contributes to the genetic environment for solonization. Of 15 samples of the Exline parent materials tested, all of them had 0.4% or more of soluble salts present. Moreover, the pH of these samples in a soil-water suspension of 1:10 was 8.5 or higher, indicating presence of some sodium.

The saline and alkali characteristics for typical parent materials of the six lake bed soils investigated in this publication are listed in table 2. These data indicate that the parent materials of this Beotia soil and of the three solodized-Solonetz soils—Harmony, Aberdeen and Exline—were strongly saline. The parent material of this particular Great Bend was not saline while that of the Tetonka was not reached in the sampled depth. The Beotia, Aberdeen and Exline parent materials, in

Table 2. Saline and alkali characteristics of parent materials of six Lake Dakota Basin Soils described in Appendix.

		Salts*	Alkali†	
Soil series	Depth of horizon (inches)	Conductivity of saturation extract, mmhos/cm	Percent exchangeable sodium	Classification‡
Great Bend	36-53	0.4	0.9	normal
Beotia	46-60	13.5	42.1	saline-alkali
Harmony	40-60	11.0	13.8	saline
Aberdeen	40-60	9.5	24.2	saline-alkali
Exline	46-60	9.8	17.4	saline-alkali
Tetonka	64-90	0.3	1.7	normal

*Saline if conductivity of saturation extract 4 mmhos/cm.

†Alkali if percent exchangeable sodium exceeds 15. These data are from analyses done by the Bureau of Plant Industry, Soils and Agricultural Engineering, Mandan, North Dakota.

‡These saline and alkali standards are taken from the Regional Salinity Manual (43). The term "alkali" is used in these standards and in portions of the discussion herein as an adjective, in quotation marks, as well as a noun.

addition to being saline, are also classed as "alkali." The Harmony parent material narrowly misses being "alkali" while the parent materials of Great Bend and Tetonka have very low percentages of exchangeable sodium. Thus, for these profiles the parent materials for the Solonetz soils were saline and high in exchangeable sodium. Beotia, a friable Chernozem soil, also has developed from very saline materials high in exchangeable sodium, indicating that a saline-alkali parent material alone will not insure solonization. The conclusion that salinity and/or an "alkali" condition of a soil's parent material, when taken by itself, is a passive rather than an active factor in the formation of natural Solonetz soils, is supported by additional data. Of the parent materials of 30 Great Bend samples tested, 11 of them, or 37%, were saline, and of 87 Beotia parent material samples tested, 35 of them, or 40%, were saline.

Although it cannot be stated definitely that lake bed soils developed from material similar to the horizon herein referred to as the soil parent material, it is reasonable to believe they were. It is likely that only the surface few inches of these soils have had some wind reworking. There could not have been a substantial amount of loess deposited on the Lake Plain or there would be the same loess mantle present on the glacial till soils surrounding the lake basin. These glacial till soils lack a loess capping.

In considering the environmental conditions of solonization, the possible addition to solonetzic soils of salts by seepage must be considered. To begin with, it would appear that an environment sufficiently salty for solonization is present in the soils studied simply by reason of the salt content of their parent material. In a preceding discussion of the topographic positions of the principal lake basin soils it was pointed out that the lower the relative topographic position on the lake basin, the more deeply the soil is leached. The end point is reached in the case of the Tetonka. The soil occurs in the lowest topographic position and is leached to 5 feet or more while the Great Bend soil occurring on the slope leading down to the Tetonka soil is leached only to 2 or 3 feet. It doesn't appear from this that much salt seeped from the calcareous Great Bend to the deeply leached, acidic Tetonka. It is far more likely that only enough water entered the Great Bend profile to maintain a slow rate of leaching. Water in excess of this ran over the Great Bend soil surface, which has a pH of about 7 and only a trace of soluble salts, down to the Tetonka position where it entered as practically salt-free water.

Data in table 2 show that the zonal soil, Beotia, has developed from saltier and more "alkali" material than have either of the two associated solonetzic soils. Data for the entire soil profiles, presented in table 8, show that in addition, the entire Beotia profile is saltier and has a higher exchangeable sodium content than have the three associated solonetzic soils. Although the Beotia soil occurs on a slightly higher topographic position than its three associated solonetzic soils, it does not appear likely that there was much loss by seepage of soluble salts, particularly sodium salts, from the Beotia soil to these three lower-lying solonetzic soils.

The biotic factor of solonetzic soil genesis in the Lake Dakota Basin is difficult to analyze since the native vegetation of the basin has largely been replaced by cultivated and introduced varieties of plants. Moreover, it is felt that solonization is essentially a chemical and physical, not a bacteriological phenomenon. However, the dispersed condition of the solonetz horizon may be caused in part by the lack of soil-aggregrating gums ordinarily produced by bacteria.

Considering the uncultivated portions of the lake bed, the dominant vegetation now growing on the principal soil series is as follows:

Great Bend, Beotia and Zell soils —Kentucky bluegrass *(Poa pratensis)*, Blue grama *(Bouteloua gracilis)*, and Needle-and-thread grass *(Stipa comata)*.

Harmony, Aberdeen and Exline soils — Western wheatgrass *(Agropyron smithii)*, especially if the solonetz horizon is near the surface. Other plants associated with these three series are Blue grama grass, Kentucky bluegrass and Wild rose *(Rosa arkansana)*. Western wheatgrass is usually the best plant indicator for Exline.

Tetonka soils—Tanweed *(Ploygonum muhlenbergia)*, Hop sedge *(Carex lupulina)*, and Curled dock *(Rumex crespus)*. In general, the best plant indicator for Tetonka is Tanweed.

Chernozem soils—These have a wide variety of plants growing on them with Kentucky bluegrass perhaps being the most common plant.

Based on radiocarbon studies of Nebraska artifacts by Arnold and Libby (1), the last Wisconsin glacial substage in South Dakota is thought to have occurred about 11,000 years ago. If this conclusion is approximately correct, the Lake Dakota Basin soils are somewhat younger than 11,000 years. That the Tetonka soils are leached to 6 feet or more is in itself evidence that considerable water has moved down through the profiles in these positions. The effective rainfall which these low-lying positions have received is considerably in excess of the average 18 inches of rainfall which is normal for the James Basin area.

It is apparent that sufficient time has passed for solonization to proceed quite far in soils of the Lake Dakota Basin. Undoubtedly the fine texture of the lake bed materials has been a factor in this since these fine-textured materials would give considerable surface upon which the soil forming processes could operate. Soils closely resembling Solonetz soils are known to have formed in very short time periods in these lake bed materials under certain conditions. For example, in the James Basin the principal source of well water is artesian and it has been a practice in this area to allow the wells to flow continuously. As a result, many farmsteads have a shallow artesian pond 5 or 10 acres in size. Because of high evaporation rate, the water in these ponds recedes in late summer exposing a wide shoreline of dispersed soils. These exposed soils are black and when wet are very sticky, but when dry they are extremely hard. They

Table 3. Analysis of artesian water in Aberdeen-Redfield district (Redfield well).

Chemicals	p.p.m.
SiO_2	11.0
Fe_2O_3 & Al_2O_3	8.8
Ca	34.0
Mg	19.0
Na & K	635.0
Li	Trace
CO_3	126.0
SO_4	1,061.0
Cl	159.0
Total solids by evaporation	2,054

appear quite similar to the B horizon of natural Aberdeen and Exline soils. The Lake Plain Area was settled in about 1900 so these "artificial Solonetz" soils have developed within about 60 years. Composition of artesian water from a James Basin well is given in table 3. It is the high sodium content of this water that is thought to give soils this dispersed condition. It was well known among settlers in the Lake Dakota Basin that artesian water was harmful to the soil. At least three rather large scale irrigation projects using artesian water were started and then abandoned when the soils became so dispersed they could not be cultivated.

Laboratory Results and Discussion

Physical Measurements.

1. **Bulk Density.** Bulk density results for five of the seven lake bed soils are listed in table 4. The C2 or parent material horizons of the Great Bend, Beotia, Harmony and Aberdeen soils are similar; all have a density of about 1.3. The parent material of the Tetonka soil was not reached in the sampled depth of 90 inches. The Beotia, Harmony, Aberdeen and Tetonka profiles show a similar pattern of density. Each succeeding horizon from the surface downward is more dense until the B2 horizon is reached and in all cases this is the most dense horizon in the profile. Proceeding from the B2 horizon to the parent material density gradually decreases. It is reasonable to expect the B2 horizon to be the most dense horizon in solonetzic profiles because it is dispersed and hence would be low in pore space. In comparing the B horizons of these profiles density increases from the Great Bend through the Beotia, Harmony, Aberdeen and Tetonka soils. These density results reflect degree of development. The Great Bend B horizon is relatively undeveloped and development is just starting in the Beotia B horizon. The Harmony and Aberdeen B horizons show, respectively, slight and moderate compaction. The bulk density results for the B horizon mirror the degree of solonization which was used in the field differentiation of these three solonetzic soil series. The increase in density of the A2, B and Cca horizons of these soils over the density of the parent ma-

terials seems to indicate that these horizons have all received materials from the leaching of overlying horizons or the soil fabric has collapsed. Undoubtedly both possibilities have been realized. It is not possible to give a quantitative expression to each because no independent reference such as percent resistant minerals is available for judging profile changes which have taken place.

The low bulk densities of the C2 horizons of these soils are noteworthy. In contrast to the low density of these lacustrine materials, the glacial till parent material of adjacent soils have a density of about 1.70.

2. Mechanical Analyses. The particle size distribution of five of the lake bed soils are given in table 5. Data are presented in percent.

Referring to data in table 5, it is seen that the two solodized Solonetz soils, Harmony and Aberdeen, and the Chernozem soil Beotia show, from the surface to the parent material, a decrease in sand and coarse silt and an increase in medium and fine silt and clay. The Great Bend soil, from the surface to the parent material, shows a decrease in sand and clay, an increase in medium and fine silt and a constant coarse silt content. Changes in Great Bend soil are of smaller magnitude than are

Table 4. Physical properties.

Horizon	Depth in inches	Bulk density	Percentage moisture for: Moisture equivalent	⅓ Atm.	15 Atm.	100 cm H_2O
GREAT BEND SILT LOAM (50-SD-58-6)						
A1p	0-11	1.34	26.0	30.8	12.3	46.2
B2	11-16	1.32	24.0	29.1	10.5	41.4
Cca	16-36	1.42	21.5	27.3	8.6	38.9
C1	36-53	1.31	24.8	34.3	8.9	43.2
C2	53-80	......	37.9	45.2	22.8	48.9
BEOTIA SILT LOAM (50-SD-58-4)						
A1p	0- 8	1.25	28.9	35.8	14.2	46.6
A2	8-11	1.36	26.1	31.2	14.9	41.3
B2	11-16	1.49	28.5	33.2	16.4	40.5
B3	16-21	1.44	26.7	33.7	13.5	42.4
C11ca	21-31	1.40	27.9	33.4	13.8	41.0
C12ca	31-46	1.37	37.4	43.7	16.5	51.3
C2	46-60	1.31	43.7	52.0	17.6	59.6
C3	60-80	......	43.2	51.7	32.2	59.5
HARMONY SILTY CLAY LOAM (50-SD-58-3)						
A1p	0- 7	1.25	34.3	40.4	17.0	53.1
A2	7-11	1.37	31.7	38.9	17.2	47.1
B2	11-18	1.64	28.8	33.8	17.8	43.2
B3	18-22	1.45	30.2	36.6	21.9	45.8
C1ca	22-40	1.39	34.2	38.8	15.8	47.4
C2	40-60	1.28	43.8	51.0	28.4	56.7
C3	60-80	......	45.3	51.7	36.4	59.8
ABERDEEN SILTY CLAY LOAM (50-SD-58-1)						
A1p	0- 7	1.18	35.7	42.5	17.0	50.9
A2	7-11	1.40	28.8	33.6	17.7	42.3
B2	11-18	1.74	31.8	36.5	20.8	43.8
B3	18-22	1.67	31.1	35.6	19.0	45.0
C11ca	22-30	1.34	30.5	34.6	16.7	44.4
C12ca	30-40	1.33	36.0	49.6	19.5	50.0
C2	40-60	1.33	42.8	41.4	38.6	56.8
C3	60-80	......	44.7	51.0	34.1	60.4

Table 5. Particle size analyses (particle size in mm.)

Horizon	Depth in inches	Very coarse sand 2-1	Coarse sand 1-0.5	Medium sand 0.5-0.25	Fine sand 0.25-0.1	Very fine sand 0.1-0.05	Total sand 2-0.05	Coarse silt 0.05-0.02	Medium and fine silt 0.02-0.002	Clay <0.002
ZELL SILT LOAM* (49-SD-58-9)										
A1	0- 8	0.1	0.2	0.2	1.8	20.8	....	37.9	21.5	17.5
AC	8-15	....	0.1	0.2	1.3	16.8	....	48.2	18.9	14.5
Cca	15-36	....	0.2	0.2	1.4	16.0	....	47.2	21.8	13.2
C1	36-60	....	0.1	0.2	1.2	17.3	....	46.3	21.3	13.6
GREAT BEND SILT LOAM† (50-SD-58-6)										
A1p	0-11	....	0.1	0.2	0.7	5.8	....	41.6	28.6	23.0
B2	11-16	....	....	....	0.7	3.6	....	40.7	32.9	22.1
Cca	16-36	....	....	....	0.5	5.2	....	46.6	30.1	17.6
C1	36-53	....	0.1	0.1	0.6	3.3	....	44.4	38.8	12.7
C2	53-80	....	0.1	0.1	0.4	0.4	....	8.3	69.0	21.7
BEOTIA SILT LOAM† (50-SD-58-4)										
A1p	0- 8	....	....	0.1	0.5	2.7	....	28.4	41.4	26.9
A2	8-11	....	0.1	0.1	0.2	3.7	....	27.6	41.6	27.7
B2	11-16	....	....	....	0.2	1.7	....	24.9	43.6	29.6
B3	16-21	....	0.1	0.1	0.2	0.7	....	24.5	48.7	25.7
C11ca	21-31	....	....	0.1	0.2	0.2	....	24.4	43.5	31.6
C12ca	31-46	....	....	....	0.2	0.2	....	8.2	58.7	32.7
C2	46-60	....	....	....	0.3	0.1	....	3.2	63.7	32.7
C3	60-80	....	....	....	0.4	0.1	....	17.2	43.2	39.1
HARMONY SILTY CLAY LOAM† (50-SD-58-3)										
A1p	0- 7	0.1	0.1	0.1	0.3	2.0	....	20.1	46.8	30.5
A2	7-11	....	....	0.1	0.3	1.9	....	18.0	45.9	33.8
B2	11-18	....	....	0.1	0.3	0.8	....	14.5	48.4	35.9
B3	18-22	....	....	0.1	0.2	0.8	....	11.8	53.9	33.2
C1ca	22-40	....	0.2	0.4	1.0	0.3	....	4.0	58.5	35.6
C2	40-60	....	....	....	0.4	0.2	....	0.8	64.7	33.9
C3	60-80	....	....	0.1	0.3	0.1	....	0.5	56.5	42.5
ABERDEEN SILTY CLAY LOAM† (50-SD-58-1)										
A1p	0- 7	0.1	0.1	0.2	0.4	1.8	....	18.2	47.7	31.5
A2	7-11	....	....	0.1	0.2	0.6	....	12.8	48.3	38.0
B2	11-18	....	....	....	0.2	0.5	....	8.3	46.3	44.7
B3	18-22	....	....	0.1	0.2	0.2	....	4.4	52.8	42.3
C11ca	22-30	....	0.1	0.1	0.2	0.1	....	1.2	49.8	48.5
C12ca	30-40	....	0.1	0.4	0.7	0.2	....	1.1	53.6	43.9
C2	40-60	....	....	0.1	0.3	0.1	....	0.7	59.5	39.3
C3	60-80	....	....	0.1	0.3	0.1	....	0.8	43.5	55.2
EXLINE SILT LOAM* (49-SD-58-5)										
A1	0- 2	0.2	0.6	0.6	2.0	4.2	....	24.4	42.1	25.9
A2	2- 4	0.1	0.5	0.5	1.6	3.2	....	18.9	48.9	26.3
B2	4-17	0.1	0.3	0.3	1.1	1.9	....	9.6	36.9	49.8
B3	17-20	0.1	0.2	0.2	0.6	0.9	....	4.5	44.4	49.1
Cca	20-36	0.2	0.2	0.2	0.6	1.4	....	7.7	43.6	46.1
II	36-65	4.2	6.9	6.2	7.7	16.0	....	11.4	15.4	22.2
TETONKA SILT LOAM† (50-SD-58-5)										
A1p	0-19	....	0.2	0.2	0.7	4.8	....	30.7	37.5	25.9
A21	19-26	....	1.0	0.7	1.0	6.3	....	33.5	37.6	19.9
A22	26-32	....	0.8	0.6	1.1	4.9	....	28.3	42.5	21.8
B2	32-41	....	0.1	0.1	0.5	2.7	....	22.6	36.2	37.8
B31	41-64	....	0.1	0.2	0.6	3.2	....	19.1	38.3	38.5
B32	64-90	....	....	....	0.4	3.7	....	13.5	30.8	51.6

*Analyses by Beltsville Laboratory of USDA
†Analyses by Mandan (N.D.) Laboratory (now at Lincoln, Nebraska) of USDA

those of the two solodized Solonetz soils. Tetonka soil shows a constant sand and medium and fine silt content from the surface to the parent material, a decrease in coarse silt and an increase in clay. As stated previously, the Harmony, Aberdeen and Exline soils, and to a lesser extent the Beotia soils, occupy flat, settling-basin topography. It is hypothesized that during the later stages of Lake Dakota, natural levees were built up by overflow and deposition of sediments along the numerous channels of the lake bed. Particle size data in table 5 show that these last sediments deposited on the lake basin are coarser than those deposited earlier. Apparently most of the Great Bend soils are developed from these younger sediments as are the upper portions of the Beotia, Harmony, Aberdeen and Exline soils. This mantle of young, coarser sediments is thinner on the Exline and Aberdeen soils which is expected because they are farthest removed from the channels. Particle size distribution of the Tetonka profile shows that it has probably received as much as 64 inches of local alluvium mostly from the younger, coarser lake bed sediments.

The B horizons of the Harmony, Aberdeen and Exline profiles show a distinct increase in clay content over that of their parent materials. Some of this increase is undoubtedly due to collapse and compaction of the soil fabric and some to weathering causing the formation of clay in place. Some also may be due to illuviation.

3. Other Physical Properties. Data for bulk density, moisture equivalent, and moisture held at ⅓ and 15 atmospheres of tension are in table 4. Moisture equivalent is used to show the activity of the clay and organic matter.

Excellent correlations are apparent between water held under tension and soil texture as reported in table 5. These data also are useful as a laboratory measure of the moisture storage potential of the soils.

Chemical Measurements.

1. Total Chemical Analyses. These data reflect the macro changes in soils that have taken place due to soil formation. Total chemical analyses also are of value

Table 6. Total chemical analyses of sel

Horizon and depth (inches)	SiO_2 Percent	SiO_2 Grams per 100 cc.	Al_2O_3 Percent	Al_2O_3 Grams per 100 cc.	Fe_2O_3 Percent	Fe_2O_3 Grams per 100 cc.	Ti Percent
GREAT BEND SILT LOAM (50-SD-58-6)							
B1 11-16	74.40	98.0	8.81	11.6	3.39	4.4	0.59
Cca 16-36	62.09	88.0	7.30	10.3	2.75	3.9	0.48
C2 36-53	64.30	84.4	8.85	11.6	2.96	3.8	0.47
HARMONY SILTY CLAY LOAM (50-SD-58-3)							
A2 7-11	68.40	93.8	12.00	16.4	3.79	5.2	0.64
B2 11-18	66.60	108.0	12.40	20.4	4.49	7.3	0.68
Cca 22-40	52.80	75.0	13.00	18.4	4.14	5.9	0.61
C2 40-60	55.60	71.0	11.70	15.1	4.17	5.3	0.63

in determining uniformity of soil parent materials and profiles which have developed from these parent materials. In addition, these data supply information on the chemical composition of glacio-lacustrine materials in an area where little previous information is available.

The total chemical analyses of selected horizons of Great Bend and Harmony are presented in table 6. Data are given in both percent and in grams per 100 cc. The chief difference in total chemical composition between the Great Bend soil and the Harmony is that in the Great Bend profile the four basic elements—calcium, magnesium, sodium and potassium—show highest concentrations in the horizon of lime accumulation, (Cca), while in the Harmony only calcium and magnesium have highest concentrations in the horizon of lime accumulation whereas sodium and potassium have highest concentrations in the B horizon. In the case of the other four elements analyzed – silica, aluminum, iron, and titanium —all show highest concentration in the B horizon in both Chernozem and solodized Solonetz profiles. The accumulation in the B horizon of these four elements is most pronounced in the solodized-Solonetz profile.

These data show a loss of some chemical constituents from the profile. The four basic elements—calcium, magnesium, sodium and potassium—appear to have been lost to some extent to the ground water while silica, aluminum, iron and titanium tend to be retained in the soil. Analyses by the U. S. Geological Survey (23) of James River water taken at Redfield show a fairly high content of bases. Bicarbonate and sulfate are the principal anions. Table 7 lists the U.S.G.S. data fore five periods over the years 1956-57. Leaching losses of the lacustrine soils are reflected, generally, in composition of the James Basin drainage waters.

2. Extractable cations and total exchange capacity; salinity, including total soluble salts, carbonates, gypsum and soluble sodium and potassium; organic carbon and total nitrogen; and soil reaction. These data for the seven soils are in table 8.

rizons of two Lake Dakota Plain Soils.

CaO		MgO		Na_2O		K_2O		Loss on Combustion	
cent	Grams per 100 cc.	Percent	Grams per 100 cc.	Percent	Grams per 100 cc.	per cent	Grams per 100 cc.	Percent	Grams per 100 cc.
.63	2.3	1.18	1.5	1.36	1.8	2.00	2.6	6.22	8.2
.92	12.7	3.19	4.5	1.30	1.8	2.10	3.0	10.19	14.4
.47	9.7	2.33	3.0	1.33	1.7	1.68	2.2	8.50	11.1
.35	1.8	1.05	1.4	1.23	1.6	2.45	3.3	8.01	11.0
.04	1.7	1.42	2.3	1.39	2.3	2.58	4.2	6.47	10.5
.95	14.1	3.32	4.7	1.21	1.7	2.22	3.1	12.26	17.4
.76	9.9	3.29	4.2	1.19	1.5	2.17	2.7	11.58	14.8

Extractable cations, total exchange capacity and salinity. The total exchange capacity for the soils was determined using ammonium acetate for extraction. When percentage of cation is mentioned in this publication it has been calculated on a total exchange capacity figure which is the sum of the extractable cations.

Regional Salinity Laboratory investigators in their manual (30) define a soil as "saline" if the conductivity of the saturation extract exceeds 4 millimhos per cm., and "alkali" if 15% or more of the exchangeable cations are sodium. According to this definition and considering the 5-foot soil profile, the Beotia and Aberdeen soils are "saline-alkali," the Harmony and Exline "saline-nonalkali," while the Great Bend and Tetonka soils are normal. The Great Bend and Tetonka soils miss being "saline-alkali" by a wide margin while the Harmony and Exline soils only narrowly miss being "saline-alkali." The Beotia soil is saline below 21 inches, the Harmony below 22 inches, the Aberdeen below 30 inches and the Exline below 17 inches. The Beotia soils are "alkali" below 23 inches and the Aberdeen below 40 inches. Thus the Beotia and Harmony soils are leached of high concentrations of salts and of "alkali" down to about 20 inches while the Aberdeen is leached of high salts down to about 30 inches and of "alkali" down to about 40 inches. Of the seven lacustrine soils studied, the Beotia profile is by far the most saline and has the highest concentration of "alkali."

According to the generally accepted theory on Solonetz soil formation, the B horizon has been dispersed due to the action of adsorbed

Table 7. Chemical analysis of James River at Huron (23).

	Aug. 13-24 1956	Oct. 6-8, 30-31 Nov. 2, 4-15, 1956	Jan. 1-17 1957	Apr. 5-7 1957	May 24 June 20 1957
Runoff (acre feet)	2,040	354	91	361	20,180
SiO_2 (ppm)	20	9.1	18	11	16
Ca	2.45	2.94	4.29	2.45	3.44
Mg	2.15	2.36	3.95	1.71	3.40
Na Equil	3.65	3.61	5.48	2.35	6.00
K per	0.33	0.31	0.36	0.28	0.43
HCO_3 million	4.29	4.34	6.11	2.82	4.38
SO_4	3.12	3.77	6.41	3.44	6.95
Cl	1.07	1.07	1.80	0.62	1.69
F	0.01	0.01	0.01	0.02	0.02
NO_3	0.01	0.01	0.03	0.01	0.01
Bo (ppm)	0.32	0.28	0.72	0.20	0.43
TDS (ppm)	509	545	884	429	840
% Na	43	39	39	34	45
SAR	2.4	2.2	2.7	1.6	3.3
Conductivity micromhos at 25 degrees C	794	861	1300	600	1230
pH	7.8	8.2	7.9	7.8	7.6

Remarks: TDS=dissolved solids; SAR=Sodium absorption ratio. Extremes for Aug. 1956 to Sept. 1957—Specific Conductance: Maximum daily, 2,270 micromhos March 9; Minimum daily, 483 micromhos March 30. Percent sodium: Maximum, 55 May 1-10; Minimum, 30 March 29 to April 4.

sodium (14, 38, 47, 48, 51, 52, 53). Data for the lake bed soils show that exchangeable sodium is low in the B horizon of the solonized soils—Harmony, Aberdeen and Exline. It is significant that the Beotia soil has a higher exchangeable sodium content than the three solonized soils. It is expected that the B horizon of Tetonka, the Solod soil, should have a low exchangeable sodium content. Although sodium makes up less than 10% of the exchangeable cations in the B horizons of these soils, the content of exchangeable magnesium is very high, making up over 50% of all exchangeable cations in the zonal Beotia B horizon and the B horizons of the Harmony and Aberdeen soils. This pattern of low exchangeable sodium and high exchangeable magnesium in the B horizons of solonized soils is of wide occurrence as has been referred to earlier under the discussion of the term Solonetz. It is discussed further here. The question arises: What is the role of magnesium in the solonization process?

Breshkovsky (6) carried out irrigation experiments to determine the effects of calcium, magnesium and sodium salts on the structure of soils. In cases of complete saturation with a single cation, the relative values for magnesium and sodium, respectively, (compared to calcium = 100) were: dispersion 132, 1358; rate of swelling, 226, 5384; reduction in velocity of filtration, 223, 6778.

Usov (44) found that with more than 40% of the total absorptive capacity of a soil saturated with magnesium, the soil acquires certain saline properties (including hygroscopicity, dispersion, swelling capacity, coloration of the filtrate, and diminished permeability to water) but to a far smaller degree than with sodium.

Joffe (17) states that the cation effect on dispersion is an expression of peptization and can be measured quantitatively. He believes it follows the Hofmeister series where Li>Na>K>Mg>Ca>Ba.

Ellis and Caldwell (8) believe magnesium clays can be highly hydrated and that the whole process of solonization can take place without the presence of appreciable quantities of sodium.

Joffe and Zimmerman (16) conclude from some experiments with calcium, magnesium and sodium, that the calcium-magnesium ratio and percent sodium give the clue to solonization. They conclude that if sodium is present in low concentration, the calcium-magnesium ratio may be narrow. If much sodium is present, the calcium-magnesium ratio must be wide. This essentially is what what White and Papendick (48) concluded in South Dakota. Joffe and Zimmerman state that in the case of the narrow calcium-magnesium ratio where the sodium content is low, it is rather the low calcium than the high magnesium that is harmful to the soil and plant.

Kelley (21) believes exchangeable magnesium may have contributed to solonization.

Sushko (42) concludes that the amount of exchangeable magnesium present is correlated with the degree of solodization in the profile but does not associate the presence of this base with the evolution of the profile.

Riecken (31) assumes that magnesium does not function in the role of sodium in Solonetz genesis.

Bentley and Rost (2) assume that sodium is responsible for solonization and that magnesium accumulates after solonization.

Joffe (17) quotes Antopov-Karatev that magnesium acts additively to sodium toward solonization; and Sedletsky that magnesium does not cause much solonetzic effect in the absence of sodium.

Scientists at the Regional Salinity Laboratory (30) say the physical properties of nonsaline-alkali soils (which approximate Solonetz soils) are largely determined by the exchangeable sodium present.

Klages (19) has shown experimentally that high exchangeable magnesium and exchangeable sodium at the levels found in solonetz samples were each capable of increasing dispersion and decreasing permeability of the samples investigated.

Smith et al. (37) conclude that magnesium does not cause deterioration of the physical properties of soils high in calcium. White and Papendick (48) in describing a thin Solonetz developing in bedrock conclude that sodium causes solonization in the absence of mineral calcium.

Some workers, therefore, believe that magnesium by itself may cause some dispersion and decrease permeability but only if calcium is low. If calcium is present in quantity, magnesium alone is ineffective. Sodium, on the other hand, apparently can cause dispersion even if calcium is high if a wetting and drying environment is present. If a wetting and drying environment is not present, sodium in sufficient amounts still can cause dispersion if calcium is low.

It was mentioned in the general description of the Beotia soil than an incipient gray A2 layer was apparent when the profile had been allowed to dry thoroughly although there was no field evidence of solonetzic development in the B horizon. From this it was deduced that the Beotia soil was in the balance between a zonal soil and a solonetz during its genesis. The slight slope on which it occurs precluded all but minor ponding and this is what prevented it from becoming solonized since it appears to have the chemical potential for solonization. The B horizon of the Beotia soil has the same pattern of exchangeable base saturation (57% Mg, 9% Na, 28% Ca, 6% K) as is displayed by the Harmony and Aberdeen soils, yet it did not solonize while the others did. It appears then that in the case of the Beotia soil, exchangeable mangnesium accumulated by a process other than that of solonization and that exchangeable magnesium alone cannot alone cause solonization.

Another question then becomes apparent: What is the source of exchangeable magnesium and how is it retained?

Kelley (21) and Joffe (17) believe that the bulk of magnesium in Solonetz soils is inherited from the Solonchak from which it has descended. It enters the exchange because the solubility limits for calcium compounds are exceeded before those for magnesium compounds.

Riecken (31) believes that in the

B horizon of the solodized-Solonetz soils of Saskatchewan there is considerable magnesium released by weathering-in-place while at the same time calcium is removed from this soil horizon by plant roots. He found that at high pH's the percentage of exchangeable calcium released to the plant is greater than the percentage of exchangeable magnesium.

Bower and Truog (3) give what may be a mechanism for the retention of exchangeable magnesium at the expense of other cations. They state that both calcium and magnesium form basic exchange salts in aqueous and alcoholic solutions at pH 7. It was found that more magnesium than calcium salts were formed; the exchange capacity for magnesium being 131.4 against 126.8 for calcium. The difference would be greater for pH's over 7.0. It was noted throughout the study that cations which form basic exchange salts are much more difficult to displace.

Staikoff (40) found the absorbability of magnesium relative to calcium is favored by an alkaline reaction. No mechanism is given.

Magnesium may not always follow sodium on the exchange, however. White (49) describes a soil which he calls a solodi in which he feels calcium has replaced sodium giving a soil that he believes will not degrade but will develop planosolic characteristics.

Soils having higher magnesium than calcium percentages are not confined to arid regions or solonetzic soils, however. Jeffries and White (19) report on a gray-brown podzolic soil in Pennsylvania developed from dolomite which has more magnesium than calcium in certain horizons, and Bray and DeTurk (4) report on a gray-brown podzolic soil from southern Illinois which shows the same chemical pattern. Brown et al. (7) and Bray (5) report that as weathering progresses in soils, total magnesium increases relative to total calcium. This conclusion can be drawn from the data on total analyses presented for the soils reported on in this bulletin.

One reason frequently advanced to explain the retention of magnesium in soils is that magnesium forms resistant minerals in soils while calcium does not. This explanation undoubtedly helps to account for the fact that total magnesium increases relative to total calcium. However, in the cases where exchangeable magnesium increases relative to exchangeable calcium, it would not seem to apply.

The environment under which solonization takes place has been investigated by a number of workers. White (50) has demonstrated the importance of a description of the environment when discussing solonetz soil genesis. Authors of the *Soil Survey Manual* (38) feel that solonization is initiated by improved drainage of a saline soil. Then with leaching and removal of excess salts, the sodium Solonchak may change to a Solonetz or solodized-Solonetz and perhaps finally to a Soloth, before the process responsible for the development of a zonal soil becomes dominant.

Other investigators have been more specific in detailing the local climate and parent material environments of solonization. Hilgard

(13) in explaining the formation of sodium carbonate in alkali soils states that the reactions involving the formation of this salt have been "found to occur most readily in the moister portions of the soil and subsoil and invariably when an alkali soil is swamped by excess irrigation or rise of bottom water." Glinka (12) describes the environment of alkali soils as one of "temporary excessive moisture." Glinka believed that the columns of the Solonetz develop after drying. Ellis and Caldwell (8) believe that the Magnesium Solonetz soils of Manitoba are due to "periodic swamping of highly plastic clays." De Sigmond (35) concludes that the factors responsible for formations of alkali soil are: an arid or semiarid climate, an impervious subsoil or hardpan layer, and a temporary abundance of humidity in the soil interspersed with dry periods. De Sigmond believes the wet-dry environment causes desalinization, alkalization and salinization having occurred concomitantly at an earlier stage. Smith (36) in describing the environment of Solonetz soils of southwestern Australia says that these soils occur in depressions and flats where surface drainage is poor and water-logging occurs during the winter months while drought conditions prevail during the long dry summer.

Nikiforoff and Drosdoff (29) describe the local climate of the Dayton soil, a Solod, as being water-saturated soon after the beginning of the rainy season then becoming thoroughly desiccated during the hot dry summer.

Although not specifically relating the process to Solonetz formation, it is pointed out by workers at the Regional Salinity Laboratory (30) that exchangeable sodium may be adsorbed by soil colloids in a wet-dry environment even though sodium is present in small concentration in the soil solution. In general, half or more of the soluble cations must be sodium before appreciable amounts are adsorbed by the colloids. However, upon drying, calcium and magnesium compounds precipitate as their solubility limits are exceeded and the sodium concentration increases to the point where sodium may be absorbed.

Although a fluctuating water table is mentioned by many writers as a part of the environment of solonization, White and Papendick (48) describe a solonetz formed under well drained conditions. They conclude that in this case a solodized solonetz developed due to the action of the sodium ion where mineral-Ca was low. Genesis here was not related to a fluctuating water table.

The material from which the Solonetz and related soils have developed has received attention from some authors. Shaw and Kelley (34) in defining the morphology of a typical Solonetz soil say that the C horizon generally consists of stratified sediments of alluvial, lacustrine or marine deposition. Ellis and Caldwell (8) state that the magnesium Solonetz soils of Manitoba occur on the fine lacustrine clay of glacial Lake Agassiz. De Sigmond (35) states that the parent material of leached alkali (Solonetz) soils in Hungary is "bluish gray impervious lake clay." White and Papendick

(48) describe a solonetz developed from sodium-rich residual bedrock. Wilding and others (53) describe solonetz soils from Illinois developed in loess. The sodium causing dispersion in these soils was thought to be released by weathering in place of sodium-rich feldspars. Solonetz soils are developing in loess, glacial till and residual materials in South Dakota. Although solonetz soils often developed on flats from transported material, the conditions for parent material must only include the presence of sodium or conditions for its release by weathering and either a low percentage of calcium or a wet-dry environment.

It appears that most workers feel activity of the sodium ion is the major cause of solonization. Magnesium ions may be abundant in solonized soils but apparently they have accumulated after dispersion by sodium or, if present during dispersion, they had little effect upon it. For the soils of the Lake Dakota Plain the source of sodium apparently is the lacustrine parent material which is saline-alkali.

The environment usually associated with solonization includes a fluctuating water table but solonetz soils may be well drained if conditions allow sodium to remain on the exchange.

Referring to table 8 it is seen that the B horizon of the zonal Beotia soil has the most favorable chemical potential for solonization of any of these seven soils. It has the highest percentage of exchangeable sodium and in addition has a high exchangeable magnesium percentage. If exchangeable magnesium alone were responsible for solonization, this soil should be a Solonetz. Moreover, the parent material from which it has been derived has the highest salinity of any of the soils here considered. Actually Beotia soil exhibits no textural, structural or color manifestation of solonization in the B horizon. It is believed that the explanation for this anomaly lies in the fact that the Beotia soil has not had the wet-dry environment necessary for solonization. It has been stated that the Beotia soil is found only on a sloping surface where it has not had a wet-dry environment. The environment it did have apparently resulted in an almost immediate loss by leaching of sodium. The Exline has a smaller percentage of exchangeable sodium but the depressional position of this soil plus a nearly impermeable substratum caused periodic saturation to take place allowing the exchangeable sodium present to be fully effective. The low percentage of exchangeable calcium and the high percentage of exchangeable magnesium and potassium may also have contributed toward solonization. It is noted that the slightly solonized Harmony soil has present slightly more exchangeable sodium than does the moderately solonized Aberdeen soil. Here again, however, as Aberdeen soil occurs on a dead flat and Harmony soil on a very slight slope, the former has a chance to become more completely dispersed because it remains wet for a longer period before desiccation. In addition, Harmony soil has more exchangeable calcium and less exchangeable magnesium than does Aberdeen soil. Apparently all of these solodized Solonetz soils at one

Table 8. Total exchange capacity, extractable cations, solub gypsum, organic carbon, total nitrogen, an

Horizon and depth (inches)		Total exchange capacity	Extractable cations me. per 100 gr. CA	Mg	Na	K	H	Soluble sodium and potassiu me. per 100 gr. Na	K
ZELL SILT LOAM (49-SD-58-9)‡									
A1	0- 8	20.8	*	*	0.1	1.3	–	0	0.
Ac	8-15	14.3	*	*	0.1	0.6	–	0	0.
Cca	15-36	12.1	*	*	0.1	0.5	–	0	0
C	36-60	12.3	*	*	0.4	0.7	–	0	0
GREAT BEND SILT LOAM (50-SD-58-6)†									
A1p	0-11	24.15	17.47	6.54	0.26	2.31	0.9	0.00	0.
B2	11-16	17.65	*	*	0.23	1.38	–	Trace	0.
Cca	16-36	12.72	*	*	0.12	1.24	–	Trace	Tr
C1	36-53	12.63	*	*	0.40	1.03	–	0.10	0.
C2	53-80	16.84	*	*	0.80	1.65	–	0.30	0.
BEOTIA SILT LOAM (50-SD-58-4)									
A1p	0- 8	25.27	12.99	8.59	0.89	4.26	3.7	0.1	0.
A2	8-11	23.36	8.53	12.20	1.64	2.12	2.4	0.1	0.
B2	11-16	26.29	8.05	16.10	2.62	1.56	–	0.4	0.
B3	16-21	21.99	*	*	1.47	1.73	–	3.4	0.
C11ca	21-31	16.69	*	*	5.56	1.35	–	6.3	0.
C12ca	31-46	20.33	*	*	5.16	1.98	–	7.7	0.
C2	46-60	21.85	*	*	9.25	2.46	–	7.2	0.
C3	60-80	22.84	*	*	3.90	3.33	–	6.4	0.
HARMONY SILTY CLAY LOAM (50-SD-58-3)									
A1p	0- 7	32.49	20.61	8.68	0.46	3.86	4.0	Trace	0.
A2	7-11	29.19	15.23	11.76	0.47	2.32	2.8	Trace	0.
B2	11-18	28.76	9.91	16.74	1.06	1.68	2.1	0.1	0.
B3	18-22	24.26	*	*	2.46	1.44	–	0.5	0.
C1ca	22-40	19.43	*	*	0.80	0.98	–	3.2	0.
C2	40-60	23.15	*	*	3.23	2.04	–	4.5	0.
C3	60-80	24.94	*	*	2.70	2.13	–	6.1	0.
ABERDEEN SILTY CLAY LOAM (50-SD-58-1)†									
A1p	0- 7	31.40	15.92	9.99	0.22	0.91	7.0	Trace	0.
A2	7-11	29.33	8.08	17.46	0.52	0.74	3.9	Trace	Tr
B2	11-18	33.58	7.83	23.77	0.96	2.26	3.1	0.1	0.
B3	18-22	30.70	*	*	1.15	1.70	–	0.2	0.
C11ca	22-30	22.19	*	*	1.25	2.35	–	0.4	0.
C12ca	30-40	23.05	*	*	1.89	2.02	–	2.4	0.
C2	40-60	23.29	*	*	5.66	2.89	–	5.7	0.
C3	60-80	28.25	*	*	4.50	2.72	–	6.4	0.
EXLINE SILTY CLAY LOAM (49-SD-58-5)‡									
A1	0- 2	29.9	*	*	0.1	2.2	–	0.1	0.
A2	2- 4	21.5	*	*	0.5	1.4	–	0.2	0.
B2	4-17	33.2	*	*	1.9	1.6	–	0.8	Tr
B3	17-20	30.5	*	*	3.1	1.2	–	1.7	Tr
Cca	20-36	25.3	*	*	2.4	0.7	–	1.7	Tr
II	36-65	13.5	*	*	1.7	0.3	–	1.6	Tr
TETONKA SILT LOAM (50-SD-58-5)†									
A1p	0-19	27.59	17.35	6.32	0.36	1.49	6.4	0	Tr
A21	19-26	17.02	9.45	3.96	0.20	0.96	5.2	0	0.
A22	26-32	17.38	9.87	4.58	0.33	0.40	4.4	Trace	0.
B2	32-41	28.98	16.93	9.16	0.48	1.23	5.7	Trace	0.
B31	41-64	28.83	17.35	9.64	0.46	2.02	4.3	0.1	0.
B32	64-90	33.51	22.24	12.54	0.50	2.19	2.5	0.1	0.

–Not determined.
*Calcareous horizon, cations not determined.
†Analyses by Mandan Laboratory (N.D.); laboratory now located in Lincoln, Nebraska, USDA.
‡Analyses by Beltsville Laboratory, USDA.

odium and potassium, salinity, pH, carbonates, :N of soils from Lake Dakota Basin†

alinity illimhos er cm.	pH Satur- ated paste	Dilution of 1:10	Car- bonates percent	Gypsum me. per 100 gr.	Organic carbon percent	Total nitrogen percent	C:N
1.3	7.4	....	3	0	2.16	....	......
1.4	7.5	....	15	0	1.27	....	......
1.2	7.8	....	15	0	0.56	....	......
1.0	8.0	....	13	0	0.32	....	......
0.3	7.4	8.1	Trace	0	1.65	0.146	11.3
0.4	7.8	8.8	8.9	0	0.90	0.095	9.5
0.3	8.2	9.1	17.5	0	0.42	0.044	9.5
0.4	8.4	9.2	14.9	0	0.26	0.028	9.3
3.4	7.6	8.5	13.4	12.5	0.18	0.028	6.4
0.7	6.5	7.1	0.5	0	2.35	0.204	11.5
0.4	6.9	7.9	Trace	0	1.03	0.117	8.8
0.5	7.4	8.6	0.7	0	0.89	0.106	8.4
2.4	8.1	9.3	4.1	0	0.75	0.086	8.7
10.0	8.2	8.7	22.0	36.5	0.28	0.035	8.0
13.5	8.1	8.8	18.9	17.8	0.31	0.038	8.2
13.5	8.0	8.7	10.6	13.0	0.25	0.034	7.4
10.5	7.6	8.6	9.8	18.4	0.19	0.037	5.1
0.5	6.6	7.3	Trace	0	3.90	0.294	13.3
0.3	6.9	7.6	0.5	0	2.14	0.190	11.3
0.4	7.0	7.9	Trace	0	1.02	0.113	9.0
1.8	7.9	9.0	0.5	0	0.77	0.067	8.8
8.0	7.9	8.4	19.7	49.6	0.38	0.041	9.3
11.0	7.8	8.5	13.4	8.8	0.25	0.036	6.9
11.0	7.8	8.6	10.4	.....	0.20	0.938	5.3
0.4	6.0	6.7	0.4	0	3.64	0.283	12.9
0.3	6.2	7.1	0.4	0	1.43	0.145	9.9
0.3	6.5	7.6	0.4	0	1.07	0.133	8.0
0.6	7.5	8.8	1.2	0	0.85	0.101	8.4
2.0	7.8	8.9	21.3	0	0.44	0.055	8.0
6.0	7.8	8.4	18.4	36.5	0.29	0.040	7.2
9.5	8.0	8.5	13.0	9.9	0.22	0.038	5.8
10.0	7.9	8.4	8.7	15.4	0.19	0.039	4.9
0.6	5.8	6.3	0.6	0	5.88		
0.8	5.7	6.2	0.5	0	3.19		
1.8	7.0	7.7	0.6	0	1.04		
4.0	7.9	8.8	0.5	5.0	0.61		
4.5	7.9	8.6	13.3	18.0	0.56		
6.5	7.8	8.5	14.3	13.0	0.19		
0.4	6.3	7.0	Trace	0	2.81	0.223	12.6
0.2	5.7	6.5	Trace	0	1.09	0.100	10.9
0.2	5.7	6.6	Trace	0	0.68	0.074	9.2
0.2	5.5	6.7	Trace	0	0.55	0.079	7.0
0.2	5.9	7.1	0.5	0	0.39	0.060	6.5
0.3	7.0	7.9	Trace	0	0.29	0.044	6.6

time had appreciable concentrations of exchangeable sodium.

The process whereby sodium enters the base exchange of a soil usually at the expense of calcium and magnesium is called alkalization. Under normal conditions calcium and magnesium are preferentially adsorbed by the soil colloids and sodium cannot be adsorbed unless half or more of the cations are sodium. However, according to the view held by workers at the Regional Salinity Laboratory (30), sodium may enter the soil exchange when the soil dries out because of water loss through evaporation and water absorption by plants. This causes the solubility limits of calcium sulfate, calcium carbonate and magnesium sulfate to be exceeded with the result that these compounds are precipitated and the proportion of sodium ions increases. Eventually, by this continued wetting and drying, sodium reaches a concentration where it can be adsorbed by the soil colloids and in the absence of excess salts can cause the dispersion which is part of solonization. This appears to be the mechanism which operates in these Lake Plain soils.

Soluble Sodium and Potassium. The relationship between water soluble and exchangeable sodium among seven lake bed soils is seen from data in table 8. Soluble sodium is low in the Great Bend and Tetonka profiles and in the A and B horizons of the three solodized Solonetz profiles—Harmony, Aberdeen and Exline. However, the soluble sodium content of the B3 horizon of the Beotia soil is high as is the amount in the C horizon of this soil and the C horizons of the Harmony and Aberdeen soils. The C horizon of the Beotia soil has the highest amount of soluble sodium of any horizon of the seven soils studied. Considering the relationships between soluble and exchangeable sodium of these profiles, it is seen that in the Harmony, Aberdeen and Exline soils, the bulk of the sodium in the A and B horizons is in exchangeable form. In the case of the Beotia soil the bulk of the sodium in the B2 is exchangeable while in the B3 horizon most of the sodium is in the soluble form. In the horizon of lime accumulation (Cca) of Harmony and Aberdeen, most of the sodium is in soluble form while in the parent material horizon (C2), of these soils, the sodium is about equally divided between exchangeable and soluble. To summarize, it can be said that in solodized Solonetz profiles, the bulk of sodium present in B horizons is in exchangeable form and so is in a position to disperse the soil. Soluble sodium originally present in the B horizon of the Solonetz soils has either leached out of the horizon or has gone over to exchangeable form. In Beotia soil the bulk of sodium in the upper part of the B horizon is in exchangeable form while most sodium in the lower part of the B is in soluble form. It appears from this that the B21 horizon of the Beotia soil is nearer being solonized than is the B22 horizon.

The soluble potassium percentage follows the same pattern for the seven soils as that just discussed for soluble sodium.

Carbonates. No free carbonates are in the Tetonka profile. In going from the Great Bend to the Exline to the Beotia to the Harmony to the Aberdeen soils, the carbonates are found to occur progressively deeper in the profile. Great Bend soil is leached free of carbonates to 11 inches, Beotia to 16 inches, Exline to 17 inches and Harmony and Aberdeen to 22 inches. Considering these five profiles, all show a higher carbonate content in the Cca horizon than in the C2 horizon, showing that these soils have a definite horizon of carbonate accumulation.

Gypsum. No gypsum is in Great Bend and Tetonka profiles analyzed but the other five profiles all show definite horizons of gypsum accumulation. The horizon of gypsum accumulation of these soils coincides with the horizon of carbonate accumulation. Data from a number of soil profiles analyzed by the U. S. Bureau of Reclamation (18) indicate that there is sufficient native gypsum to neutralize sodium in most lake plain soils.

Organic Carbon. The B horizon of solonetzic soils is nearly black in color while the A2 horizon in most cases is light gray. The organic carbon data for the soils indicates that the characteristic color of these two horizons is not reflected in percent organic carbon. In the three solodized solonetz soils—Harmony, Aberdeen and Exline—in the Solod soil Tetonka and in the Chernozem soil Beotia, the B horizon has less organic carbon than does the A2 horizon. In fact all profiles show the same pattern of progressive decrease in organic carbon from the surface to the parent material. Considering organic carbon, the difference among Chernozem and the solonetzic soils is that the former have lower percentages of organic carbon in the surface horizons.

Total Nitrogen and C:N. Total nitrogen for the soil profiles progressively decreases from the surface to the parent material. The difference in total nitrogen among Chernozem and solonetzic soils is that the former have lower percentages in the surface horizons, thus total nitrogen and organic carbon show the same pattern of occurrence in these soils. Because total nitrogen decreases at a higher rate in going from the surface to the parent material, the C:N drops. The ratio of carbon to nitrogen is not as wide in the case of the Chernozem soils as it is in the four solonetzic profiles although this difference is small.

Summary and Conclusions

Two aspects of the genesis of Chernozem and Solonetzic soils of the Glacial Lake Dakota Plain were considered in this study: the specific environment of soil formation and the way soil formation proceeds in this environment.

The soils investigated are in the north central portion of the James Basin physiographic division in Spink County, South Dakota. Spink County contains about 460,000 acres of the Lake Dakota Plain. The seven soil profiles studied had developed from lacustrine sediments of Glacial Lake Dakota. Two of these soils are Chernozems (Great Bend and Beotia), one is a Regosol (Zell), three are solodized-Solonetz soils (Harmony, Aberdeen and Exline), and one is a Soloth soil (Tetonka).

Field study of topographic relationships of the soils, soil profile characteristics and factors of soil formation plus physical and chemical data on key profiles was used to determine the environmental conditions of soil formation. The Chernozem soils and the Regosol were studied to compare their environments and genesis with those of the associated solonetzic soils.

About two-thirds of the soils of the nearly level Lake Dakota Basin consist of solodized-Solonetz and Soloth soils; the former occupy level or slightly depressed areas while the latter are found in deeper depressions and in stream-abandoned channels. Chernozem soils of the Lake Dakota Basin occupy gently sloping positions which are never ponded. Regosols occur on moderate slopes.

The Chernozem environment is one of mild leaching. The environment of solonization is one of alternate wet and dry conditions caused by periodic ponding. Ponding is caused by a combination of an enclosed depressional position or a flat, and a very slowly permeable substratum. Desiccation even in these depressions or flats follows because of the high evaporation and transpiration in this area of only 18 inches annual precipitation. Environment for solodized-Solonetz and Soloth soils is the same (alternate ponding and desiccation) except that Soloth soils are flooded for longer periods each year.

The approximate exchangeable calcium, magnesium and sodium percentages, respectively, of the B horizons of these soils are: Chernozem Great Bend–65, 30, 3; solodized Solonetz–30, 65, 5; Solod–64, 30, 1. Data have shown that solonetzic soils have developed from saline parent material having a higher content of exchangeable sodium. The principal anions in order of abundance are sulfate, chloride and bicarbonate. Thus, the parent material in the soils studied appears to be the Solonchak stage of development. As these parent materials are high in exchangeable sodium, they are alkali originally before salt removal (desalinization) begins.

The entry of sodium and magnesium into the base exchange of Solonetz soils is believed to be the result of differential solubilities of sodium, magnesium and calcium compounds in soils subject to alternate waterlogging and drying. Source of sodium, calcium and magnesium ions is the soil parent material although it is possible that some sodium comes from weathering-in-place of sodium-rich minerals. During initial stages of soil formation, sodium especially, and magnesium to a lesser extent, would be in solution to a far greater extent than calcium. By mass action these cations tend to replace exchangeable calcium.

If salts are lost by lateral seepage or other means, the soil does not become stable until the Soloth stage is reached. If leaching losses are very slow or if sodium salts are added to the soil by seepage or from weathering in place of sodium-rich minerals, the Solonetz stage may be fairly stable. Vegetation, by returning relatively large amounts of calcium to the soil surface, favors calcium saturation of the exchange.

Exchangeable sodium is thought to be the cation responsible for solonization, but exchangeable magnesium is present in substantial concentrations in the solodized-Solonetz soils.

Differential solubilities can explain the entry of magnesium into the exchange complex of Solonetz and solodized-Solonetz soils. Exchangeable magnesium once adsorbed has been shown to be more tenaciously retained than exchangeable calcium. Although some investigators believe that exchangeable magnesium contributes toward solonization, apparently it cannot cause dispersion if calcium concentrations are high or if the soils do not pond. The Beotia soil reported on in this publication had extractable Ca, Mg, Na and K percentages, respectively, of the exchange of the B horizon of: 28, 57, 9, and 6, yet the soil was not solonized. It appears, then, that high magnesium saturation by itself cannot cause solonization. The solonized Harmony soil has ionic concentrations of cations similar to that displayed by Beotia soil. Beotia soil occurs on topographic positions which are never ponded while the Harmony soil occurs on flats which occasionally pond.

The cycle of soil development of the solonetzic soils of the Lake Plain is thought to be: parent material → Solonetz → solodized-Solonetz → Soloth. The Solonetz itself is rarely found in mappable units. Solodized Solonetz is the common form of solonetzic soils.

On sloping positions Chernozem soils may develop from the same saline, sodium-rich materials which are the parent materials of Solonetz soils. Excess water runs off from these sloping soils and they never are ponded. The water which does enter the soil by percolation tends to leach out the cations which are in solution—sodium and magnesium—while calcium tends to remain on the exchange. Thus a sloping topography favors leaching of sodium and magnesium and retention of calcium (moisture movement is always downward), while an alternate ponding and drying environment favors entry into the base exchange of sodium and magnesium, rather than calcium.

The morphology of the profile appears to provide the best criteria for classifying solonetzic soils into series on the Lake Dakota Plain. The data show that Solonetz soil in this area retains its distinctive morphology from the time when, under alternating wet and dry conditions, it is initially solonized and has a high content of exchangeable sodium until it begins to solodize. The soil does not begin to solodize until most of the exchangeable sodium has been replaced. Magnesium enters the exchange at this time. Chemical composition, by itself, is an unsatisfactory criterion for use in the classification of these soils.

A considerable volume decrease may accompany solonization. Data from adjacent till plain soils (54) show that the B2 horizon of one Solonetz decreased 27% in volume while the B2 horizon of a Soloth soil decreased 33% as compared with the parent material. The volume decrease for solonetzic profiles as a whole is about 10% because decreases in upper horizons are compensated for by expansion of horizons of calcium carbonate accumulation. Data show that zonal profiles do not decrease in volume materially during genesis. From these data it seems apparent that solonization and solodization result in a gradual widening and deepening of the depressions in which these processes occur and that this maintains or intensifies their action. Eventually the exchange complex of these soils becomes saturated with calcium even though the now deep-lying B horizon remains hard. This stage has been called the Soloth and Tetonka is the representative series. It has been noted that in some Tetonka soils the solonetzic B horizon has been completely degraded and a new friable prismatic B horizon has developed above it from old A2 horizon material. This soil probably should be classified as Chernozem.

One conclusion that can be drawn from the data presented in this publication is that the friable Chernozem soils have escaped becoming solonized because their sloping position has prevented ponding of their profiles. If these soils are to be maintained in friable condition under irrigation, they must be handled in such a way that water movement is always downward. This has been the direction of water movement during their genesis under natural conditions; thus, an artificial drainage system should accompany irrigation development to maintain these friable soils in good physical condition.

Maintaining a downward direction of drainage waters likewise is important in preventing a further deterioration in the physical condition of solonetzic soils contemplated for irrigation. Currently, Harmony soil is not dispersed to a degree harmful to irrigation. It can be maintained and possibly improved by use of artificial drainage with possibly some added gypsum or sulfur. However, there is considerable native gypsum in the substrata of these lake bed soils. Aberdeen likewise requires artificial drainage if irrigated and, since it is starting out as a less desirable soil, it will require closer spacing of drains and perhaps some chemical amendments.

An artificial drainage system suitable for irrigation of Exline soil would be quite expensive. Further complicating the issue is the fact that physical condition of the soil is very poor as the claypan starts at or near the surface.

Zell soil, because of its shallow nature and sloping position, would be a poor prospect for irrigation. After leveling, the soil parent material essentially would be the soil. This material probably would be saline-alkali and would lack any soil organic matter. Elements normally present in organic matter, such as zinc, also would be deficient. Successful irrigation would entail installing a drainage system to aid in flushing out salts and alkali. Only after this was accomplished could the soil material be brought to production.

References

1. Arnold, J. R. and W. F. Libby, 1950. Radiocarbon dates. University of Chicago. Institute for Nuclear Studies.
2. Bentley, C. F. and C. O. Rost. 1947. A Study of Some Solonetzic Soil Complexes in Saskatchewan. Sci. Agr. (Canada) 27: 293-313.
3. Bower, C. A. and E. Truog. 1941. Base Exchange Capacity Determination as Influenced by Nature of Cation Employed and Formation of Basic Exchange Salts. Soil Sci. Soc. Proc. Amer. (1940) 5:86-89.
4. Bray, R. H., and E. E. DeTurk, 1932. Chemical Aspects of Some Illinois Soils as Related to Their Genesis and Morphology. Proc. 2nd Int. Cong. Soil Sci. 5: 118-140.
5. Bray, R. H. 1935. The Origin of Horizons in Clay-pan Soils. Amer. Soil Survey Assoc. Bul. 16: 70-75.
6. Breshkovsky, P. M. 1937. The Importance of Absorbed Magnesium with Respect to the Observed Salinity of the Soil. Uchen. Zap. Kazan Gosud. Univ. 97: 1(151-176) C. A. 34 (208).
7. Brown, I. C., T. D. Rice, and H. G. Byers. 1933. A Study of Claypan Soils. USDA Tech. Bul. 399.
8. Ellis, J. H., and O. G. Caldwell. 1935. Magnesium Clay "Solonetz" Trans. Third Internatl. Cong. Soil Sci. 1: 348-350.
9. Gedroiz, K. K. 1912. Colloidal Chemistry as Related to Soil Science. I Colloidal Substances in the Soil Solution. Formation of Sodium Carbonate in the Soil. Alkali Soils and Saline Soils. Zhur. Opit. Agron. (J. Exptl. Agron. Russian) 13: 363-412.
10. Gedroiz, K. K. 1926. Solodization of Soils. Nossov. Agr. Expt. Sta. Bul. 44: 1-67.
11. Gedroiz, K. K. 1928. Solonetz Soils, Their Origin, Properties and Amelioration. Nossov Agr. Expt. Sta. Bul. 46: 1-115.
12. Glinka, K. D. 1914. *Die Typen der Bodenbildung, ihre Klassifikation und Geographische Verbreitung, Gebruder Borntraeger.* Berlin. Translated in part by C. F. Marbut as "The Great Soil Groups of the World" 1927. Edwards Brothers, Ann Arbor, Michigan.

13. Hilgard, E. W. 1906. *Soils*. The MacMillan Company. New York.
14. Horn, M. E., E. M. Rutledge, H. C. Dean, and M. Lawson. 1964. Classification and Genesis of Some Solonetzic (Sodic) Soils in Eastern Arkansas. Soil Sci. Soc. Amer. Proc. 28: 688-692.
15. Jeffries, C. D., and J. W. White. 1937. Some Mineralogical and Chemical Characteristics of a Hagerstown Soil Profile. Soil Sci. Soc. Amer. Proc. (1938) 2: 133-141.
16. Joffe, J. S. and Miryam Zimmerman. 1944. Sodium, Calcium, and Magnesium Ratios in the Exchange Complex. Soil Sci. Soc. Amer. Proc. (1945) 9: 51-55.
17. Joffe, J. S. 1949. Pedology, 2nd Ed. Somerset Press Inc. Somervelle, N. J.
18. Jones, Paul, 1969 Personal Communication.
19. Klages, M. G. 1966. Effect of Clay Type and Exchangeable Cations on Aggregation and Permeability of Solonetz Soils. Soils Sci. 102:46.
20. Kelley, W. P. 1934. The So-called Solonetz Soils of California and Their Relation to Alkali Soils. Amer. Soil Survey Assoc. Bul. 15: 45-52.
21. Kelley, W. P. 1951. *Alkali Soils, Their Formation, Properties, and Reclamation*. Reinhold Publishing Corporation, N. Y.
22. Kellogg, C. E. 1934. Morphology and Genesis of the Solonetz Soils of Western North Dakota. Soil Sci. 38: 483-500.
23. Love, S. K., 1960. Quality of Surface Waters for Irrigation, Western United States 1957. USGS Water Supply Paper 1524 USGPO, Washington, D. C.
24. MacGregor, J. M., and F. A. Wyatt. 1945. Studies on Solonetz Soils of Alberta. Soil Sci. 59: 419-435.
25. Marbut, C. F. 1935. Atlas of American Agriculture Part III. Soils of the United States. U. S. Gov't. Printing Office, Washington, D. C.
26. Mitchell, J. and F. F. Riecken. 1937. The Chemical Nature of Some Typical Soil Profiles of Saskatchewan (Canada). Sci. Agr. (Canada) 18: 109-119.
27. Nikiforoff, C. C. 1930. Solonetz and Solonchak Soils of the Red River. Amer. Soil Survey Assoc. Bul. 11: 141-150.
28. Nikiforoff, C. C. 1937. The Solonetz-like Soils in Southern California. Jour. Amer. Soc. Agron. 29: 781-796.
29. Nikiforoff, C. C., and M. Drosdoff. 1943. Genesis of a Claypan Soil. I. Soil Sci. 55: 459-482.
30. Richards, L. A. Editor. 1947. Diagnosis and Improvement of Saline and Alkali Soils. U. S. Regional Salinity Laboratory, Riverside, California.
31. Riecken, F. F. 1943. Some Considerations in the Magnesium Cycle of Weathering in Solonetz Soils. Soil Sci. Soc. Amer. Proc. (1944). 8: 391-395.
32. Rost, C. O. 1936. Characteristics of Some Morphological Solonetz Soils of Minnesota. Jour. Amer. Soc. Agron. 28: 92-105.
33. Rost, C. O., and K. A. Maehl. 1943. Some Solodized Soils of the Red River Valley, Soil Sci. 55: 301-312.
34. Shaw, C. F., and W. P. Kelley. 1935. The Meaning of the Term Solonetz. Trans. Third Internatl. Cong. Soil Sci. 1: 330-334.

35. Sigmond, A. A. J. de 1938. *The Principles of Soil Science.* Thomas Murby and Co., London.
36. Smith, Robert. 1950. Solonetz Soils of the Subhumid Zone of Southwestern Australia. Trans. Fourth Internatl. Cong. of Soil Sci. 1: 386-389.
37. Smith, H. V., F. F. Buehrer, and G. A. Wickstrom. 1949. Effect of Exchangeable Magnesium on the Chemical and Physical Properties of Some Arizona Soils. Soil Sci. 68: 451-462.
38. Soil Survey Staff. *Soil Survey Manual.* Agr. Handbook No. 18, USDA.
39. Soil Survey Staff. 1960 Soil Classification, A Comprehensive System. SCS, USDA., Washington, D. C.
40. Staikoff, Z. 1940. Einfluss des Aziditatgrades auf der Sorption von Kalzium und Magnesium in den Boden (The influence of soil reaction on the sorption of calcium and magnesium) Bodenk. PflErnahr 21/22 (581-600)
41. Storie, R. E. 1933. Profile Studies of The Solonetz Soils of California Amer. Soil Sur. Assoc. Bul. 14: 43-46.
42. Sushko, S. Ya. 1933. The Role of Absorbed Mg in the Formation of Solonetz Properties in Soils. Chem. Abs. 27: 5458.
43. Teakle, L. J. H. 1950. An interpretation of Some "Solonized" (alkali) Soils in South-western Australia. Trans. Fourth Internat. Cong. Soil Sci. 1: 389-394.
44. Usov, N. I. 1938. Effect of Absorbed Magnesium on Saline Properties of Soil. Trudy Knof. Pachvoved. Fiziol. Saratov i, 44-61 BCA 58 (303).
45. Vilensky, D. G. 1932. Brief History and Principal Summary of Investigations of Saline and Alkali Soils of the USSR. Proc. Second Internat'l. Cong. Soil Sci. Soc. 5: 309-326.
46. Westin, F. C. 1953. Solonetz Soils of Eastern South Dakota: Their Properties and Genesis. Soil Sci. Soc. Amer. Proc. 17: 288-293.
47. Westin, F. C., G. J. Buntley, W. C. Moldenhauer, and F. E. Shubeck. 1954. Soil Survey of Spink County, South Dakota. S. Dak. Agr. Expt. Sta. Bul. 439. Brookings.
48. White, E. M., and R. I. Papendick. 1961. Lithosolic-Solodized-Solonetz Soils of Southwestern South Dakota. Soil Sci. Soc. Amer. Proc. 25: 504-506.
49. White, E. M. 1961. Calcium-Solodi or Planosol Genesis from Solodized Solonetz. Soil Sci. 91: 175-177.
50. White, E. M. 1964. The Morphological-Chemical Problem in Solodized Solonetz. Soil Sci. 98: 187-191.
51. White, E. M. 1964. Morphological-Chemical Relationships of Some Thin A Horizon Solodized Solonetz Soils Derived from Moderately Fine Material on a Well-Drained Slope. Soil Sci. 98: 256-263.
52. Whittig, L. D. 1959. Characteristics and Genesis of a Solodized-Solonetz of California. Soil Sci. Soc. Amer. Proc. 23: 469-473.
53. Wilding, L. P., R. T. Odell, J. B. Fehrenbacher, and A. H. Beavers. 1963. Source and Distribution of Sodium in Solonetzic Soils in Illinois. Soil Sci. Soc. Amer. Proc. 27: 432-438.

APPENDIX A

Description of the Lake Dakota Plain

The surface of the Lake Dakota Plain is remarkably level, broken only by shallow, flat-bottomed trenches of stream channels. Elevation of the entire basin varies less than 15 feet except where streams have excavated shallow valleys.

The Lake Dakota Plain is set apart from the glacial till plain on the west by a distinct topographic break. A short, steep slope breaks down from the till plain to the lake bed. This is in contrast to the east and south shores of the lake bed which gradually merge with till and outwash plains. Lacustrine silts in basins within the till plain east and south of the lake bed proper indicate that Glacial Lake Dakota may have been more extensive for short periods than the present boundaries would indicate.

The soil materials of Lake Dakoto Plain are mainly of silt and clay size with silt predominating. Sand may occur in lenses but never makes up more than a minor percentage of the materials. Pebbles and boulders occur only at the contact of the lacustrine materials with the substratum which is glacial till or Pierre shale. Table 9 lists the particle size distribution of a typical sample of the Lake Dakota Plain materials. It has been found that the substratum of the Great Bend soil series is coarser textured than are the substrata of the solonetzic soils.

Below the soil profile, materials of the Lake Dakota Plain when dry are pale yellow, mottled with white and light olive-brown. When moist they are light yellowish-brown mottled with light gray and light olive-brown. They are calcareous, having a calcium carbonate equivalent ranging from 7% to 10%. The average bulk density of these materials is about 1.30, and they are distinctly laminated. The lamination begins about 3½ feet below the land surface and extends in most cases to 6 or 7 feet. The laminae in places are found in pairs of a light and dark member and are very lenticular. They vary in thickness from an eighth or a sixteenth of an inch to about three-quarters of an inch. In consistence these materials are hard to slightly hard when dry, and friable or very friable when moist.

Table 9. Mechanical composition of the substratum* of Aberdeen Silty Clay Loam.

(Location of sample: T117N, R63W, Sec. 34, 0.2 mile east of NW corner)

Separate and diameter of particles	Percent of separate
Total Sand (> 0.05 mm.)	0.6
Coarse Silt (0.05—0.02 mm.)	2.7
Medium Silt (0.02—0.0005 mm.)	53.8
Fine Silt (0.005—0.002 mm.)	13.0
Coarse Clay (2.0—0.2 u)	12.0
Medium Clay (0.2—0.08 u)	5.9
Fine Clay (< 0.08 u)	12.0
Total	100.0

*Between 3-5 feet from surface.

Data for the substrata from a number of soil profiles indicates that the lake bed materials are generally quite saline and have rather high percentages of exchangeable sodium. As a rule the lake bed materials below the solonetzic soils are inclined to be more salty than are the materials below the Chernozem soils. This is brought out in appendix table 1. In addition, the pH of the soil:water extract of 1:10 was 8.5 or higher for the saline samples verifying that considerable sodium is present in the lake basin materials.

The lacustrine mantle covering the Lake Dakota Plain is from 5 to 35 feet thick. The James River has exposed underlying Pierre shale or glacial till at numerous places, especially just north of the town of Frankfort. During soil survey operations the shale occasionally was encountered within the 5 foot profile, well away from the shore line of the lake basin, indicating that the topography of the underlying shale is quite variable.

The principal stream of the Glacial Lake Dakota Plain is the James River. It flows south in a narrow trough about 10 to 20 feet below the bench-like lake bed surface. Its over-all, north-south gradient in Spink County is only about an inch per mile. Tributary streams flow into the James River from both sides, eastward from the Missouri Coteau and westward from the Prairie Coteau. After they reach the nearly level James Basin, these streams flow in a southerly direction, nearly parallel to the James River and join in at an acute angle.

In addition to the James River and it tributaries, the Lake Dakota Basin is crossed by numerous small connecting channels. A peculiarity of these channels is that most of them have no defined stream courses. Materials in these channels are lacustrine rather than alluvial although the surface of the soils present in them is usually local alluvium. Most of these channels are 10 to 50 feet wide and 5 to 10 feet lower than the lake bed surface. In the southern third of the lake bed these channels are especially numerous and produce on this portion of the lake bed an intricate distributary pattern similar to that of a delta.

The soil associations of the Lake Dakota Basin, discussed elsewhere in this publication are more easily described if related to the genesis of the lake basin.

Appendix Table 1. Salinity of soil parent materials (3-5 feet from surface)

Soil series	Classification	Profiles tested	Number samples having >0.2% salt	Percent samples having > 0.2% salt
Great Bend	Chernozem	29	12	41
Beotia	Chernozem	75	31	41
Harmony	Solodized Solonetz	88	47	53
Aberdeen	Solodized Solonetz	31	18	58
Exline	Solodized Solonetz	20	18	90
Tetonka	Soloth	18	2	11

The fact that a large glacial lake, now called Glacial Lake Dakota, existed late in the Pleistocene epoch, is well established (2, 3, 7, 9). The principal evidence is the presence of old beach lines and fore-deeps which are especially noticeable near the city of Aberdeen in Brown County. However, there has been some question as to how the materials now covering the lake basin were deposited. There were three possibilities: (1) deposition as loess after the lake had drained, (2) deposition of loess into the lake and subsequent settling out of the particles in water, and (3) deposition of materials into the lake by glacial streams.

Results of work done in the basin by Upham (9), Todd (8) and Rothrock (6, 7) point toward the deposition of material into the lake by glacial streams as the most logical explanation. The idea that the material is loess is discounted by the fact that there are no large quantities of loess around the lake. The thin patchy loess deposits east of the lake could have come from the lake basin after it drained and before it was stabilized by vegetation. The large area of sand and gravel in the northern part of the basin in Brown and Marshall counties was undoubtedly water-deposited so it seems likely that the fine materials in the central and southern parts of the lake bed also were deposited by water. A fact which argues against wind deposition after the lake had been drained is the presence of well developed laminae in the materials below the zone of weathering.

A reconstruction of events in the James Basin and in Lake Dakota can be attempted based on the work of Upham (9), Todd (8), and Flint (2). Before the last Wisconsin glacial substage, drainage in the James Basin was to be north. The ice as it receded formed the north shore of Lake Dakota and blocked the basin's northern outlet. The James River then was forced to flow south, cutting its channel during the retreat of the glacier. It apparently eroded a channel so rapidly that it prevented the northern part of Lake Dakota from retaining sufficient depth to flow eastward into the south end of Lake Agassiz when the way was opened by a farther departure of the ice. By the time the Wild Rice River and the south end of the Red River Valley were uncovered by the ice sheet, Lake Dakota had apparently already drained. Evidence of this is the fact that the lowest portion of the Wild Rice River's watershed is only about 10 feet above the general level of the James Valley. It appears that the bulk of the materials in the Lake Dakota Basin must have been deposited quite rapidly. Apparently the lake consisted for a time of numerous very shallow ponds or marshes of large areal extent which probably dried up at times. The drainage at this time probably consisted of a great number of interconnected channels all heading in the general direction of the James River. Deposition of material was slow and the lake or ponds gradually drained away as the James River eroded southward, deepening and extending its channel.

Evidence that deposition of materials was rapid in the early period of the lake and then was much slow-

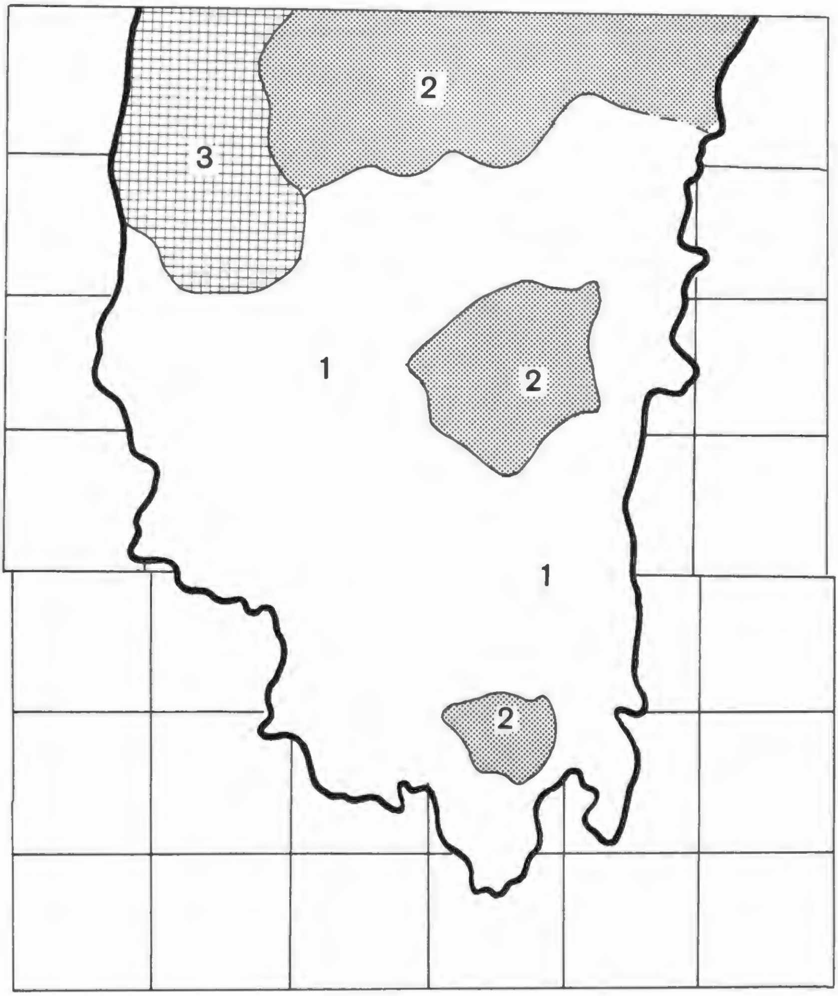


Figure 4—Salinity of soils. Percent of profiles having six or more millimhos/cm of salt above the 48-inch depth. No. 1=35%-50%; No. 2=50%-70%; No. 3=over 70%. (Based on analysis of 12,000 soil profiles by the U. S. Bureau of Reclamation.)

er during its later stage, is found in the fact that lamination is much less pronounced at 8 or 10 feet than it is at 3 to 4 feet. In addition, the salinity of the deeper lying materials is rather low while the higher-lying laminated silts and clays are quite saline. Five deep borings were made at widely scattered sites on the lake bed to establish the salinity of the materials in relation to depth. All five borings showed the same pattern of decreasing salinity with increasing depth. Appendix table 2 lists the data for one of the sites.

As the lake decreased in size, the

portion of the bed which had slightly more slope developed more channels than the flatter areas and rid itself more readily of excess water. The flatter areas probably lost more water by evaporation than through surface runoff at this stage with the result that the sediments became more saline. Standing water on these areas would also favor the settling out of finer materials than could be sedimented in an area having a network of drainage channels. A final phase of the history of the lake was the formation of levees along the channels and stream courses. These levees are slightly higher than the lake bed proper and were caused by occasional overflow and deposition from the channels.

From this discussion of the genesis of the Lake Dakota Basin, it can be stated in summary that the most saline and best laminated deposits in the basin lie from 3½ to 7 or 8 feet from the surface. There is also a tendency for the materials nearest the stream channels to be coarser, less saline and at a slightly higher elevation than are those which are located back of the channels. Figure 4 shows in a general way the salinity of the soil parent materials in Spink County.

Appendix Table 2. Relation of salinity to depth in Lake Bed Materials. Substratum of Exline Silt Loam*

Depth (inches)	Percent soluble salts
60- 64	0.47
64- 72	0.44
72- 78	0.42
78- 90	0.41
90- 94	0.26
94-102	0.30
102-112	0.41
112-132	0.24
132-145	0.18
145-151	0.10
151-168	0.17
168-205	0.14
205-216	0.03

*Location: T116N, R62W, Section 25, 700 feet east of north quarter corner.

APPENDIX B
Methods of Investigation

Field Methods

The use of both field and laboratory data are necessary if valid conclusions are to be drawn regarding the genesis of soils. Soils investigated in this study were observed over a 7-year period to determine their topographic relationships, their profile characteristics and the factors of soil formation. These field data are used with physical, chemical and mineralogical data on key profiles to establish the specific environment of soil formation.

Selection of typical samples is of extreme importance in soil genesis studies if results are to be extended over a survey area. The extreme complexity of soil pattern which is the rule in regions having solonetzic soils makes this task difficult. Samples for this study were taken, therefore, after the natural land unit in question was surveyed. After a survey has been completed the variations within a soil series are known and it is also known which particular morphological features are dominant in the series so that modal profiles can be sampled. Moreover, if the sample sites are selected after the survey is advanced, they can be taken from a geographical area which contains large tracts of the soils in question.

The soil series reported on in this study, except for Zell and Exline, were taken from natural soil sequences. A natural sequence, as the term is used here, refers to a group of associated soils derived from similar parent materials. For this study the procedure was to select a typical zonal soil which always occupies a convex upland position and proceed down-slope to a depression, sampling the soil in each topographic position. As the surface of the land changes from convex to plane and finally to concave, the soil changes from Chernozem on the convex surface to various kinds of intrazonal soils, which in this case are mostly solonetzic variations, on the level and depressional positions. With parent material relatively constant among the members of a sequence, attention is focused on other differences in environment between friable and solonetzic soils.

Laboratory Methods

Physical measurements

1. *Bulk density.* Clods for bulk density determinations were taken from sampling pits at the lake bed site. The sequence of Aberdeen, Harmony, Beotia, Great Bend and Tetonka series, extends over approximately one-third of a mile.

The natural clods taken from each horizon of these profiles weighed approximately 200 grams. They were air-dried at the survey field quarters and then wrapped in cotton and packed in ice cream cartons for transportation to the laboratory. The profiles were sampled in duplicate.

In the laboratory the clods were oven-dried and weighed and then soaked in hot paraffin until saturated. The waxed clods were then weighed in air and in water. The weighing in water was done on the same torsion balance used for the other weighings. A tripod arrangement constructed with stiff picture wire was based on the weighing pan. A ring stand supported a beaker of water inside this tripod. The sample was suspended in a small wire basket from the top of the tripod so that it was completely immersed in water. A small amount of detergent was added to the water in which the clods were weighed to reduce surface tension.

2. *Mechanical analyses.* This determination was performed by the United States Department of Agriculture Soil Survey Laboratory at Mandan, North Dakota, following the pipet procedure of Kilmer and Alexander (4). In this procedure the carbonates are not removed.

Chemical measurements.

Approximately 8 quarts of soil were taken from each horizon of each profile from the sample pits. After breaking the larger structural clods by hand, these samples were thoroughly mixed on an oil cloth and split; half of the sample being taken for analysis by the Soil Survey Laboratory of the USDA and half being retained by the South Dakota State University Agronomy Department.

Pint samples for chemical and mineralogical study were taken by quartering the South Dakota samples. These pint samples were passed through a 2 mm. sieve. An aliquot of this 2 mm. material was ground to pass a 100 mesh sieve for the total chemical analyses.

1. Total chemical analyses. A semi-micro colorimetric method developed by Corey (1) was used for this determination.

2. Exchangeable cations and total exchange capacity; salinity, including total soluble salts, carbonates, gypsum, and soluble sodium and potassium; organic carbon and total nitrogen; and soil reaction, were determined by the Soil Survey Laboratory at Mandan, North Dakota.

All the above determinations except total nitrogen and calcium carbonate followed procedures given by Peech, et al. (5) in USDA Circular 57, and in the Regional Salinity Manual.

Total nitrogen was determined by a modification of the standard Kjeldahl - Gunning method. Samples were digested with a mixture of potassium sulfate, ferrous sulfate and copper sulfate with concentrated sulfuric acid. Distillation was in an alkaline medium into 4% boric acid and back titration was with standard acid.

Calcium carbonate was estimated by utilizing a method for measuring the gas evolved when a sample was treated with hydrochloric acid and shaken repeatedly.

APPENDIX C
Detailed Descriptions of Soils

Figure 4 is a scale diagram showing the topographic relationships of all but the Zell Soils. The occurrence of these soils and their general character is described in a preceding section. Detailed soil descriptions follow.

ZELL SILT LOAM

49-SD-58-9

Location: T. 117N., R. 63W., Center of Sec. 34.
Vegetation: Native grasses of blue grama and stipa.
Parent material: Calcareous lacustrine silts and clays.

Horizon	Depth in inches	Description*
A_1	0-8	Dark grayish-brown to very dark brown (10YR 4/2 to 2/2 moist) mildly calcareous silt loam/soft moderately developed fine granular structure; very friable when moist, Grades into
ACca	8-15	Light yellowish-brown to light olive-brown (2.5Y 6/3 to 5/3 moist) strongly calcareous silt loam with a slight amount of segregated lime; soft moderately developed fine granular structure; very friable when moist. This grades into
C_1	15-36	Pale-yellow to light yellowish-brown (2.5Y 7/4 to 6/4 moist) strongly calcareous silt loam; soft single grain structure; very friable when moist.
C_2	36-60	Pale-yellow to light yellowish-brown (2.5Y 7/4 and 7/6 to 6/4 and 6/6, moist) strongly calcareous silt loam; soft single grain structure; very friable when moist.

REMARKS: At 73-76 inches there is a layer of moderately calcareous sand. At 76-121 inches the soil is moderately calcareous fine laminated silt loam. This field has been plowed once.

*The horizon nomenclature and the soil color, texture, structure and consistence terms used in the soil descriptions of these soils correspond to those used in the Soil Survey Manual (44).

GREAT BEND SILT LOAM

Number 50-SD-58-6

Location: T120N, R64W, Section 25; 300 feet W, 150 feet S of NE corner.

Vegetation: Grain stubble

Parent material: Laminated lacustrine silt

Horizon	Depth in inches	Description
A_1	0-11	Dark gray, dry; very dark gray, moist, (10YR 4/1, 3/1), noncalcareous silt loam; weakly developed, fine-crumb structure; slightly hard when dry; very friable when moist. This grades into,
B_1	11-16	Grayish-brown, dry; very dark grayish-brown, moist (10YR 5/2, 3/2), noncalcareous silt loam; weakly developed, medium prismatic structure; slightly hard when dry; very friable when moist. This changes clearly but in an irregular boundary into,
C_1ca	16-36	Light yellowish-brown, mottled with pale yellow when dry; light olive-brown, moist, (2.5Y 6/4, 8/4, dry; 5/4 moist), strongly calcareous silt loam with a slight amount of visible lime; weak granular structure; soft when dry; very friable when moist.
C_2	36-53	Light yellowish-brown, moist, (2.5Y 6/4, 8/2, dry, 5/4 moist), strongly calcareous silt loam with a slight amount of visible lime; indistinctly laminated; soft when dry; very friable when moist.

BEOTIA SILT LOAM
Number 50-SD-58-4

Location: T120N, R64W, Section 25; 0.35 mile east of the NW corner of the NE¼.

Vegetation: Grain stubble.

Parent material: Laminated lacustrine silt and clay.

Horizon	Depth in inches	Description
A_1	0-8	Dark gray, dry; very dark gray, moist, (10YR 4/1, 3/1), noncalcareous silt loam; weakly to moderately platy; breaks down into moderately-developed fine crumbs; slightly hard when dry; very friable when moist. This grades into,
A_2	8-11	Grayish-brown, dry; very dark grayish-brown, moist, (10YR 5/2, 3/2), noncalcareous silty clay loam; moderate amount of fine vesicles in massive to weakly granular material; slightly hard when dry; very friable when moist. This grades into,
B_2	11-16	Between grayish-brown and dark grayish-brown, dry; very dark grayish-brown, moist, (10YR between 5/2 and 4/2, dry; 3/2 moist), noncalcareous silty clay loam; moderately-developed, medium-sized prisms that are readily broken down into moderately-developed fine uniform aggregates; hard when dry; friable when moist. This grades into,
B_3	16-21	Between grayish-brown and light olive-brown, dry; between very dark grayish-brown and olive-brown, moist, (2.5Y between 5/2 and 5/4, dry; between 3/2 and 4/4, moist), noncalcareous silt loam; weakly-developed coarse prisms that are only weakly granular; slightly hard when dry; friable when moist.
$C_{11}ca$	21-31	Between white and pale-yellow, dry; between light brownish-gray and light yellowish-brown, moist, (2.5Y 8/2 and 8/4), dry; between 6/2 and 6/4 moist), strongly calcareous silty clay loam; crystals of gypsum or soluble salt; porous massive structure; slightly hard when dry; very friable when moist.
$C_{12}ca$	31-46	Strongly calcareous silty clay loam having the same color, texture, and consistency as the horizon above.
C_2	46-60	Mottled pale yellow and white (2.5Y 8/4, 8/2, dry), moderately calcareous silty clay loam; moderately defined fine laminatians; slightly hard when dry; very friable when moist.

HARMONY SILTY CLAY LOAM

Number 50-SD-58-3

Location: T120N, R64W, Section 25; 0.2 mile east of the NW corner of the NE¼.

Vegetation: Grain stubble.

Parent material: Laminated lacustrine silt and clay.

Horizon	Depth in inches	Description
A_1	0-7	Dark gray, dry; black, moist, (10YR 4/1, 2/1), non calcareous silty clay loam; moderately developed fine-crumb structure; slightly hard when dry; very friable when moist. This changes clearly into,
A_2	7-11	Dark gray, dry; black, moist, (10YR 4/1, 2/1), noncalcareous silty clay loam; weak fine granular structure; slightly hard when dry; very friable, moist. This changes clearly into,
B_2	11-18	Dark grayish-brown, dry; very dark brown or black, moist, (between 10YR 4/2 and 2.5Y 4/2, dry; between 10YR 2/2 and 2/1, moist), noncalcareous light-textured silty clay loam. Strongly developed, medium coarse granular structure; hard when dry; friable when moist. This grades into,
B_3	18-22	Between light brownish-gray and light yellowish-brown dry; between dark grayish-brown and olive-brown, moist (2.5Y between 6/2 and 6/4, dry; and between 4/2 and 4/4 moist), noncalcareous silty clay loam having a porous massive structure; hard when dry; friable when moist. This changes clearly into,
C_1ca	22-40	Between light gray and pale-yellow, dry; between light brownish-gray and light yellowish-brown, moist, (2.5Y between 7/2 and 7/4, dry; between 6/2 and 6/4, moist), strongly calcareous, massive silty clay loam having a moderate to large quantity of crystalline gypsum or salts; hard when dry; friable when moist. This grades into,
C_2	40-60	Mottled pale-yellow and white, dry; pale-yellow and light gray, moist (2.5Y 8/2, 8/2, dry; 7/4, 7/2, moist) moderately calcareous; distinctly laminated silty clay loam; slightly hard to hard when dry; friable when moist.

ABERDEEN SILTY CLAY LOAM
Number 50-SD-58-1

Location: T120N, R64W, Section 25; 0.4 mile east of the northwest corner.

Vegetation: Grain stubble.

Parent material: Laminated lacustrine silt and clay.

Horizon	Depth in inches	Description
A_1	0-7	Dark gray, dry; black, moist, (10YR 4/1, 2/1), noncalcareous silty clay loam; weakly granular structure; slightly hard when dry; very friable when moist. This changes abruptly into,
A_2	7-11	Gray, dry; very dark gray, moist, (10YR 5/1, 3/1), noncalcareous, light-textured silty clay loam; strongly developed, medium sized granular structure; slightly hard when dry; friable when moist. This changes abruptly into,
B_2	11-18	Dark gray, dry; very dark gray, moist, (10YR 4/1, 3/1), noncalcareous, heavy-textured silty clay; moderately developed, medium-sized prisms that break down into moderately developed coarse granules; hard when dry; firm when moist; this changes clearly into,
B_3	18-22	Light yellowish-brown, dry; between brown and olive-brown moist, (between 10YR 6/4 and 2.5Y 6/4, dry; between 10YR 4/3 and 2.5Y 4/4, moist), noncalcareous silty clay; moderately developed, medium prisms grading into massive structure; hard when dry; firm when moist. This changes clearly into,
$C_{11}ca$	22-30	Between light gray and pale yellow, dry; light olive-brown, moist, (between 2.5Y 7/2 and 7/4, dry; 5/4, moist), strongly calcareous silty clay; weakly granular structure; slightly hard when dry; friable when moist. This grades into,
$C_{12}ca$	30-40	Color same as horizon above, excepting that the soil is mottled with amount of segregated lime; weak granular structure; slightly hard when dry; friable when moist. This changes gradually into,
C_2	40-60	Color same as horizon above, excepting that the soil is mottled with white (2.5Y 8/2). This is distinctly laminated silty when moist; moderately calcareous but without segregated lime; crystals of gypsum or soluble salts present.

EXLINE SILT LOAM

49-SD-58-5

Location: T117N, R63W, Section 13, SW corner.

Vegetation: Native Grass Hayland—Red Top, Fescue, Big Bluestem, Switchgrass, Saltgrass, Wild Rose.

Parent Material: Calcareous lacustrine materials.

Horizon	Depth in inches	Description
A_1	0-2	Dark-gray to very dark-gray (10YR 4/1 to 3/1, moist) noncalcareous silty clay loam; weak fine platy structure; soft when dry, very friable when moist. pH 5.8. This changes abruptly to
A_2	2-4	Light-gray to very dark-gray (10YR 6/1 to 3/1 moist) noncalcareous silty clay loam; moderately developed fine platy structure; soft when dry, very friable when moist. pH 5.7. 2% exchangeable Na. This rests abruptly on
B_2	4-17	Dark-gray to black (10YR 4/1 to 2/1 moist) noncalcareous silty clay with very strongly developed medium sized round topped columns; columns are 4 or 5 inches long, the tops are coated with a small fraction of an inch of white (10YR 9/1, dry) silica. The lower part of this horizon has a massive or weak blocky structure; extremely hard when dry, very firm when moist. pH 7.0. 6% exchangeable Na. This grades into
B_3	17-20	Gray to very dark-gray (1.25Y 5/1 to 3/1, moist) mildly calcareous silty clay loam without segregated lime, massive structure; hard dry, firm when moist. pH 7.9. 10% exchangeable Na. 0.24% soluble salts. This changes clearly into
Cca	20-36	White to light olive-gray (5Y 8/2 to 6/2, moist) strongly calcareous silty clay loam without segregated lime, massive structure; hard when dry, friable when moist. pH7.9. 9% exchangeable Na. 0.26% soluble salts. This rests abruptly on
C	36-65	White and pale-yellow to light brownish-gray mottled with light olive-brown (2.5Y 8/2 and 7/4 to 6/2 and 5/6, moist) stratified silty clay and fine sandy loam; moderately calcareous; massive structure; both hard and soft when dry, friable when moist. pH 7.8. 13% exchangeable Na. 0.23% soluble salts.

TETONKA SILT LOAM

Number 50-SD-58-5

Location: T120N, R64W, Section 25; 150 feet West, 150 feet south of NE corner of section.

Vegetation: Grain stubble.

Parent material: Lake bed silts and clays, some local alluvium.

Horizon	Depth in inches	Description
A_1	0-19	Dark gray, dry; very dark gray, moist, (10YR 4/1, 3/1), noncalcareous silt loam; moderately developed; very fine crumb structure in the plowed layer but having a moderately developed fine platy structure in the undisturbed portion; slightly hard when dry; very soluble salts. This changes clearly into
A_{21}	19-26	Between gray and light gray, dry; dark gray, moist, (10YR 6/1, 4/1), noncalcareous silt loam; weakly developed medium prismatic structure; prisms separating into strongly-developed fine plates; slightly hard when dry; very friable when moist.
A_{22}	26-32	Light gray, dry; gray, moist, (10YR 7/1, 5/1), noncalcareous silt loam; moderately developed medium prisms having a horizontal breakage into moderately developed fine plates; hard when dry; very friable when moist. This changes abruptly into,
B_2	32-41	Dark gray, dry; very dark gray, moist (10YR 4/1, 3/1), noncalcareous silty clay loam having a moderately developed fine- and medium-prismatic structure; prisms moderately separable into fine blocks; extremely hard when dry; firm when moist. This changes clearly into,
B_{31}	41-64	Light yellowish-brown, dry; olive-brown moist, noncalcareous silty clay loam having moderately developed coarse prismatic structure; prisms separate into moderately developed fine and medium blocky aggregates. The outsides of the prisms are coated with soil from above; grayish-brown when dry (10YR 5/2); very dark grayish-brown when moist (10YR 3/2); extremely hard when dry; very firm when moist. This grades into,
B_{32}	64-90	Mottled light olive-brown, pale yellow, and olive-yellow (2.5Y 5/4, 8/4 and 6/6 dry) noncalcareous, heavy-textured silty clay loam; weak coarse prismatic structure; sized blocky aggregates; hard when dry; firm when moist.

APPENDIX D
Effects of Leaching Lake Dakota Plain Soils

Redfield Irrigation Farm Results

Studies by the U. S. Bureau of Reclamation to determine salt occurrence in two soils on the Redfield Irrigation Development Farm were begun in 1951. Salt readings on a well drained soil (presumably Beotia silt loam) and a poorly drained soil (presumably a Solonetz) were made in 1951, 1960 and 1966. The results are shown in appendix table 3.

The data in the table show that where the soil is well drained a stable low level of salt concentration exists. The poorly drained profile shows evidence of salt accumulation at shallower depths and a continued high concentration of salt at greater depths.

Appendix Table 3. Comparison of salt occurrence in soils of the Redfield Irrigation Development Farm, from 1951 through 1966.
(U. S. Bureau of Reclamation data.)

Depth (inches)	Texture	Conductivity-saturation extract (millimhos per centimeter) 1951	1960	1966
WELL DRAINED PROFILE				
0-8	SiL	0.81	0.64	0.95
16	SiL	.95	.66	.88
26	SiL	.75	.84	.90
36	SiL	.55	1.54	.90
45	SiL	1.05	.68	.85
55	SiL	1.40	1.88	.90
67	SiL	1.14	2.10	1.00
77	SiL	1.63	1.90	1.00
87	SiL	1.61	1.74	1.08
96	SiL	1.51	2.45	1.08
108	SiL	1.40	3.10	1.49
120	SiL	1.30	4.38	2.00
POORLY DRAINED PROFILE				
0-6	SiL	0.93	3.20	5.90
12	SiL	.97	1.90	10.00
20	SiL	1.03	6.00	13.00
30	SiL	4.30	6.00	13.50
36	SiL	3.80	9.00	15.00
48	SiL	4.53	14.00	14.90
60	SiL	11.80	15.00	14.00
73	SiCl	12.00	15.00	12.00
86	SiCl	15.00	15.00	14.00

Laboratory Leaching Tests (U. S. Bureau of Reclamation)

Laboratory leaching tests were made in 1957 on the Northville block and in 1958 on the Frankfort block. Data for these tests are available from the Bureau of Reclamation, James Division, in Huron.

The 1957 data are for six profiles sampled at 1-foot intervals to 10 feet. "Before" and "after" leaching results are given for (1) conductivity of saturation extract, (2) estimated exchangeable sodium percentages, and (3) pH. In addition, the disturbed permeability is recorded for periods of 24 hours, 48 hours, and 72 hours, and the conductivity of the leachate at the beginning of the tests and at 72 hours. The leaching was done with synthetic Missouri River water having 450 p.p.m. T.D.S. and 38% sodium.

The soils generally are well supplied with native gypsum. Leaching tests were continued for all soil depths having slow permeability and high salt until equilibrium was reached with quality of leaching water. This point was reached within 264 hours or 11 days with a few exceptions. The amount of water passing through the soil columns ranged from 35 inches in 72 hours to 15 inches in 264 hours. There was an appreciable increase in permeability for some of the slowly permable horizons.

The 1958 data are similar to those for 1957. Both of these experiments indicate the importance of maintaining water movement downward on all soils of the Lake Dakota Plain. On the basis of these data and other tests, the Bureau of Reclamation plan provides for installation of subsurface drains before irrigation. Spacing of these drains will vary with soil conditions but will accomodate percolating water in the 4- to 10-foot zone.

APPENDIX E

General Distribution of Soils

The general distribution of five of the most extensively occurring soils is shown in figures 5, 6, 7, 8, and 9.

These maps were compiled from the line maps of scale 1 inch = 1 mile which are part of the Soil Survey. The figures represent the general soil distribution patterns of major soils but are not suitable for planning.

In general, the maps show the dominance of the solonetzic soils Aberdeen, Harmony and Exline on flats away from the major drainageways. Near the streams the principal soils are the friable Chernozems Great Bend and Beotia.

5 Aberdeen


0 2 3

Great Bend 8


0 1 2 3
SCALE IN MILES

Appendix References

1. Corey, R. B. 1951. Silicate Analysis by Rapid Micro Spectrochemical System. Unpub. Masters thesis. University of Wisconsin.
2. Flint, R. F. 1947. *Glacial Geology and the Pleistocene Epoch.* John Wiley and Sons Inc. New York.
3. Flint, R. F. 1955. Pleistocene Geology of Eastern South Dakota. USGA Professional Paper No. 262. USG PO Washington, D. C.
4. Kilmer, V. J. and L. T. Alexander. 1949. Methods of Making Mechanical Analyses of Soils. Soil Sci. 68: 15-24.
5. Peech, M., L. T. Alexander, L. A. Dean, and J. Fielding Reed. 1947. Methods of Soil Analysis for Soil Fertility Investigations. U. S. Dept. Agr. Cir. 57. 25 pp.
6. Rothrock, E. P. 1943. *A Geology of South Dakota.* Part I. The Surface. State Geol. Survey, Vermillion, South Dakota.
7. Rothrock, E. P. 1946. The Surface of a Portion of the James Basin in South Dakota. South Dakota State Geol. Surv. Report of Investigations. No. 54.
8. Todd, J. E. 1909. Aberdeen-Redfield Folio. Northville, Aberdeen, Redfield and Byron Quadrangles, South Dakota. Geologic Atlas of the United States. U. S. Geological Survey, Geol. Atlas, Folio 165. Washington, D. C.