# THE OCCURRENCE AND DEVELOPMENT OF "MAGNESIUM SOLONETZ" IN THE SOILS OF THE RED RIVER VALLEY.

A THESIS

Submitted to the Committee on Post-Graduate Studies
of the University of Manitoba.

by
ORVAL G. CALDWELL.

In Partial Fulfillment of the Requirements for the
Degree of
MASTER OF SCIENCE.

April
1934

# ACKNOWLEDGMENTS.

The Writer wishes to express his indebtedness to Professor J. H. Ellis of the Soils Division, Department of Agronomy, University of Manitoba, who suggested the problem, and under whose direction the work was conducted, for his helpful advice in carrying out the laboratory procedure. Thanks are also tendered to Professor Ellis for the use of the soil descriptions and pen sketches of the Red River Valley soils from the Red River Valley Soils Report.

Grateful acknowledgment is also made to Professor L. Shanks, Assistant Professor of Civil Engineering, University of Manitoba, for the results of Dynamometer Studies in the Red River Valley Soils.

# TABLE OF CONTENTS.

# TABLE OF CONTENTS.

# INDEX OF TABLES.

# INDEX OF CHARTS.

## 1. STATEMENT OF THE PROBLEM.

The alkalinization of a considerable area of soils in the Red River Valley, which results in a poor physical condition, constitutes some important problems, involving technical and practical aspects. A study of these problems was undertaken to ascertain the nature and cause of the phenomena observed with a view to arriving at a solution of the problems and of outlining methods for their amelioration.

## 2. LITERATURE REVIEW.

The attention of soil scientists in other countries has been focused for some time upon the formation, the structural characteristics, physical condition and the amelioration of alkali, and saline soils. However, the fundamental facts relating to the formation of alkalinized soils as they occur in the Red River Valley in Manitoba have not been studied previously.

J. Szabo (11) as early as 1891 recognized two types of alkaline soils in Hungary: First, soils containing quantities of sodium carbonate with other salts, and second, soils containing only small quantities of sodium carbonate and free from other salts. P. Tuitz (11) states in 1894 that soils containing sodium carbonate were impervious to water and very difficult to till.

Hilgard (31) working in the United States, separated alkaline soils into two groups, depending upon the presence or absence of sodium carbonate. He attributed the poor physical condition of soils containing sodium carbonate,(i.e.), the so-called black alkali soils), to the influence of this salt.

De Sigmond (11) in 1902--1905 distinguished two types of alkali soils in Hungary, noting a difference in physical and chemical characteristics and structural formation.

At about the same period the soil workers in Russia (65) were differentiating between alkali and saline soils by morphological differences and to some extent by their chemical variations. Glinka (65) further classified saline soils using the predominating salt as the basis of classification.
He was a supporter of Hilgard's theory that alkali soil formation is due to sodium carbonate which is formed from the reaction of sodium chloride or sodium suphate with the alkali earth carbonates. The development of alkali structure was attributed by Glinka to the formation of a zone in the soil profile considerably enriched in colloidal gels and suspensions, followed by a process analogous to the production of prismatic columns in basalt.

Russian "Salzboden" were classified by Glinka (30) in 1914 into two groups on morphological differences alone, as follows:

A. Soils with structure - "Solonetz Soils".
   1. Solonetz soils - Columnar, prismatic or lumpy structure.
   2. Transitional Solonetz soils - more or less Solonetz-like.

B. Soils without structure - "Saline Soils".

Popov (65) in 1914 described a further type of alkali soils calling it a "Soloti" soil. This type was formed from alkali soils by a process of degradation.

Vilensky (64) in a recent publication classified "Solonetz" soils or alkali soils upon their structural type. He found that their structural characteristics depended to a large extent upon the physio-geographical distribution of the genetic soil zones, which vary in Russia from south to north. Vilensky also recognized the degraded alkali or "Soloti" soil type, and stated that the degradation processes were caused by water stagnating on the surface,with the settling of meadow and swampy vegetation or the advance of forests.

Hilgard (31) described alkaline soils as being formed under arid conditions, where the rainfall is insufficient to leach out the soluble salts, but Glinka (30) in classifying soils in relation to moisture finds alkaline soils occurring under periodic and temporary excessive moisture conditions, that is, a temporary excess of water occurring locally in the soil regions where dry climate prevails. Sigmond (11), believed that Glinka was correct in this theory as the alkali soils of Hungary apparently have followed former swampy conditions. In Egypt also the alkali soils are developed where the land is periodically flooded by the overflowing of the River Nile.

The development of alkali soils was not fully understood until Gedroiz (27) in 1912 developed the theory of the formation of alkali soils from sodium saline soils by the removal of the soluble salts. This theory is now generally accepted by soil scientists throughout the world.

By his theory a saline soils is a soil containing large amounts of soluble salts. An alkali soil differs from a saline soil in that it contains adsorbed sodium and the soluble salts have been removed. This theory implies that alkali soils are developed only from sodium saline soils. If the saline soils contain calcium salts but not sodium salts they do not produce an alkali soil when the salts are removed. Vilensky (65), Nikiforoff (43). The adsorbed sodium increases the dispersion of the adsorbing complex of the soil and causes the development of physical properties such as impermeability to water, compactness, stickiness, and the columnar and prismatic structure characteristic of alkali soil. The degradation of such a soil may occur rapidly with the formation of a podzol-like soil known as the "Soloti" or a degraded alkali soils. Gedroiz (43) recognized three main divisions of alkali soils, namely the "Solonchack" the Solonetz" and the "Soloti" types. These types are all consecutive stages of the process of alkalinization. The "Solonchack" is converted to the "Solonetz" if the supply of salts are cut off and the drainage improved, resulting in a removal of the salts. The "Solonetz" is changed into the "Soloti" by a degradation process which is caused by the downward movement of water in a soil which has quantities o of adsorbed sodium in the exchange complex.

Gorshenin in 1921 (65), writing on the "The Chernozem soils of Western Siberia" stated that:

> "The places, (soils), more impregnated with salts formed alkali soils which in depressions were subject

"to the process of degradation and turned into "Soloti". The places less salinized gave saline Chernozems which later turned into an alkaline Chernozem".

Gedroiz (27) in his work on alkali soils, attributes the presence of the sodium ion with its dispersing influence as the cause of alkali soil structure and its accompanying bad physical condition. Vilensky (64), (65), gives one of the characteristics of "Solonetz" soil as the presence of adsorbed sodium. He produced alkali soil artificially in two years time by the use of sodium salts. Sigmond (11) in Hungary, and Kelly (52) in the United States, associated a soil which has alkali structure and poor physical condition with a soil colloidal complex saturated with sodium.

Recently however, several workers have studied soils which have structural or physical characteristics which indicate a sodium saturated soil, but which upon examination were found to be soils containing very little adsorbed sodium.

Rosov (50) studied a Russian soil with "Solonetz" characteristics, which had been morphologically called a "Solonetz", and found but 1 to 5 per cent adsorbed sodium in the colloidal complex. Rosov makes the statement that this is but one of the frequent cases where the morphological characteristics of "Solonetz" soil does not agree with the chemical data.

Lewis and Marmoy (41) pointed out that some heavy clay soils in Great Britain which were generally regarded as sodium saturated soils due to their poor physical condition were actually very low in replaceable sodium.

The review of the available literature on the subject of alkalinization of soils would indicate:

(1) That "Solonetz" or alkali soils are formed from saline soils.

(2) That the poor physical conditions and characteristic structure development are due in may cases at least to the dispersing influence of adsorbed sodium in the fine material in the soil and to the absence of electrolytes to counteract this effect.

(3) That "Solonetz" soils become degraded to form "Soloti" in degraded alkali soils.

(4) That soils have been studied recently which have characteristic alkali structures but do not contain any adsorbed sodium.

The occurrence of soils with alkali characteristics was observed in the Red River Valley and a study of these soils and their related types was undertaken.

## 3. MORPHOLOGICAL DESCRIPTION OF RED RIVER VALLEY SOIL TYPES STUDIED.

The Red River Valley is a vast lacustrine clay plain stretching south from Winnipeg in Manitoba into the States of North Dakota and Minnesota. This plain is drained by the Red River flowing northward, and emptying into Lake Winnipeg. It was formerly the bed of Glacial Lake Agassiz.

During the years of 1928 to 1930 a reconnaissance soil survey of that portion of the valley between Winnipeg and the International Boundary was conducted by Professor J. H. Ellis of the Soils Division, Department of Agronomy, University of

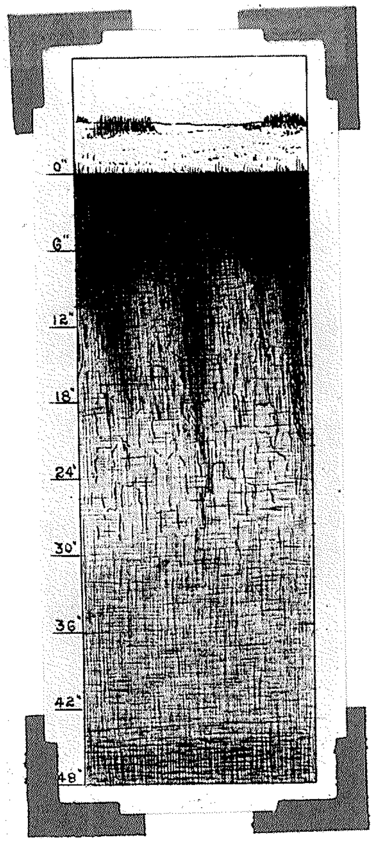
Manitoba. Approximately 1,250,000 acres were surveyed and the soils were classified according to the Nikiforoff system of soil classification. (17)

The morphological descriptions of soil in this area, that are subsequently dealt with in this paper, were taken from the Red River Valley Soil Survey Report(16) by Prof. J. H. Ellis, which is as yet unpublished.

The soils of the Red River Valley Combination are classified into three associations and a number of associates. The morphological description of these soils is as follows:

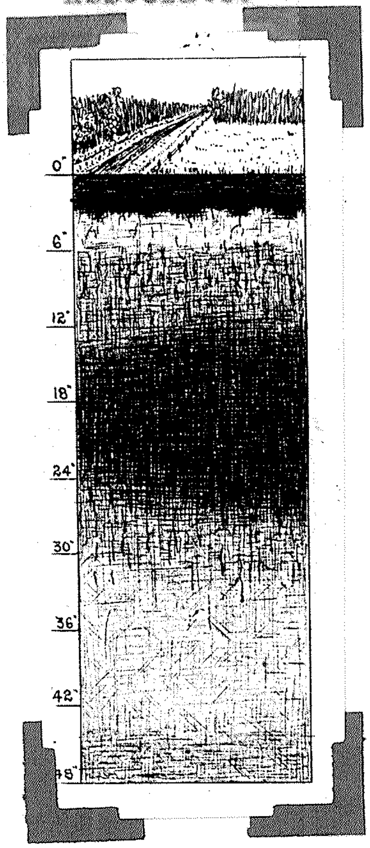
Phytomorphic B. Soils of the Red River Association.
Prairie i.e., soils developed on lacustrine fine clay
Associate C. Soils developed under well drained or normal moisture conditions.

D. Well drained prairie, Red River Clay



| Inches | |
|---|---|
| 0--2 | Black very finely granular clay and sod mat. |
| 2--8 or 10" | Very dark brown friable clay in buckshot sized granules above to wheat sized granules below, (Black when wet, very dark brown when dry) Tooth-like tongues of the $A_1$ horizon extend as intrusions from above to 24" or more. Neutral to very slightly acid in reaction. |
| 8-18" | Light greyish brown clay in irregular granules and prismatic aggregates, and with tongues of surface material intruding from above, due to the cracking of the soil in dry seasons. |
| 18-30" | Greyish brown to brownish drab clay, finely fragmental, effervesces freely with acid. |
| 30"- | Grey brown to olive drab clay, with yellowish grey calcareous concretions grading into lacustrine clay. |

Red River Phytomorphic wooded Associate.



D$_2$ Wooded associate (or degraded prairie)

### St. Norbert Clay.

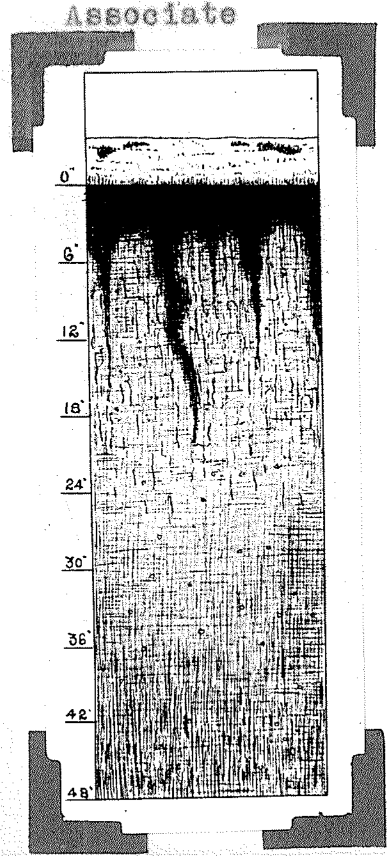
| inches | |
|---|---|
| 0--2" | Brown leaf mold. |
| 2-2$\frac{3}{4}$" | Dark brown to greyish black. Finely granular clay mixed with organic matter. (Acid reaction). |
| 2$\frac{3}{4}$-5" | Whitish grey clay, irregular dull granules, weakly plated. (Acid reaction). |
| 5-14" | Grey brown clay, tough, hazel-nut structure. (Acid reaction). |
| 14-24" | Black and grey streaked clay, tongued to 36". Tough compact, shiny aggregates, grading into |
| 30"-- | Mottled olive drab clay with carbonate concretions. Effervesces with acid at about 30". Horizons show irregular junction. |

C$_3$ Meadow soils developed under locally excessive moisture.

D. Non-salinized meadow associate.

### Osborne Clay.

Red River Hydromorphic Associate



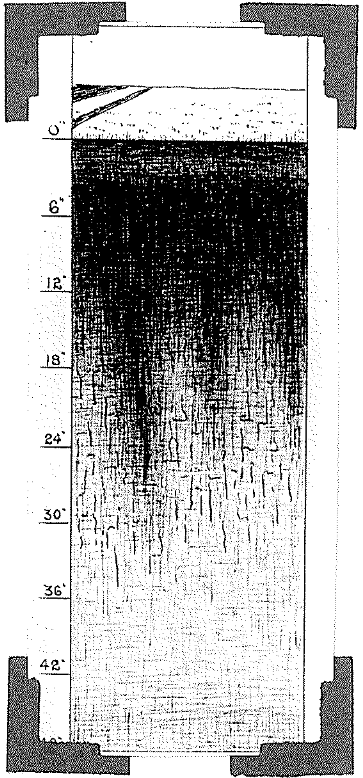
| inches | |
|---|---|
| 0--4" | Black clay, tough when cultivated, but mucky and friable in virgin condition. |
| 4-20" | Grey clay, finely fragmental, more or less stained or with iron in specks as buckshot concretions or deposited in dead root channels. Short thin tongues of dark surface material intrudes into the upper portion, but these are only feebly developed. Lime carbonate in marly patches is frequent. |
| 20"-- | Olive grey to grey drab clay which becomes grey on drying, with profuse concretions of lime carbonate, usually effervesces with acid below the black surface horizon. May contain some gypsum crystals in C material. |

Red River Halo-
morphic

$C_4$ Alkalinized Associates.

(Alkalinized Phase)

$D_2$ Alkalinized phase. <u>Morris Clay.</u>

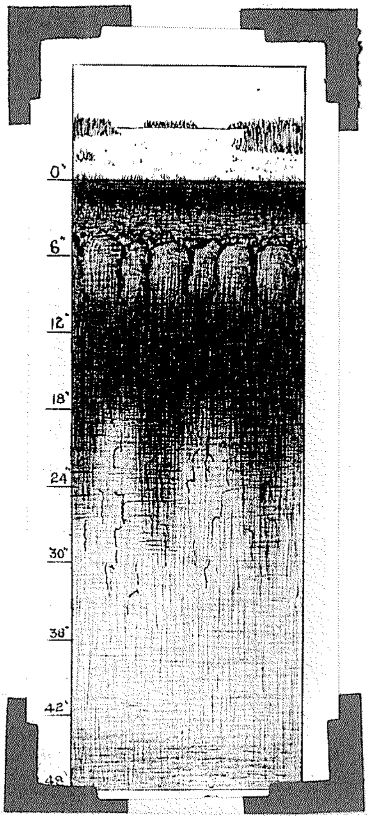


| inches. | |
|---|---|
| 0--4" | Very dark greyish black clay often diagonally plated. |
| 4-11" | Black clay, tough, compact, small irregular angular fragments which form dull irregular pillared aggregates when dry. |
| 11-14" | Very dark grey and black stained clay, closely packed finely fragmental aggregated with shiny faces. |
| 14-18" | Dark grey clay stiff and tough. |
| 18"-- | Sticky gray clay effervesces weakly with acid in upper portion. Grades into greyish olive drab clay with lime carbonate concretions at about 30" |

Red River Halo-
morphic
(Degraded alkal-)
(inized phase. )

$D_3$ Degraded phase.

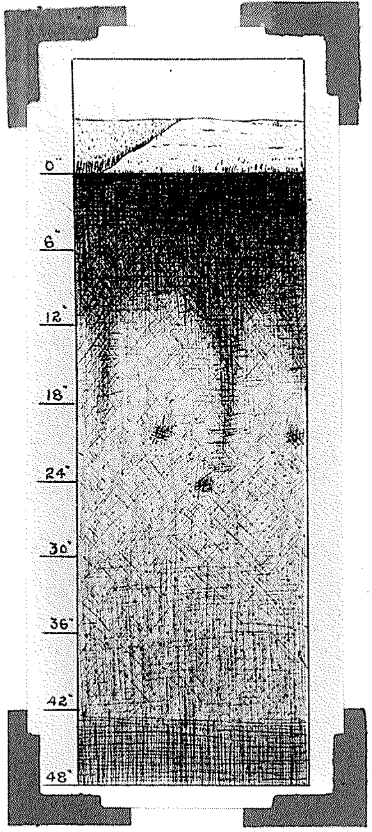
<u>Degraded Morris Clay.</u>



| inches. | |
|---|---|
| 0--2" | Leaf mat. |
| 2--4" | Grey and ashlike clay, platy in structure. |
| 4-10" | Large columnar clods,some more or less flat on top while others are seeming grey in color and rounded on top. |
| 10-24" | A black tough tarlike horizon with pea sized aggregates. |
| 24"-- | Grey clay with carbonate concretions. |

## $B_2$ Soils of the Emerson Association.

Emerson Phyto-
hydromorphic
Prairie.



C. Soils developed with good surface drainage over buff colored silty delta deposits and lacustrine sediments.

D. Prairie Associate. Emerson.

inches

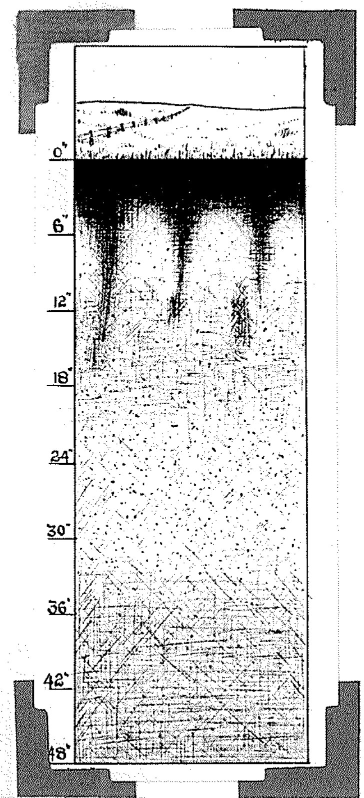
9-10" Black or greyish black silty to silty clay A horizon, structureless to finely granular, grey cast when dry due to faint infloresence which can be seen under a hand glass. Effervesces with acid from the surface. Irregularly tongued and streaked into underlying horizon.

10-12" or 18-20" Light grey marl-like horizon.on Whitish, friable and crumb-like when dry, pasty when wet. Broad black and dark grey stained tongues intrude from above.

18-20" to 27" Buff to straw colored silt to silty clay, structureless, friable.

27"-- Buff and grey mottled silty clay on silt. Porous and friable, buff colored when dry. More or less profusely iron stained and with bean like iron concretions.

Emerson Hydro-
Halomorphic
Associate
(Salinized phase)



C. Low salinized associate of the Emerson association.

D. Emerson silty clay, low salinized phase.
Emerson salinized silty clay loam.

inches

0--6" Grey black mucky silty clay, impregnated with gypsum salt as pseudo-mycilium and powder. Structureless. Effervesces fiercely at surface.

6-11" Grey horizon with irregular junction. Dark stained from above and with profuse gypsum crystals.

11-20" Buff fine sandy clay loam mixed with gypsum crystals and with numerous iron specks and concretions.

11-32" Mottled grey and buff fine sandy loam mixed with clay in cubical fragments, iron stained and streaked.

## $B_3$ Soils of the Altona Association.

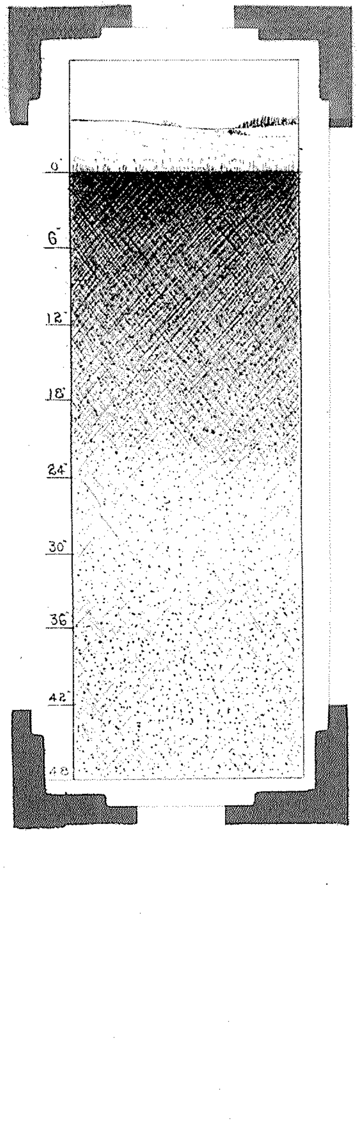
1. Soils with brownish yellow or buff colored subsoil.

$C_1$ Soils developed under well drained or normal moisture conditions.

D. Prairie associate.

### Altona Very Fine Sandy Loam.

Altona Phytomorphic Associate.



| inches | |
|---|---|
| 0--6" | Dark greyish brown to dark brown very fine sandy loam, structureless to finely granular. Friable, alkaline reaction. |
| 6 or 8" to 16" | Very dark grey brown very fine sandy loam, more or less indurated when dry, and tending to form weakly pillared aggregates. Effervesces at lower junction. Alkaline reaction. |
| 16 to 28" or 32" | Yellowish grey to buff transition. Moderately compact but not indurated. Carbonate accumulation. Effervesces. |
| 32"-- | Buff or brownish yellow very fine sandy loam without structure and sometimes weakly specked with iron. Effervesces. |

## 4. GENERAL DESCRIPTION OF THE RED RIVER SOIL TYPES STUDIED.

The soils of the Red River Combination include three soil associations, namely, the Red River, the Emerson and the Altona associations. The soil of the Red River associations were developed on the heavy clays deposited in the deeper portions of Lake Agassiz. The Emerson association are silty clays to silty clay loams, and the Altona association are very fine sandy loams formed on materials deposited in the shallower portions of the Lake.

The Emerson and Altona soil associations are confined to the Southern portion of the Red River Valley in Manitoba. The Emerson association comprises 8.22 per cent and the Altona association 8.27 per cent of the total area mapped. These relatively lighter textured soils are practically all good agricultural soils. The exceptions to this are the salinized associates. These are very limited in area and constitute only one per cent of the total area mapped.

These soils are all more friable and more easily cultivated than are the heavy clay soils of the Red River association. The problems that arise in keeping these soils in a good physical condition are not of the importance as those presented by the heavy soils within the area.

The Red River association formed on the heavy clay soils comprises 66.2 per cent of the area surveyed, although the well drained or phytomorphic phase includes only 13.8 per cent of the total area. The phytomorphic or prairie associate is the better soil of the association, having a high organic matter content and granular structure and it is relatively friable. The objectionable structural characteristics of the alkalinized soils do not occur in this type. It is adapted to the growth of cereals, grasses and clovers.

The phytomorphic wooded phase is a small area under oak woods distributed adjacent to the banks of the Rat, La Salle and Red Rivers. This type is a degraded soil, and although well drained at the present time, this investigation would indicate that the drainage has not always been favorable.

The hydromorphic associate is the meadow type of the Red River association and includes 41.2 per cent of the associate or 27.2 per cent of the total area, and thus it should is classed as an important type. It is normally under the influence of water due to the flat topography and adsence of relief. The chief problem relating to this soil is that of drainage. Two phases of this associate may occur:--(1) The salinized phase. (2) The non salinized phase.

This soil will be improved, from an agricultural standpoint, when it is freed from the periodic inundations of water upon it and the organic matter increased within the profile rather than upon it, with the resulting improvement in physical properties. The drainage of a portion of this land at the present time is accomplished by ditches, a method which has proved to be none too satisfactory, when the rainfall becomes heavy periodically.

The alkalinized and degraded alkalinized phases of the Red River association together consist of 19.6 per cent of the association, or 13.0 per cent of the total area mapped. The degraded alkalinized phase is considered as differing from the alkalinized phase only in the degree of alkalinization and subsequent degradation. The structure and morphological description of the alkalinized soil resembles closely that of a "Solonetz" while in some respects the degraded alkalinized soil resembles closely a "Soloti" or degraded "Solonetz". There are many degrees of alkalinization and degradation in these soils.

The degraded alkalinized soil is found as small islands in the areas occupied by the alkalinized soils and is of little importance from a practical standpoint.

The general characteristics of these soils include heaviness and difficulty of tilling. When wet they puddle and bake to form large clods which are very hard to break up by ordinary means of cultivation. An illustration of this may be taken from data by Shanks (55) of dynamometer measures of plow draft in soils of the phytomorphic associate and the alkalinized phase. The plow draft per square inch was found to be 5.55 pounds in the soil of the phytomorphic associate, while in the alkalinized phase it reached the relatively high value of 12.2 pounds. The alkalinized soils are also very impermeable to water and present a problem of drainage that is not present in the phytomorphic associate. After a heavy rain during the late spring surface water will not percolate rapidly enough through the alkalinized soil to prevent injury, or the complete drowning out of the growing crops.

The outstanding differences between the phytomorphic associate, and the alkalinized and degraded alkalinized phases also of the same association are the characteristic chernozem structure, friability, easy tillability and good drainage of the phytomorphic associate compared with the prismatic and cloddy structure, toughness, intractibility and impermeability to water of the alkalinized and degraded alkalinised phases.

## 5. EXPERIMENTAL - CHEMICAL STUDY OF RED RIVER VALLEY SOIL TYPES.

Laboratory studies were conducted on typical soil associates in the Red River Valley, namely the Red River phytomorphic prairie, (two samples), Red River alkalinized, Red River degraded alkalinised, Phytomorphic wooded, Hydromorphic, Emerson phyto-hydromorphic, Emerson hydromorphic salinized, and Altona phytomorphic associates, which have been previously morphologically described.

### A. SAMPLING.

The sampling was accomplished by digging a pit, in each type of soil, and removing the samples from the pit wall. All samples were taken by horizon depths. Each soil type was studied down to and including the C horizon.

### B. INORGANIC CARBONATE, ORGANIC MATTER AND REACTION.

(a) Methods.

The hydrogen ion concentration, inorganic carbon, and organic matter were determined in all samples according to the following methods:-

The hydrogen ion concentration was determined electrometrically in both water and normal KCl solutions, using the quinhydrone electrode as described by Biilman and Tovborg-Jensen (6).

The inorganic carbon content of the soil was determined by digesting the soil in a 1-5 hydrochloric acid solution, passing the $CO_2$ given off through a drying and purifying train and absorbing it in Ascarite. The Ascarite is contained in a Nesbitt absorption bulb. The $CO_2$ absorbed equals the difference in weight of the Ascarite and bulb before and after the determination.

The method of Robinson, McLean and Williams (49) was used in determining the organic matter content of the soil.

(b) Results and Discussion.

The results of these three determinations are given in Table No. 1.

The hydrogen ion concentration of the Red River soils ranges from a pH of 6.2 to 8.3 in water solutions with a slightly more acid reaction in KCl solution. The A horizon of the heavy textured soils of the Red River association vary from neutral to slightly acid, while the A horizon of the soils of the lighter textured soils of the Emerson and Altona associations are definitely alkaline. All the soils except the Red River degraded alkalinized associate however become definitely alkaline at some depths in the profile, the depth depending upon the upper limits of the alkaline earth carbonates. The salinized Emerson however, is more alkaline at the surface, due to the heavy concentration of salt. (See Table No.2). The Red River associates are generally less alkaline and contain less inorganic carbon within the profile than the Emerson and Altona soils. The Red River phytomorphic and hydromorphic associates have traces of carbonate present in the A horizon and a marked accumulation in the B horizon. In the Red River alkalinized soil and in the Red River phytomorphic wooded soil the carbonate, where present, is in the lower depths of the profile, while in the Red River degraded alkalinized phase it is absent entirely. The hydrogen ion concentration is highest in the soils where the carbonate has been removed to lower depths in the profile. The Red River phytomorphic wooded phase has a higher hydrogen ion concentration at a depth of 6½ to 15 inches, with an increase in pH values towards the surface, suggesting a super-imposing of one soil process upon another. The Emerson and Altona soils therefore differ from the soils of the Red River association in at least one respect, i.e., the inorganic carbon is not being removed to such a degree in the first named soils as in the latter soils, and consequently the accumulation is much higher in the profile. The hydrogen ion concentration of these soils is below a pH of 8.5 indicating that the alkaline reaction is due chiefly to alkaline earth carbonates and not alkali carbonates. (1)

## TABLE No. 1

## HYDROGEN ION CONCENTRATION, AND PER CENT OF ORGANIC MATTER AND INORGANIC CARBONATE IN RED RIVER VALLEY SOILS.

| Soil Associate | Depth in inches | Hydrogen ion Concentration | | Inorganic Carbonate ($CO_2$) in per cent of soil | Organic Matter in per-cent of soil |
|---|---|---|---|---|---|
| | | $H_2O$ Solution | KCl Solution | | |
| Red River phytomorphic prairie Associate (No. 1) | 0--2" | 7.0 | 6.3 | trace | 18.61 |
| | 2--8" | 7.1 | 6.5 | trace | 7.88 |
| | 8-18" | 7.9 | 7.2 | 2.36 | 1.96 |
| | 18-23" | 8.1 | 7.4 | 5.13 | 1.47 |
| | 23-28" | 8.0 | 7.3 | 4.23 | |
| | 28"-- | 8.2 | 7.3 | 5.58 | 1.13 |
| Red River phytomorphic prairie Associate (No. 2) | 0--2" | 6.8 | 6.3 | trace | -- |
| | 2--9" | 6.9 | 6.3 | trace | -- |
| | 9-19" | 7.4 | 7.0 | 1.28 | -- |
| | 19-29" | 7.7 | 7.2 | 3.48 | -- |
| | 29"-- | 8.0 | 7.4 | 4.31 | -- |
| Red River Alkalinized phase | 0--3" | 7.1 | 6.7 | trace | 5.73 |
| | 3-12" | 7.1 | 6.7 | trace | 1.37 |
| | 12-18" | 7.3 | 6.9 | 0.16 | 1.12 |
| | 18-27" | 8.0 | 7.4 | 5.85 | 0.97 |
| | 27"-- | 7.9 | 7.4 | 6.53 | 0.60 |
| Red River degraded Alkalinized phase | 0--2" | 6.2 | 6.2 | 0.0 | leaf mat |
| | 2--4" | 6.3 | 5.8 | 0.0 | 3.54 |
| | 4-24" | 6.8 | 6.3 | 0.0 | 1.66 |
| | 24"-- | 6.4 | 6.7 | 0.0 | 0.85 |

(Continued)

## TABLE No. 1. (Continued)

| Soil Associate | Depth: in inches | Hydrogen ion Concentration<br>H$_2$O Solution | <br>KCl Solution | Inorganic carbonate (CO$_2$) in per cent of soil | Organic Matter in per cent of soil |
|---|---|---|---|---|---|
| Red River Phytomorphic (wooded phase) | 0-1½" | 7.1 | 6.9 | 0.0 | leaf mat |
| | 1½-2½" | 6.8 | 6.4 | 0.0 | 18.16 |
| | 2½-6½" | 6.7 | 6.3 | 0.0 | 7.45 |
| | 6½-15" | 6.4 | 6.3 | 0.0 | 1.86 |
| | 15-26" | 7.1 | 6.8 | 0.0 | 2.79 |
| | 26"-- | 8.0 | 6.4 | 1.20 | 0.88 |
| Red River Hydromorphic Associate | 0--3" | 6.7 | 6.4 | trace | --- |
| | 3--8" | 7.0 | 6.7 | 0.17 | --- |
| | 8-14" | 8.0 | 7.3 | 3.37 | --- |
| | 14-24" | 8.3 | 7.4 | 5.49 | --- |
| | 24-36" | 8.2 | 7.5 | 6.24 | --- |
| Emerson Phyto-hydro-morphic Associate | 0-12" | 7.9 | 7.4 | 3.43 | 10.13 |
| | 12-24" | 8.2 | 7.9 | 16.78 | 1.25 |
| | 24--- | 8.1 | 7.8 | 16.34 | 0.65 |
| Emerson Salinized Phyto-Hydro-morphic Associate | 0--3" | 8.4 | 8.2 | --- | 8.60 |
| | 3-10" | 8.0 | 7.9 | --- | 3.12 |
| | 10-21" | 7.8 | 7.6 | --- | 0.79 |
| | 21-37" | 7.7 | 7.5 | --- | 0.35 |
| | 37-48" | 7.7 | 7.7 | --- | 0.48 |
| | 48-60" | 7.6 | 7.5 | --- | 0.48 |
| Altona Phytomorphic Associate | 0--7" | 7.3 | 7.2 | 0.49 | 7.30 |
| | 7-16" | 7.8 | 7.5 | 2.11 | 2.85 |
| | 16-24" | 8.2 | 8.1 | 7.17 | 1.01 |
| | 24-28" | 8.3 | 8.0 | 11.45 | 0.24 |

## TABLE No. 2

## WATER SOLUBLE SALTS IN PARTS PER MILLION OF RED RIVER VALLEY SOILS.

| Soil Associate | Depth in Inches | CATIONS | | | ANIONS | | | Total Salts |
|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg. | Alkalies | $SO_4$ | Cl | $HCO_3$ | |
| Red River phytomorphic prairie associate (No. 1) | 0--2" | 257 | 93 | 39 | 465 | 41 | 514 | 1409 |
| | 2--8" | 413 | 134 | 51 | 446 | 85 | 743 | 1872 |
| | 8-18" | 471 | 149 | 148 | 879 | 52 | 816 | 2515 |
| | 18-23" | 468 | 96 | 117 | 1018 | 84 | 552 | 2335 |
| | 23-28" | 430 | 129 | 168 | 1009 | 41 | 778 | 2555 |
| | 28"-- | 357 | 128 | 207 | 1061 | 252 | 546 | 2551 |
| Red River phytomorphic prairie associate (No. 2 ) | 0--2" | 553 | 215 | 0 | 0 | 164 | 900 | 1832 |
| | 2--9" | 339 | 150 | 0 | 218 | 48 | 483 | 1231 |
| | 9-19" | 447 | 163 | 52 | 234 | 30 | 1077 | 2003 |
| | 19-29" | 317 | 118 | 89 | 133 | 31 | 909 | 1597 |
| | 29"-- | 214 | 107 | 161 | 316 | 25 | 816 | 1639 |
| Red River alkalinized phase | 0--3" | 199 | 207 | 0 | 0 | 128 | 386 | 920 |
| | 3-12" | 225 | 206 | 0 | 152 | 114 | 215 | 912 |
| | 12-18" | 199 | 207 | 0 | 149 | 128 | 193 | 876 |
| | 18-27" | 315 | 222 | 0 | 650 | 121 | 552 | 1860 |
| | 27"-- | 318 | 222 | 36 | 674 | 121 | 636 | 2007 |
| Red River degraded alkalinized phase | 0--4" | 114 | 100 | 0 | 0 | 269 | 180 | 663 |
| | 4-10" | 321 | 202 | 0 | 102 | 144 | 110 | 879 |
| | 10-24" | 190 | 136 | 64 | 668 | 145 | 222 | 1425 |
| | 24"-- | 244 | 158 | 83 | 1427 | 134 | 155 | 2201 |

## TABLE No. 2. (Continued)

| Soil Associate | Depth in inches | CATIONS | | | ANIONS | | | Total Salts |
|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Alkalies | $SO_4$ | Cl | $HCO_3$ | |
| Red River phytomorphic (wooded phase) | 0-1½" | Leaf Mat | | | Leaf Mat | | | |
| | 1½-2½" | 227 | 100 | 0 | 238 | 0 | 195 | 760 |
| | 2½-6½" | 146 | 78 | 0 | 196 | 0 | 131 | 551 |
| | 6½-15" | 200 | 158 | 0 | 402 | 452 | 44 | 1,256 |
| | 15-26" | 177 | 177 | 60 | 576 | 565 | 45 | 1.600 |
| | 26"-- | 342 | 272 | 232 | 1224 | 772 | 419 | 3,261 |
| Red River hydromorphic associate | 0--3" | 263 | 183 | 275 | 592 | 318 | 966 | 2,597 |
| | 3--8" | 237 | 184 | 245 | 613 | 290 | 861 | 2,430 |
| | 8-14" | 330 | 161 | 298 | 159 | 107 | 1531 | 2,586 |
| | 14-24" | 373 | 188 | 328 | 224 | 160 | 1665 | 2,938 |
| | 24-36" | 200 | 140 | 297 | 137 | 63 | 1307 | 2,144 |
| Emerson phyto-hydromorphic associate | 0-12" | 574 | 124 | 0 | 187 | 0 | 1034 | 1919 |
| | 12-24" | 122 | 142 | 80 | 203 | 0 | 611 | 1,158 |
| | 24"-- | 173 | 143 | 0 | 204 | 0 | 429 | 949 |
| Emerson salinized phyto-hydromorphic associate | 0--3" | 2412 | 3680 | 796 | 23049 | 249 | 342 | 30,528 |
| | 3-10" | 2239 | 1468 | 484 | 12972 | 76 | 219 | 17,458 |
| | 10-21" | 2457 | 941 | 370 | 10969 | 63 | 142 | 15,042 |
| | 21-37" | 1338 | 1471 | 635 | 11443 | 81 | 153 | 15,121 |
| | 37-48" | 1263 | 1823 | 656 | 12695 | 122 | 142 | 15,701 |
| | 48"-- | 2115 | 1818 | 597 | 14412 | 112 | 149 | 19,273 |
| Altona phytomorphic associate | 0--7" | 187 | 86 | 76 | 186 | 0 | 597 | 1,132 |
| | 7-16" | 169 | 96 | 60 | 193 | 0 | 549 | 1,067 |
| | 16-24" | 131 | 141 | 36 | 232 | 0 | 525 | 1,065 |
| | 24"38" | 101 | 112 | 70 | 303 | 0 | 444 | 1.030 |

Neustreuv (2) gives a description of a normal chernozem in relation to the reaction and carbonate accumulation in the profile. He describes a chernozem as having a soil solution of about neutral reaction with carbonate accumulation within the profile. Tumin (62) classifies chernozems on the basis of the degree to which the carbonates have been leached downwards in the profile with the accompanying increase of the hydrogen in concentration in the upper horizons.

The figures for carbonate and reaction in Table No. 1 indicate that both typical and local conditions prevail in the soils in the Red River Valley. The chernozem soil processes occur in the Red River phytomorphic associates, while in the Emerson and Altona phytomorphic associates this process influences the upper part of the profile but the large amount of alkaline earths in the lower part of the profile implies the deposition of geological lime due to the periodic rise of ground water into the lower part of the profile only.

The variations in carbonate content and reaction in the Red River associates is quite marked. The Red River phytomorphic associate is a chernozem-like soil but within the same association other soil forming processes have been operating to form leached soils, as the Red River alkalinized, Red River degraded alkalinized and Red River phytomorphic wooded associates. In the case of the hydromorphic associate leaching tends to take place at the surface but deposition of geological lime by rise of ground water occurs in the lower part of the profile.

The organic matter content is noticeably different in the different Red River associates, being appreciably lower in the alkalinized and degraded alkalinized phases than in the phytomorphic associate. The organic content of the alkalinized soils is too low to permit of a good physical condition in these heavy clays. The phytomorphic wooded phase is relatively low in organic matter except in the $A_0$ and $A_1$ horizon in the virgin condition.

The Red River phytomorphic soil profile is generally well drained throughout and always well drained in the upper part of the profile. However, due to the occasional moistening of the lower part of the profile and deposition of geological lime, this soil cannot be considered a typical Chernozem.

## C. WATER SOLUBLE SALTS.

From the foregoing it is obvious that the soils of the area have developed under imperfect drainage. To ascertain the extent to which sodium soils may occur in these soils, water extracts were made of the soil studied, which included soils occupying the poorly drained positions.

### (a) Methods.

The method used for extracting the soil and the determination of the anions, except the sulphates, was that of Emerson (18). The ratio of water to soil used was 5 to 1, but to accelerate filtering only 60 grams of soil was used. Sulphates were determined by the standard gravimetric method of precipitating as barium sulphate. The water soluble magnesium

The water soluble magnesium was precipitated and weighed as magnesium pyrophosphate. The calcium was precipitated and weighed as calcium oxalate and titrated with potassium permanganate (3). The water soluble alkalies were determined by calculating the difference between the total equivalents of cations necessary to satisfy the anion equivalents and the total equivalents of calcium and magnesium. The alkalies are expressed as sodium equivalents. The results of these analyses are given in Table No. 2. (Page 20 and 21)

(b) Results and Discussion.

The results show that only one soil associate studied, namely the salinized Emerson, may be classed as a "Solonchak". In this associate the total salt content of the surface horizon amounted to over three per cent of the soil. The salts present in this soil are predominantly calcium and magnesium sulphates. In the non-salinized soils the same cations predominate but the bicarbonate anion is often larger in quantity than the sulphate anion. The alkali cations are always less in quantity than either the calcium or magnesium cations except in the hydromorphic associate, where they exceed the magnesium cations. Where present, they occur in relatively small amounts. The chloride anion is small in quantity, being more important in the heavier than in the lighter textured soils. It is a significant point that alkali carbonate is not present in these soils.

The position of the salts in the soil profile is quite different in the heavy and lighter textured soils. The salts in the Red River associates, except some of the hydromorphic associates, increase in quantity with depth in the profile, while in the Emerson and Altona associations the salts decrease with depth. This, no doubt, is an indication that a weak process of leaching is general in the soils of the Red River association but is not taking place in the other two soil associations. This process of leaching in the soils of the Red River association has proceeded noticeably much farther in the alkalinized and degraded alkalinized phases than in the phytomorphic wooded associate. The Red River phytomorphic soil has practically twice the water soluble salt content of the alkalinized and degraded alkalinized wooded phase soils.

The outstanding points in relation to this study are:-

(1) The absence of any alkali carbonates.

(2) The predominance of divalent water soluble cations.

(3) The great difference in the quantity of water soluble salts in the different soil associates of the Red River association. The salt content of the phytomorphic associate is twice that of the alkalinized associate.

Glinka's (27) theory of alkali soils points out that alkali soils are formed from saline soils where the predominating cation was sodium. In the Red River valley the predominating cations at the present time are the divalent ions calcium and magnesium, but nevertheless "Solonetz-like" soils, from a morphological standpoint, have been formed, and occur extensively.

## D. BASE EXCHANGE.

A further study was donducted on these soils to obtain information on the soil process involved in their development. This study included the determination of the exchangeable bases adsorbed, and the total adsorption capacity.

In deciding upon a method, several points had to be considered. The method used must give information on the exchangeable cations, calcium, magnesium, potassium and sodium in the soil, and also the total absorption capacity of the soil. It must also provide for a minimum amount of filtering of the soil, which is a very important factor when dealing with the heavy clays of the Red River Valley.

Several methods sere studied, with a view to their use such as Gedroiz' s method (22) in which HCl is used as the leaching agent, Hissink's method (32), using NaCl as the replacing salt, and Bobko and Askinasi's method (7) in which $BaCl_2$ is used as the replacing agent. The use of any of these methods proved impossible as they could not be adapted to give all the information required or modified to handle fine textured soils. In Hissink's method (32) an ion common to one ion to be determined is used, namely sodium, as the replacing ion, while in Gedroiz (22)and Bobko and Askinasi's (7) methods the filtering required is too detailed for the heavy soils under investigation.

The method used in this study was that of Kelly and Brown (38) which is a modification of the method of Gedroiz (21). This method consists essentially of the replacement of the exchangeable bases of the soil by ammonia which is accomplished by leaching with a normal solution of ammonium chloride.

Some modifications of this method were found necessary to successfully deal with the heavy soils studied. The details of the method which was finally adopted and found to be satisfactory, are as follows:

Ten grams of soil were placed in a 500 cc. Erlenmeyer flask and 100 ccs. of normal ammonium chloride was added. The flasks were stoppered and the soil was digested for three hours at a temperature of 70° C over a water bath. The mixture was then allowed to stand overnight.

After standing the solution was filtered from the soil by the use of No. 40 Whatman's filter paper and the soil washed by decantation with the ammonium chloride solution until 400 ccs. were leached through. The filtrate was made up to 500 ccs. and analyzed for the cations and the anions brought into solution. The soil residue was washed with water until any further washing would cause colloidal material to move through the filter paper. In the soils studied it was found that the ammonium chloride could not be entirely washed out as the method of Kelly and Brown advocates, or the removal of colloidal material would be sufficient to produce a low result for the total absorption capacity. Instead, the chlorides remaining in the soil residue were determined by a method followed by Chapman and Kelly (9) which essentially consisted of titrating the chlorides remaining in the soil residue with standard silver nitrate solution, using potassium dichromate as an indicator. The ammonia in the soil sample was then determined by distilling the ammonia into standard acid by the use of a Kjelkahl distilling apparatus. The ammonia removed from the soil residue included the adsorbed ammonia plus the ammonia of the ammonium chloride that had not been washed from the soil. The ammonia adsorbed is the total ammonia in the sample, minus the ammonia necessary to combine with the chloride as determined by titration.with silver nitrate.

The filtrate was analysed for calcium, magnesium, silica, and sulphates by A. O. A. C. analytical methods, (3). The calcium was determined by precipitating it as calcium oxalate and titrating with potassium permanganate, the magnesium was precipitated as the pyrophosphate, and the sulphates weighed as barium sulphate. The results for chlorine are taken from the water soluble determinations.

The soluble carbonates which were dissolved from the carbonate soils were determined in the filtrate by the method of Tjurin (60) and (61). In this method the dissolved carbonate is determined in the filtrate by titrating with a weak solution of HCl, using methyl orange as an indicator.

The accuracy of this method has been fully substantiated by the author. A small amount of calcium carbonate, namely 0.01 grams, was dissolved in a normal ammonium chloride solution and heated at a temperature of 70° C in a stoppered flask for a period of three hours. After cooling, the solution was titrated. The carbonate determined in the solution, expressed as $CO_3$ totalled .006 gms, which indicates one hundred per cent recovery by this method.

To determine the replaceable sodium and potassium another 10 gram sample of soil was treated similarly to the sample of soil in which the replaceable calcium, magnesium, etc., were determined. The entire filtrate obtained was used for the determination of sodium and potassium. The method of analysis followed in the determination of the sodium and potassium in the filtrate was similar to that outlined in A. O. A. C. (3), the sodium and potassium being separated by the use of chloroplatinic acid.

The exchangeable hydrogen in the soil was determined by the method of Bost and Zetterberg (51). The soil sample, 4 grams, was treated with 100 ccs. of .01/N $NH_4OH$ buffered with $NH_4Cl$. The mixture was shaken and allowed to stand over night. An aliquot was then removed by means of a pipette and titrated with .01/N HCl using an alcoholic solution of methyl red as an indicator. The replaceable hydrogen is equivalent to the amount of ammonia solution that was neutralized by contact with the soil.

The results of this study are given in Tables 3 to 18. The quantity of cations and anions replaced by ammonia or brought into solution by the action of the ammonium chloride salt are expressed in milli-equivalents. A milli-equivalent is defined as chemical equivalents expressed in milligrams, Kelly and Brown (39), and is calculated by multiplying the milligrams of the ion determined, per 100 grams of soil, by its valency and dividing the product by its atomic weight.

The soil horizons containing more than one per cent carbonate are distinguished in the Tables from horizons contain-less than one per cent carbonate by an asterisk. The reason for the distinction will be brought out in the discussion of the soils.

## TABLE No. 3.

### RED RIVER PHYTOMORPHIC PRAIRIE ASSOCIATE (Sample No. 1)

### EXCHANGEABLE BASES, HYDROGEN AND SOLUBILITY PRODUCTS, EXPRESSED AS MILLI-EQUIVALENTS

Extracted by Normal Ammonium Chloride Solution.

| Depth in inches | BASES AND HYDROGEN | | | | | | | SOLUBILITY PRODUCTS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | Na | K | H | Total bases & hydrogen | $NH_4$ adsorbed | Si | $CO_3$ | $SO_4$ | Cl | Total |
| 0--2" | 49.1 | 21.1 | 1.7 | 2.2 | 9.0 | 83.1 | 65.0 | 7.0 | 1.0 | 0 | 0.1 | 8.1 |
| 2--8" | 37.1 | 21.7 | 0.3 | 2.5 | 5.5 | 67.1 | 56.5 | 3.1 | 0.5 | 00 | 0.2 | 3.8 |
| ☒8-18" | 57.9 | 20.9 | 0.8 | 1.8 | 0 | 81.4 | 44.2 | 4.7 | 17.6 | 0 | 0.1 | 22.4 |
| 18-23" | 74.3 | 17.7 | 0.7 | 1.5 | 0 | 94.2 | 39.0 | 4.0 | 33.4 | 5.6 | 0.2 | 43.2 |
| 23-28" | 68.8 | 19.7 | 1.5 | 1.5 | 0 | 91.5 | 37.8 | 4.9 | 33.7 | 6.3 | 0.2 | 45.1 |
| 28"-- | 68.4 | 21.8 | 2.4 | 1.1 | 0 | 93.7 | 37.1 | 4.4 | 32.6 | 6.7 | 0.6 | 44.3 |

## TABLE No. 4

### RED RIVER PHYTOMORPHIC PRAIRIE ASSOCIATE (Sample No. 1)

### EXCHANGEABLE BASES AND HYDROGEN AS PER CENT OF TOTAL EXCHANGEABLE BASES AND HYDROGEN EXTRACTED.

| Depth | Ca | Mg | Na | K | H |
|---|---|---|---|---|---|
| 0--2" | 59.1 | 25.4 | 2.0 | 2.6 | 10.8 |
| 2--8" | 55.3 | 32.3 | 0.4 | 3.7 | 8.2 |
| ☒ 8-18" | 71.1 | 25.6 | 1.0 | 2.2 | 0 |
| 18-23" | 78.9 | 18.8 | 0.7 | 1.6 | 0 |
| 23-28" | 75.2 | 23.8 | 1.6 | 1.6 | 0 |
| 28"-- | 73.0 | 23.3 | 2.6 | 1.2 | 0 |

## TABLE No. 5.

## RED RIVER PHYTOMORPHIC PRAIRIE ASSOCIATE (Sample No. 2)

## EXCHANGEABLE BASES, HYDROGEN AND SOLUBILITY PRODUCTS, EXPRESSED AS MILLI-EQUIVALENTS.

Extracted by Normal Ammonium Chloride Solution.

| Depth in inches | BASES AND HYDROGEN | | | | | | | SOLUBILITY PRODUCTS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | Na | K | H | Total bases & hydrogen | $NH_4$ adsorbed | Si | $CO_3$ | $SO_4$ | Cl | Total |
| 0--2" | 42.4 | 18.4 | 1.2 | 2.2 | 6.5 | 70.7 | 63.8 | 2.7 | 1.5 | 0 | 1.8 | 6.0 |
| 2--9" | 34.9 | 19.0 | 0.0 | 2.6 | 5.9 | 62.4 | 55.6 | 2.2 | 0.5 | 0 | 0.3 | 3.0 |
| ☒9-19" | 52.9 | 22.4 | 0.7 | 1.5 | 0 | 77.5 | 46.4 | 0.9 | 13.6 | 1.6 | 0.2 | 16.3 |
| 19-29" | 60.8 | 18.7 | 1.0 | 1.3 | 0 | 81.8 | 42.1 | 1.4 | 21.9 | 1.9 | 0.2 | 25.4 |
| 29"-- | 57.1 | 25.5 | 1.6 | 1.2 | 0 | 85.4 | 40.5 | 1.4 | 24.3 | 2.0 | 0.1 | 27.8 |

## TABLE No. 6

## RED RIVER PHYTOMORPHIC PRAIRIE ASSOCIATE (Sample No. 2)

## EXCHANGEABLE BASES AND HYDROGEN AS PER CENT OF TOTAL EXCHANGEABLE BASES AND HYDROGEN EXTRACTED.

| Depth | Ca | Mg. | Na. | K | H |
|---|---|---|---|---|---|
| 0--2" | 60.0 | 26.0 | 1.7 | 3.1 | 9.2 |
| 2--9" | 55.9 | 30.4 | 0 | 4.2 | 9.4 |
| ☒9-19" | 68.3 | 28.9 | 0.9 | 1.9 | 0 |
| 19-29" | 74.3 | 22.9 | 1.2 | 1.6 | 0 |
| 29"--- | 66.9 | 29.9 | 1.9 | 1.4 | 0 |

# TABLE No. 7.

## RED RIVER ALKALINIZED PHASE.

## EXCHANGEABLE BASES, HYDROGEN AND SOLUBILITY PRODUCTS, EXPRESSED AS MILLI-EQUIVALENTS.

Extracted by Normal Ammonium Chloride Solution.

| Depth in inches | BASES AND HYDROGEN | | | | | | | SOLUBILITY PRODUCTS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg. | Na | K | H | Total Bases & hydrogen | $NH_4$ adsorbed | Si | $CO_3$ | $SO_4$ | Cl | Total |
| 0--3" | 31.3 | 20.8 | 1.4 | 1.4 | 5.9 | 60.8 | 50.9 | 3.4 | 0 | 0 | 0.4 | 3.8 |
| 3-12" | 28.0 | 22.3 | 1.0 | 1.7 | 4.1 | 57.1 | 46.2 | 1.9 | 1.0 | 2.8 | 0.3 | 6.0 |
| 12-18" | 29.5 | 29.5 | 1.0 | 1.4 | 2.4 | 63.8 | 51.3 | 3.6 | 2.0 | 3.9 | 0.4 | 9.9 |
| ☒ 18-27" | 50.5 | 27.0 | 0.8 | 1.1 | 0.0 | 79.4 | 31.2 | 4.0 | 26.6 | 3.7 | 0.4 | 34.7 |
| 27"-- | 52.7 | 31.9 | 1.0 | 1.2 | 0.0 | 86.8 | 30.8 | 2.5 | 32.6 | 3.6 | 0.4 | 39.1 |

# TABLE No. 8

## RED RIVER ALKALINIZED PHASE.

## EXCHANGEABLE BASES AND HYDROGEN AS PER CENT OF TOTAL EXCHANGEABLE BASES AND HYDROGEN EXTRACTED.

| Depth | Ca | Mg. | Na. | K | H |
|---|---|---|---|---|---|
| 0--3" | 51.5 | 34.2 | 2.3 | 2.3 | 9.7 |
| 3-12" | 49.0 | 39.0 | 1.8 | 3.0 | 7.2 |
| 12-18" | 46.2 | 46.2 | 1.6 | 2.2 | 3.8 |
| ☒ 18-27" | 63.6 | 34.0 | 1.0 | 1.4 | 0 |
| 27"-- | 60.7 | 36.8 | 1.2 | 1.4 | 0.0 |

## TABLE No. 9.

## RED RIVER DEGRADED ALKALINIZED PHASE.

## EXCHANGEABLE BASES, HYDROGEN AND SOLUBILITY PRODUCTS, EXPRESSED AS MILLI-EQUIVALENTS.

Extracted by Normal Ammonium Chloride Solution.

| Depth in inches | BASES AND HYDROGEN | | | | | | | SOLUBILITY PRODUCTS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | Na | K | H | Total bases & hydrogen | $NH_4$ adsorbed | Si | $CO_3$ | $SO_4$ | Cl | Total |
| 0--2" | | | Leaf Mat | | | Leaf Mat | | | Leaf | Mat | | |
| 2--4" | 21.7 | 23.7 | 1.7 | 2.2 | 9.7 | 59.0 | 43.1 | 3.6 | 0.0 | 0.0 | 0.7 | 4.3 |
| 4-10" | 24.4 | 27.3 | 1.9 | 2.2 | 7.7 | 63.5 | 50.0 | 3.9 | 0.0 | 3.0 | 0.4 | 7.3 |
| 10-24" | 24.7 | 31.3 | 2.9 | 2.1 | 4.5 | 65.5 | 53.7 | 3.9 | 0.0 | 3.4 | 0.4 | 7.7 |
| 24"-- | 24.9 | 32.0 | 5.4 | 1.8 | 3.2 | 67.3 | 51.9 | 3.4 | 0;0 | 4.3 | 0.4 | 8.1 |

## TABLE No. 10

## RED RIVER DEGRADED ALKALINIZED PHASE.

## EXCHANGEABLE BASES AND HYDROGEN AS PER CENT OF TOTAL EXCHANGEABLE BASES AND HYDROGEN EXTRACTED.

| Depth | Ca | Mg | Na | K | H |
|---|---|---|---|---|---|
| 0--2" | | | Leaf Mat | | |
| 2--4" | 36.8 | 40.2 | 2.9 | 3.7 | 16.4 |
| 4-10" | 38.4 | 43.0 | 3.0 | 3.5 | 12.1 |
| 10-24" | 37.7 | 47.8 | 4.4 | 3.2 | 6.9 |
| 24"-- | 37.0 | 47.5 | 8.0 | 2.7 | 4.8 |

## TABLE No. 11.

## RED RIVER PHYTOMORPHIC WOODED PHASE.

## EXCHANGEABLE BASES, HYDROGEN AND SOLUBILITY PRODUCTS,, EXPRESSED IN MILLI-EQUIVALENTS.

Extracted by Normal Ammonium Chloride Solution.

| Depth in inches | BASES AND HYDROGEN |  |  |  |  |  |  | SOLUBILITY PRODUCTS |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Ca | Mg | Na | K | H | Total bases & hydrogen | $NH_4$ adsorbed | Si | $CO_3$ | $SO_4$ | Cl | Total |
| 0-1½" | Leaf Mat |  |  |  |  | Leaf Mat |  | Leaf Mat |  |  |  |  |
| 1½-2½" | 43.2 | 28.8 | 1.9 | 2.3 | 13.4 | 89.6 | 75.9 | 3.5 | 0.0 | 0.0 | 0.0 | 3.5 |
| 2½"-6½ | 27.4 | 23.7 | 0.6 | 1.8 | 8.2 | 61.7 | 49.7 | 3.6 | 0.0 | 3.1 | 0.0 | 6.7 |
| 6½-15" | 26.5 | 30.9 | 1.2 | 1.8 | 7.2 | 67.6 | 53.0 | 3.4 | 0.0 | 3.5 | 1.2 | 8.1 |
| 15-26" | 27.2 | 33.4 | 1.8 | 1.6 | 5.3 | 69.3 | 56.5 | 3.5 | 0.0 | 1.6 | 1.5 | 6.6 |
| D 26"-- | 43.4 | 35.7 | 2.1 | 1.6 | 0.0 | 82.8 | 48.9 | 3.4 | 16.0 | 3.1 | 2.1 | 24.6 |

## TABLE No. 12.

## RED RIVER PHYTOMORPHIC WOODED PHASE.

## EXCHANGEABLE BASES AND HYDROGEN AS PER CENT OF TOTAL EXCHANGEABLE BASES AND HYDROGEN EXTRACTED.

| Depth | Ca | Mg | Na | K | H |
|---|---|---|---|---|---|
| 0-1½" | Leaf Mat |  |  |  |  |
| 1½-2½" | 48.2 | 32.1 | 2.1 | 2.6 | 15.0 |
| 2½-6½" | 44.4 | 38.4 | 1.0 | 2.9 | 13.3 |
| 6½-15" | 39.2 | 45.7 | 1.8 | 2.7 | 10.6 |
| 15-26" | 39.2 | 48.2 | 2.6 | 2.3 | 7.6 |
| D 26"-- | 52.4 | 43.1 | 2.5 | 1.9 | 0.0 |

# TABLE No. 13.

## RED RIVER HYDROMORPHIC ASSOCIATE.

## EXCHANGEABLE BASES, HYDROGEN AND SOLUBILITY PRODUCTS, EXPRESSED AS MILLI-EQUIVALENTS.

Extracted by Normal Ammonium Chloride Solution.

| Depth in inches | BASES AND HYDROGEN | | | | | | | SULUBILITY PRODUCTS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | Na | K | H | Total bases & hydrogen | $NH_4$ adsorbed | Si | $CO_3$ | $SO_4$ | Cl | Total |
| 0--3" | 46.4 | 20.8 | 1.5 | 2.1 | 9.3 | 80.1 | 73.1 | 3.6 | 3.1 | 0.0 | 0.8 | 7.5 |
| 3--8" | 39.6 | 19.1 | 1.1 | 1.7 | 4.8 | 66.3 | 59.5 | 2.1 | 1.0 | 0.0 | 0.8 | 3.9 |
| 8-14" | 57.0 | 19.4 | 0.6 | 1.4 | 0.0 | 78.4 | 43.5 | 1.9 | 19.2 | 1.8 | 0.3 | 23.2 |
| 14-24" | 61.9 | 21.8 | 0.6 | 1.2 | 0.0 | 85.5 | 39.0 | 1.6 | 27.7 | 2.3 | 0.4 | 32.0 |
| 24-36" | 55.2 | 23.4 | 1.3 | 1.1 | 0.0 | 81.0 | 35.9 | 1.9 | 26.4 | 1.4 | 0.1 | 29.8 |

# TABLE No. 14.

## RED RIVER HYDROMORPHIC ASSOCIATE.

## EXCHANGEABLE BASES AND HYDROGEN AS PER CENT OF TOTAL EXCHANGEABLE BASES AND HYDROGEN EXTRACTED.

| Depth | Ca | Mg | Na | K | H |
|---|---|---|---|---|---|
| 0--3" | 57.9 | 26.0 | 1.9 | 2.6 | 11.6 |
| 3--8" | 59.7 | 28.8 | 1.6 | 2.6 | 7.2 |
| 8-14" | 72.7 | 24.7 | 0.8 | 1.8 | 0.0 |
| 14-24" | 72.4 | 25.5 | 0.7 | 1.4 | 0.0 |
| 24-36" | 68.2 | 28.9 | 1.6 | 1.4 | 0.0 |

# TABLE No. 15.

## EMERSON PHYTO-HYDROMORPHIC ASSOCIATE.

## EXCHANGEABLE BASES, HYDROGEN AND SOLUBILITY PRODUCTS, EXPRESSED AS MILLI-EQUIVALENTS.

Extracted by Normal Ammonium Chloride Solution.

| Depth in inches | BASES AND HYDROGEN | | | | | | | SOLUBILITY PRODUCTS. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | Na | K | H | Total bases & hydrogen | $NH_4$ adsorbed | Si | $CO_3$ | $SO_4$ | Cl | Total |
| ☒0-12" | 51.7 | 19.6 | 0.4 | 1.3 | 0.0 | 73.0 | 44.3 | 2.4 | 17.5 | 0.0 | 0.0 | 19.9 |
| 12-24" | 51.2 | 21.5 | 0.7 | 0.5 | 0.0 | 73.9 | 11.9 | 2.2 | 42.8 | 2.1 | 0.0 | 47.1 |
| 24--- | 54.8 | 19.9 | 0.8 | 0.5 | 0.0 | 76.0 | 10.7 | 2.3 | 43.9 | 3.9 | 0.0 | 50.1 |

# TABLE No. 16.

## EMERSON PHYTO-HYDROMORPHIC ASSOCIATE.

## EXCHANGEABLE BASES AND HYDROGEN AS PER CENT OF TOTAL EXCHANGEABLE BASES AND HYDROGEN EXTRACTED.

| Depth | Ca | Mg | Na | K | H |
|---|---|---|---|---|---|
| ☒0-12" | 70.8 | 26.8 | 0.6 | 1.8 | 0.0 |
| 12-24" | 70.1 | 24.5 | 0.9 | 0.7 | 0.0 |
| 24"-- | 72.1 | 26.2 | 1.0 | 0.7 | 0.0 |

## TABLE No. 17.

## ALTONA PHYTOMORPHIC ASSOCIATE.

## EXCHANGEABLE BASES, HYDROGEN AND SOLUBILITY PRODUCTS, EXPRESSED AS MILLI-EQUIVALENTS.

Extracted by Normal Ammonium Chloride Solution.

| Depth in inches | BASES AND HYDROGEN | | | | | | | SOLUBILITY PRODUCTS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | Na | K | H | Total bases & hydrogen | $NH_4$ adsorbed | Si | $CO_3$ | $SO_4$ | Cl | Total |
| 0--7" | 31.4 | 10.7 | 0.1 | 1.1 | 0.0 | 43.3 | 41.8 | 1.1 | 6.4 | 0.0 | 0.0 | 7.5 |
| 7-16" | 43.6 | 15.2 | 0.3 | 0.8 | 0.0 | 59.9 | 14.5 | 0.9 | 25.2 | 0.0 | 0.0 | 26.1 |
| 16-24" | 48.5 | 17.5 | 0.1 | 0.5 | 0.0 | 66.6 | 5.0 | 0.7 | 40.0 | 0.0 | 0.0 | 40.7 |
| 24-38" | 48.7 | 16.4 | 0.1 | 0.3 | 0.0 | 65.5 | 5.4 | 0.7 | 40.0 | 3.3 | 0.0 | 44.0 |

## TABLE No. 18.

## ALTONA PHYTOMORPHIC ASSOCIATE.

## EXCHANGEABLE BASES AND HYDROGEN AS PER CENT OF TOTAL EXCHANGEABLE BASES AND HYDROGEN EXTRACTED.

| Depth | Ca | Mg | Na | K | H |
|---|---|---|---|---|---|
| 0--7" | 72.5 | 24.7 | 0.23 | 2.5 | 0.0 |
| 7-16" | 72.8 | 25.4 | 0.50 | 1.3 | 0.0 |
| 16-24" | 72.8 | 26.3 | 0.15 | 0.8 | 0.0 |
| 24-38" | 74.4 | 25.0 | 0.15 | 0.4 | 0.0 |

### (b) Results and Discussion.

The analysis of the base exchange results indicate that the base exchange method of Kelly and Brown (39) effects the complete replacement of bases in soils containing little calcium and magnesium carbonate. However, in soil horizons where magnesium and calcium carbonate are present in quantity such is not the case. This is shown clearly in the carbonate horizons of the Emerson and Altona soils where a great decrease in the ammonia adsorbed is noted in comparison to the upper horizons. The results obtained are similar to those of Kelly and Brown (39) from which they drew the conclusion that normal $NH_4Cl$ will not replace all the replaceable bases in soils containing more than one per cent carbonates. The use of normal $NH_4Cl$ however is quite satisfactory for soils containing less than one per cent carbonate.

Kelly and Brown (39) found that the addition of various amounts of calcium carbonate to a soil had no influence whatever on the quantities of magnesium, sodium and potassium replaced from the soil, while Gedroiz (23) found that cations not common to the carbonate were replaced completely and more rapidly in a carbonate soil than in one where an excess was not present. Therefore the exchangeable sodium and potassium in all the Red River soils studied was completely removed by the method used, while in the carbonate horizons only the replaceable cations common to the carbonate were incompletely removed. The soils of the Red River valley contain both calcium and magnesium carbonate so that removal of the replaceable calcium and magnesium in the carbonate horizons is incomplete, using the method of Kelly and Brown. The importance of the determination of the replaceable bases in an alkali earth carbonate soil is questionable since the composition of the absorption complex will be predominantly characteristic of the carbonates present. In soils containing calcium and magnesium carbonates the adsorbed ions will be chiefly calcium and magnesium, but the proportion of calcium to magnesium will not be known. The proportion of calcium to magnesium in such soils depends upon several factors:--

(1) The proportion of calcium to magnesium in the carbonate.

(2) The relative replacing energy of each, Gedroiz (28).

(3) The solubility of the compound before and after replacement. (Russell 52).

Therefore, as the divalent ion content and electrolytic content of alkali earth carbonate soils is high it does not seem necessary, at least for general purposes, to determine the replaceable bases in calcium and magnesium soil horizons, but only in soil horizons that are carbonate free. In such cases the extraction of bases by the Kelly and Brown method is quite satisfactory.

In all the carbonate free soil samples studied the amount of ammonia adsorbed agrees very closely with the total bases removed. The total adsorbed bases are the total amount of the bases removed in the filtrate minus the calcium equivalents of the anions dissolved. The close agreement between bases removed from the adsorption complex and the ammonia adsorbed is similar to that obtained by other workers studying base exchange of soils.

In the carbonate free soil the total absorption capacity expressed as the sum of total replaceable bases plus replaceable hydrogen does not agree with the total capacity as expressed by ammonia adsopption. As stated previously the ammonia adsorbed equals the bases removed and therfore it is apparent that ammonia will not replace exchangeable hydrogen, at least when the replaceable hydrogen is low in quantity. De Sigmond and Di Gleria (14) and Parker (47) report that ammonium chloride will replace only a portion of the hydrogen of the colloidal complex, Kelly (37) in his method for determining replaceable hydrogen reports the difference between the total adsorption capacity of the soil and the bases removed by ammonium chloride as exchangeable hydrogen. This method is based upon the assumption that ammonia will not replace hydrogen from the colloidal complex. The results obtained with the Red River soils studied in this project support the theory of practically non-removal of hydrogen by the ammonia of the ammonium chloride salt, at least, when the quantities of the exchangeable hydrogen are small.

There may appear to be a point of inconsistency in the method used in this investigation with regard to replacement of hydrogen by ammonia when we find that ammonia will not replace hydrogen, yet ammonia was used as the replacing agent in the determination of exchangeable hydrogen. Ramann (Sigmond and Di Gleria (14) ) found that potassium as potassium chloride had difficulty in replacing hydrogen but replacement was complete and rapid when potassium as the hydroxide was used. This apparently is also the case when using ammonia as a replacement agent for hydrogen. When ammonium chloride is used as the replacing agent, replaceable hydrogen, when present in small quantities, is not removed, but when ammonia is used in the form of ammonium hydroxide, replacement of the hydrogen is effected.

The base exchange results of soil horizons containing more than one per cent of carbonate show that an excess of cations is removed from the soil over and above the equivalents necessary to equal the sum of ammonia adsorbed plus the anions brought into solution. Conrey and Schollenberger (3) also report similar differences in the base exchange results of the carbonate horizons of soil studied by them. Why this difference occurs is not apparent but it is suggested that it may possibly be due to the presence of magnesium compounds of different composition to magnesium carbonate such as magnesium hydroxide or magnesium basic carbonate. If such compounds are present in the soil and the radical (OH) is not taken into consideration in the analysis the result of the base exchange study would show an excess of cation equivalents over the equivalents of ammonia adsorbed and the ions dissolved. Such a result would be similar to that found in this investigation.

The heavy clay soils of the Red River association, (See Tables 3 to 14), show a large absorption capacity with the phytomorphic prairie associate having the maximum capacity. The relatively lighter textured soils of the Emerson and Altona association have a lower capacity than the heavier soils. (Tables 15--18).

The absorption capacity of the soils studied shows a decrease with depth in all cases save in the $A_2$ horizon of the Red River degraded alkalinized associate. The decrease with depth is due chiefly to a decrease in the organic matter content of the soil. (McGeorge (42) and Page and Williams (46)).

The divalent exchangeable ions of calcium and magnesium predominate in the exchange complex of all the soils in the Red River Valley and in addition there is a large potential reserve in the carbonate horizons of many of the soils. In only one soil horizon, the $A_2$ horizon of the Red River degraded alkalinized associate, does the total exchangeable calcium and magnesium fall below eighty per cent of the total absorption capacity.

In the Altona and Emerson soils the percentage of exchangeable calcium and magnesium does not fall below ninety per cent and very little adsorbed hydrogen is present. Neustreuv (2) and Gedroiz (24), describing a chernozem soil from the standpoint of the character of the absorption complex, state that it is saturated with calcium and magnesium. Tumin (62) however, concedes more variation in the composition of replaceable ions in the chernozem adsorptive complex, the presence or absence of hydroben depending upon the physio-geographical position of the soil in the chernozem region. The soils of the Emerson and Altoan association in the upper portion of the profile compare closely with Neustreuv's and Gedroiz's descriptions of the base exchange complex of a chernozem but the heavy soils of the Red River association vary slightly from this, containing more adsorbed hydrogen in the absorption complex, the unsaturation in the surface horizons amounting to about 15 per cent. In the latter soils there apparently is a soil process operating now that is causing the removal of divalent bases and their substitution by hydrogen, a process which is modifying the chernozem-like soil type and causing varying degrees of degradation, and may be due, as Tumin has pointed out, to a variation in soil climatic conditions.

Adsorbed hydrogen was not found in any of the soil horizons containing carbonate.

The adsorbed monovalent ions sodium and potassium are low in quantity being only incidental in many of the profiles. The largest quantity of adsorbed sodium,(amounting to 15.4 milliequivalents), is in the C horizon of the Red River degraded alkalinized associate. The heavy textured soils of the Red River association contain the greatest amount of adsorbed sodium and potassium and the lightest textured soils, the Altona association, the least. In all the soil profiles a regularity is noticed in the relation of these ions depending on the depth in the profile. The adsorbed sodium increases with depth while the potassium decreases with depth. Sodium is apparently being removed from the upper portions of the profile to lower depths and while the same process is operating in the case of potassium, it is partially or entirely obscured by another process involving plant metabolism. Potassium is absorbed by plant roots from a depth of several feet in the soil and the greater portion moved into the aerial parts of the plant. When the plant dies and decomposes the potassium is adsorbed again at the surface of the soil. This absorbtion of potassium by plants increases the adsorbed potassium in the surface soil horizons at the expense of the lower horizons, and obscures the movement of potassium downwards by leaching.

In summarizing this discussion briefly it may be stated that the soils in the Red River Valley are predominantly saturated with divalent ions, while adsorbed sodium is meagre in quantity. Therefore according to Neustreuv's (2) and Gedroiz's (24) classifications of soils there are no soils in the Red River Valley that can be classified as "Solonetz" soils, since "Solonetz" soils must contain large quantities of adsorbed sodium. However, the morphological description indicates that some soils in the valley are soils of the "Solonetz" type and contain little adsorbed sodium. Other alkalinized soils in the Red River association are under the influence of degradation processes which are forming "Soloti" soils. The divalent ions in these soils are being replaced by hydrogen.

A more critical examination of the carbonate free horizons of the soils of the Red River association reveals some important factors not touched upon previously. To facilitate this study the carbonate free horizons are grouped together in Table No. 19. A graphic description of the adsorbed ions in all horizons of these soils is given in Charts No.1--6.

Gedroiz (24) in describing a chernozem soil states that its adsorbing complex is saturated with the divalent ions calcium and magnesium, the calcium predominating in all but exceptional cases. He contends also that a chernozem soil contains no adsorbed hydrogen. De Sigmond (12) disagrees with Gedroiz's description of a chernozem and shows that a chernozem soil contains some adsorbed hydrogen, sodium and potassium, and therefore is not completely saturated with calcium and magnesium.

The Red River phytomorphic prairie associate has an adsorbed ion complex very similar to De Sigmond's description of the adsorbed ion complex of a chernozem. This soil may then be classified as a soil of the chernozem type. The two samples of this associate studied agree quite well in respect to the similarity of the exchangeable ions in the absorption complex, which is an indication of the similarity of the adsorption complex within a soil type.

## TABLE No. 19.

### EXCHANGEABLE BASES AND HYDROGEN EXPRESSED AS MILLI-EQUIVALENTS, AND AS PER CENT OF TOTAL CAPACITY IN CARBONATE FREE HORIZONS OF SOILS OF THE RED RIVER ASSOCIATION.

| Soil Associate | depth in inches | MILLI EQUIVALENTS | | | | | | BASES AS PER CENT OF TOTAL CAPACITY | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na | K | H | Total capacity | Ca | Mg | Na | K | H | Percent saturated with bases |
| (1) Phyto-morphic Prairie | 0--2" | 49.1 | 21.1 | 1.7 | 2.2 | 9.0 | 83.1 | 59.1 | 25.4 | 2.0 | 2.6 | 10.8 | 89.2 |
| | 2--8" | 37.1 | 21.7 | 0.3 | 2.5 | 5.5 | 67.1 | 55.3 | 32.3 | 0.4 | 3.7 | 8.2 | 91.8 |
| (2) Phyto-morphic Prairie | 0--2" | 42.4 | 18.4 | 1.2 | 2.2 | 6.5 | 70.7 | 60.0 | 26.0 | 1.7 | 3.1 | 9.2 | 90.8 |
| | 2--9" | 34.9 | 19.0 | 0.0 | 2.6 | 5.9 | 62.4 | 55.9 | 30.4 | 0.0 | 4.2 | 9.4 | 90.6 |
| Alkalin-ized phase | 0--3" | 31.3 | 20.8 | 1.4 | 1.4 | 5.9 | 60.8 | 51.5 | 34.2 | 2.3 | 2.3 | 9.7 | 90.3 |
| | 3-12" | 28.0 | 22.3 | 1.0 | 1.7 | 4.1 | 57.1 | 49.0 | 39.0 | 1.8 | 3.0 | 7.2 | 92.8 |
| | 12-18" | 29.5 | 29.5 | 1.0 | 1.4 | 2.4 | 63.8 | 46.2 | 46.2 | 1.6 | 2.2 | 3.8 | 96.2 |
| Degraded Alkalin-ized phase | 0--2 | Leaf Mat | | | Leaf Mat | | Leaf | Mat | | | Leaf Mat | | |
| | 2--4" | 21.7 | 23.7 | 1.7 | 2.2 | 9.7 | 59.0 | 36.8 | 40.2 | 2.9 | 3.7 | 16.4 | 83.6 |
| | 4-10" | 24.4 | 27.3 | 1.9 | 2.2 | 7.7 | 63.5 | 38.4 | 43.0 | 3.0 | 3.5 | 12.1 | 87.9 |
| | 10-24" | 24.7 | 31.3 | 2.9 | 2.1 | 4.5 | 65.5 | 37.7 | 47.8 | 4.4 | 3.2 | 6.9 | 93.1 |
| | 24"-- | 24.9 | 32.0 | 5.4 | 1.8 | 3.2 | 67.3 | 37.0 | 47.5 | 8.0 | 2.7 | 4.8 | 95.2 |
| Wooded phase | 0-1½" | Leaf Mat | | | Leaf Mat | | Leaf Mat | | | | Leaf Mat | | |
| | 1½-2½" | 43.2 | 28.8 | 1.9 | 2.3 | 13.4 | 75.9 | 48.2 | 32.1 | 2.1 | 2.6 | 15.0 | 85.0 |
| | 2½-6½" | 27.4 | 23.7 | 0.6 | 1.8 | 8.2 | 49.7 | 44.4 | 38.4 | 1.0 | 2.9 | 13.3 | 86.7 |
| | 6½-15" | 26.5 | 30.9 | 1.2 | 1.5 | 7.2 | 53.0 | 39.2 | 45.7 | 1.8 | 2.7 | 10.6 | 89.4 |
| | 15-26" | 27.1 | 33.4 | 1.8 | 1.6 | 5.3 | 56.5 | 39.2 | 48.2 | 2.6 | 2.3 | 7.6 | 92.4 |
| Hydro-morphic associate | 0--3" | 46.4 | 20.8 | 1.5 | 2.1 | 9.3 | 80.1 | 57.9 | 26.0 | 1.9 | 2.6 | 11.6 | 88.4 |
| | 3--8" | 39.6 | 19.1 | 1.1 | 1.7 | 4.8 | 66.3 | 59.7 | 28.8 | 1.6 | 2.6 | 7.2 | 92.8 |

Chart No. 1. RED RIVER PHYTOMORPHIC PRAIRIE ASSOCIATE
Sample No. 1.

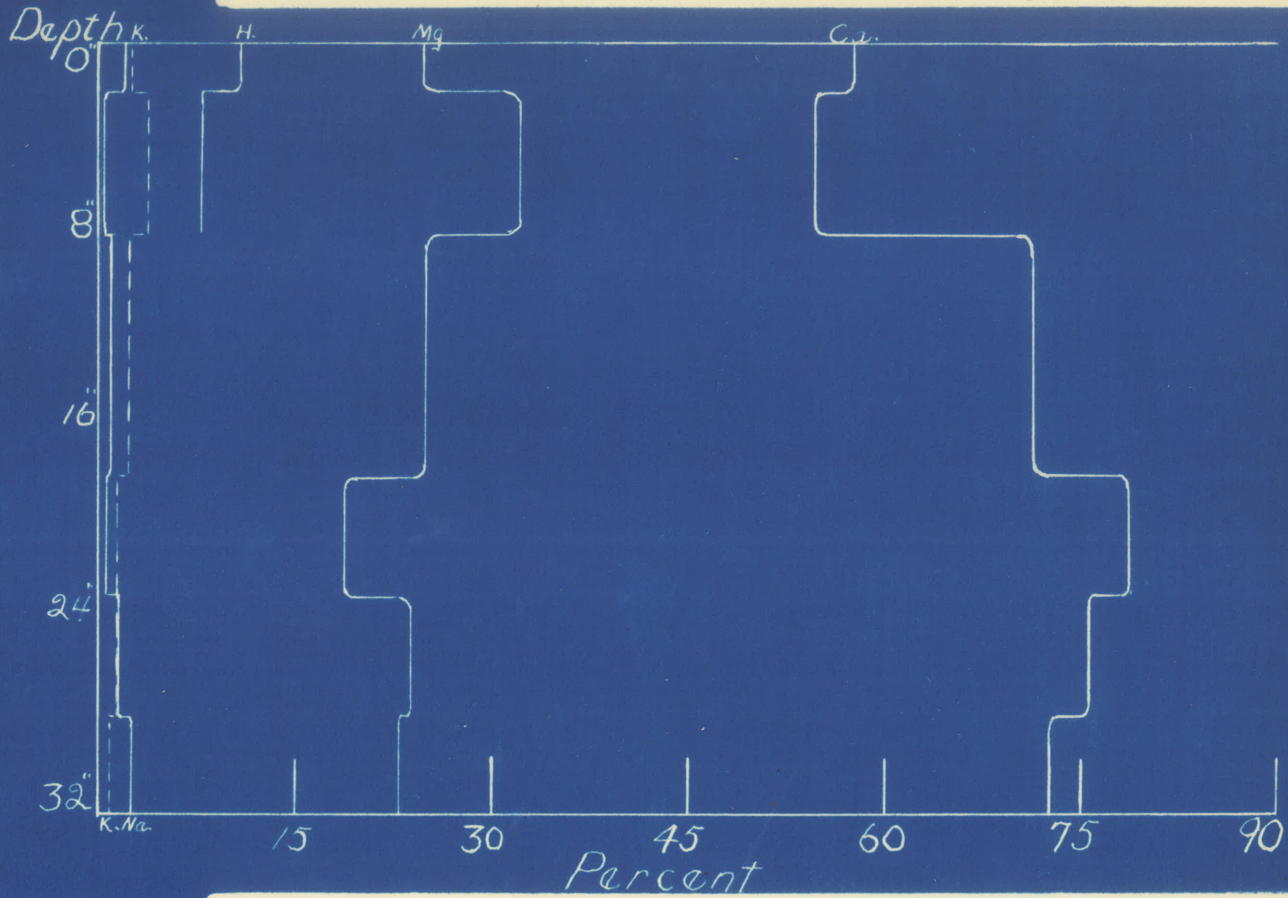


Chart No. 2. RED RIVER PHYTOMORPHIC PRAIRIE ASSOCIATE.
Sample No. 2.

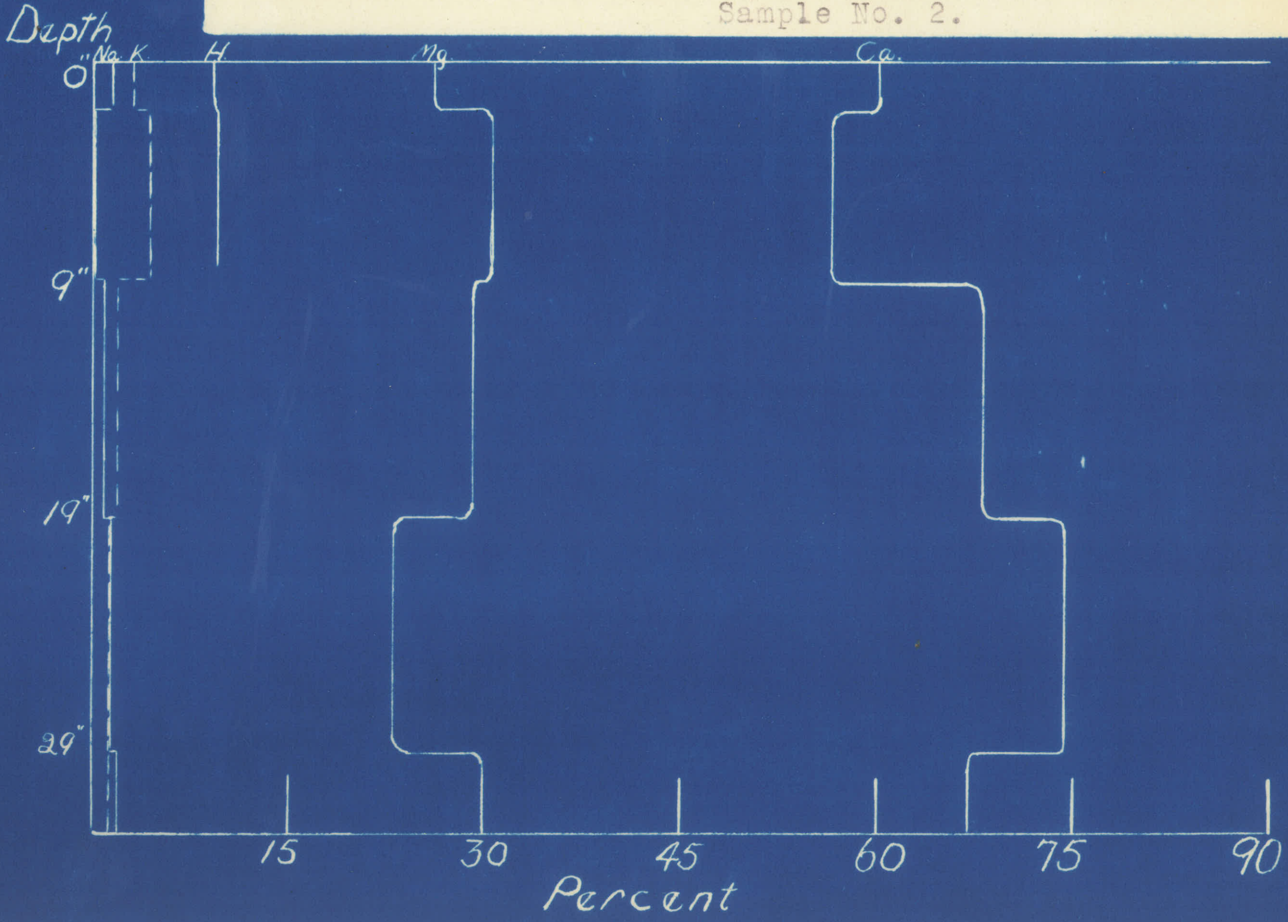


Chart No.3. RED RIVER ALKALINIZED ASSOCIATE.

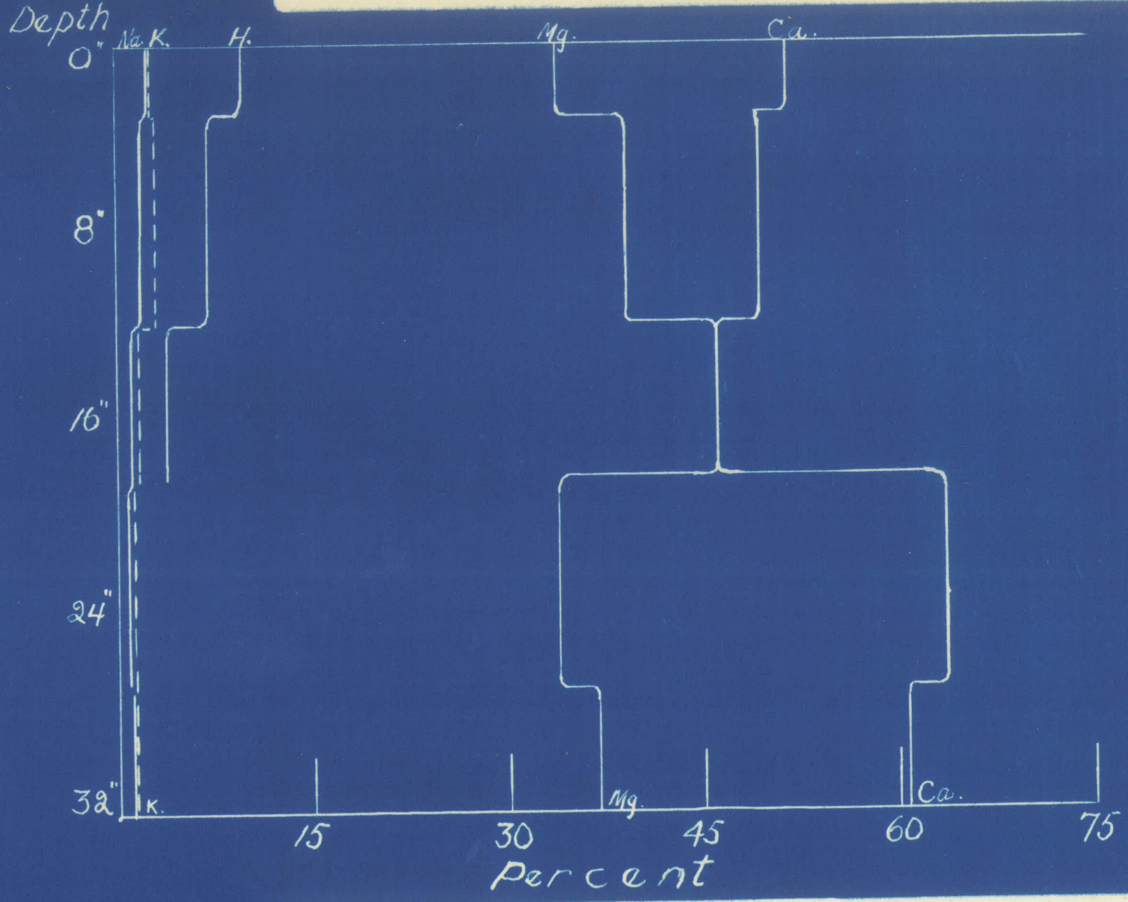


Chart No.4. RED RIVER DEGRADED ALKALINIZED ASSOCIATE

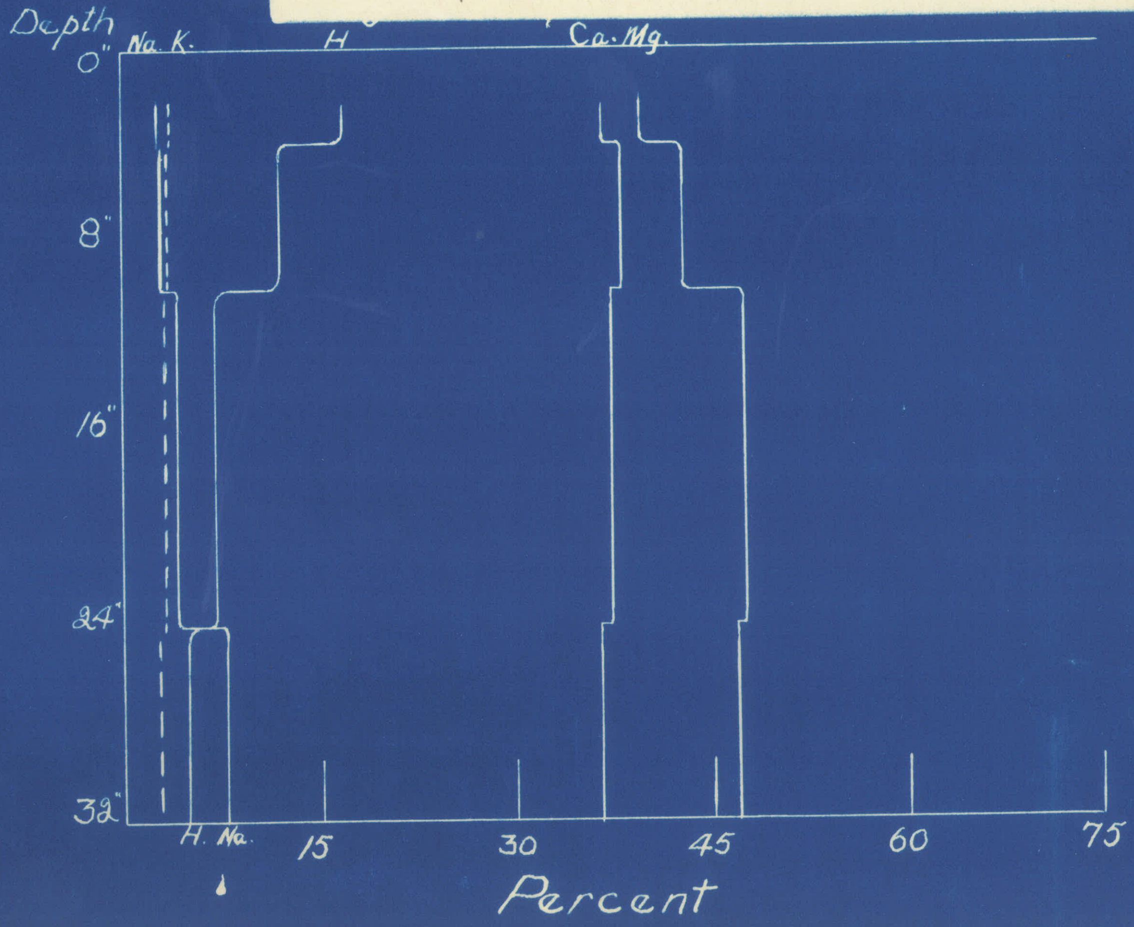


Chart No.5. RED RIVER PHYTOMORPHIC WOODED ASSOCIATE

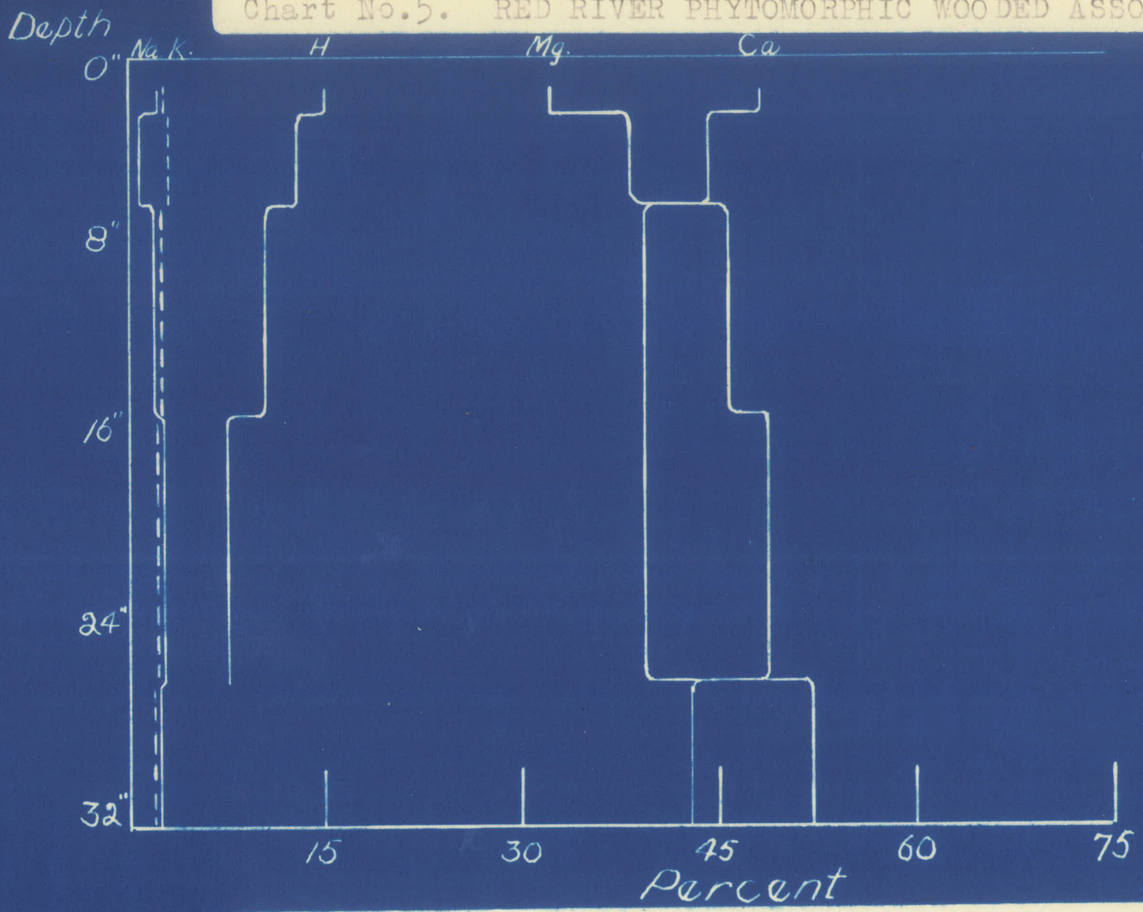
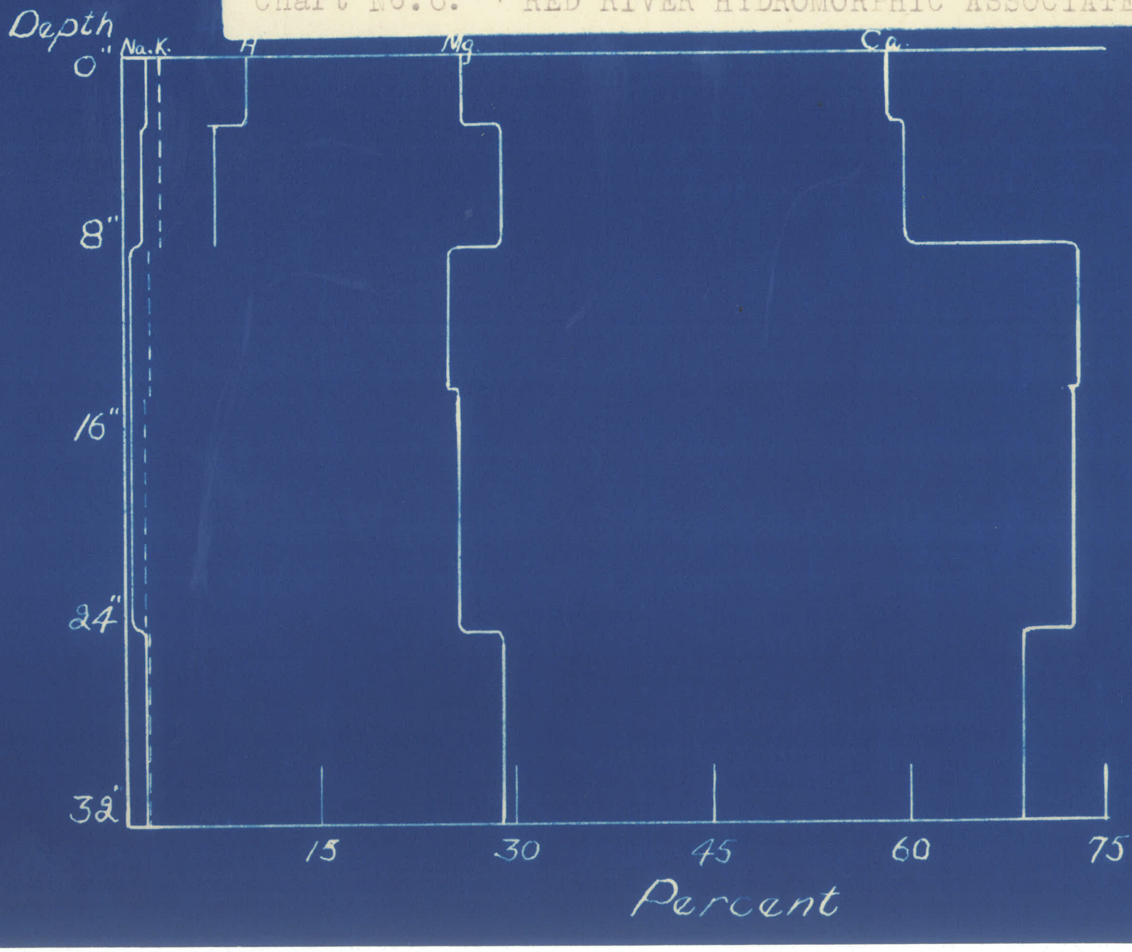


Chart No.6. RED RIVER HYDROMORPHIC ASSOCIATE



The alkalinized Red River associate has not as great an adsorption capacity as the Red River phytomorphic associate, due to the much lower organic matter content, (See Table No. 1). The carbonate has been removed and hydrogen adsorbed to a greater depth in the alkalinized soil than in the phytomorphic soil. The percentage of hydrogen in the adsorption complex, however, is no greater. An important difference is noticed in the alkalinized soil compared to the phytomorphic soil in relation to the proportion of calcium and magnesium. The ratio of calcium to magnesium has narrowed in the alkalinized soil in comparison to the phytomorphic soil. In the $B_2$ horizon, (12 inches to 18 inches), the ratio is as 1 to 1, but the ratio widens in the horizons above and below this depth.

The adsorbing complex of the alkalinized soil appears to be a transition between the complex as found in the phytomorphic soil and the degraded alkalinized soil. The degraded alkalinized soil definitely has not the absorption complex of a chernozem soil. The absorbed hydrogen in this soil has increased over that of the alkalinized soil and is distributed through greater depths in the profile. The carbonate has been removed entirely from the soil profile and magnesium constitutes a greater percentage of the ions adsorbed than the calcium, a condition not generally found in soils. The total absorption capacity of this degraded soil is similar to the alkalinized soil but both are lower than the phytomorphic soil, due to the lower organic matter content.

The adsorbed ion complex of the phytomorphic wooded so soil is somewhat similar to the degraded alkalinized phase, differing however, in the following points. The $A_1$ horizon has a high adsorption capacity due to a high organic content, while in the $A_2$ horizon the absorption capacity is much lower, due to illuviation. The adsorbed hydrogen is contained in the absorption complex in about the same proportion as in the degraded alkalinized soil. In the $A_1$ and $A_2$ horizons the adsorbed calcium is greater than the adsorbed magnesium, but in the $B_1$ and $B_2$ horizons the reverse is the case.

The adsorbed ions of the hydromorphic associates are very similar in proportion and quantity to those of the Red River associate.

It is quite evident from the study of the colloidal adsorbing complex of the soils in the Red River association that soils of different type have been formed, due to different soil forming processes.

The Red River phytomorphic prairie associate is without doubt the normal soil in this group, representing the typical soil of the physio-geographical region. The other soil types very from this chiefly in the organic matter content, the degree of unsaturation and the tendency for the adsorbed magnesium to be dominant over the adsorbed calcium. The soils which differ most in these respects from the Red River phytomorphic associate are the phytomorphic wooded soil and degraded alkalinized soils. In the morphological description of both soils they are described as having a grey leached $A_2$ horizon indicating noticeable degradation due to the weathering which has taken place.

A comparison was made of the percentage of calcium and magnesium in the adsorption complex of the carbonate free horizons of the different soil associates of the Red River soil association. This is shown in Table No. 19. The percentage of adsorbed magnesium is increased while that of adsorbed calcium is lessened in the alkalinized degraded soil and the phytomorphic wooded soil compared with the phytomorphic prairie soil. Therefore the lower proportion of adsorbed calcium of these soils is not entirely due to its replacement by hydrogen but is also due to a higher proportion of adsorbed magnesium, an indication that degradation in the soil is not due entirely to the action of hydrogen, but rather to some other factor. This is further substantiated by the fact that the adsorbed calcium content of the A1 and $A_2$ horizons of the wooded soil where the greater quantity of adsorbed hydrogen occurs, is higher than the content of adsorbed magnesium, while the reverse is the case in the $B_1$ and $B_2$ horizons.

The divalent cations removed from the carbonate horizon by the solvent action of ammonium chloride is predominantly calcium, the ratio being two or three to one of magnesium, except in the wooded soil profile, where a narrower ratio exists. being 52.4 per cent of calcium to 43.1 per cent of magnesium. Thus it would appear that calcium rather than magnesium would be the predominating adsorbed cation in the soil from which such carbonates had been removed.

The data of the water soluble salts in thses soils, (Table No. 2) show that there is a greater quantity of water soluble calcium than magnesium in the phytomorphic associate, an equal quantity in the alkalinized associate, while the calcium is slightly greater than the magnesium in the degraded alkalinized and the phytomorphic wooded soils. As previously stated, the dominant water soluble anion is sulphate. Therefore it would seem that a soil solution such as found in these soils would hardly produce an adsorption complex in which magnesium predominated over calcium.

The influence of weathering processes on the silica, acid soluble aluminium and iron of the Red River soils was also studied. These soils were extracted by hydrochloric adid, (sp. gr. 1.1), after the method of Van Bemmelin-Hissink as outlined by De Sigmond (13). The results are tabulated in Table No. 20 and illustrated graphically in Chart No. 7.

In the Red River soils the hydrochloric acid soluble aluminium and iron are slightly less at the surface than throughout the rest of the profile, indicating some movement of the sesquioxides. The soluble silica however shows more variation within the different soil profiles. The study of this variation is more easily made if the ratios of silica to sesquioxides or silica to aluminium are examined.

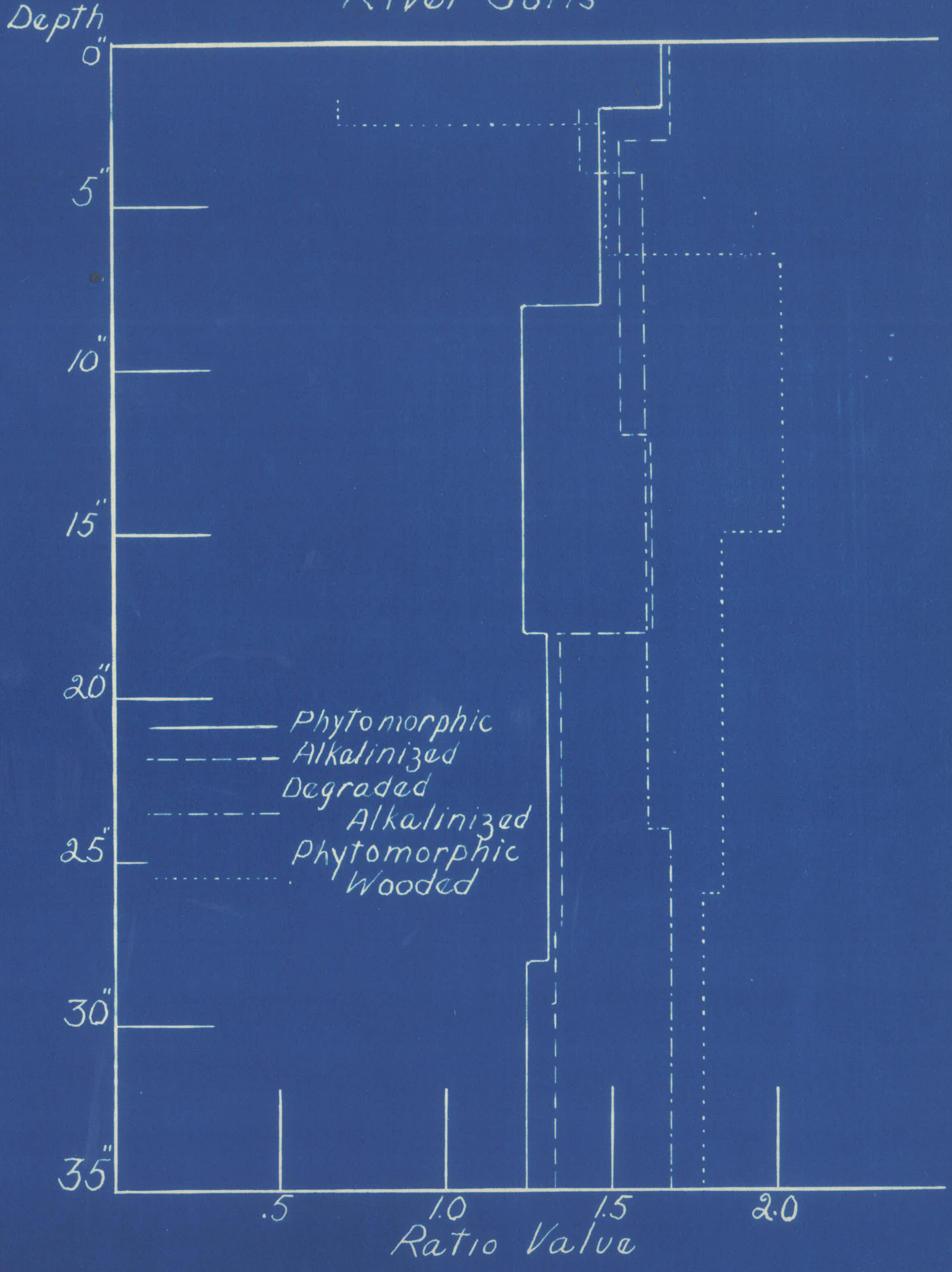
## TABLE No. 20.

## SILICA AND SESQUIOXIDES IN RED RIVER SOILS,

### As Dissolved by Hydrochloric Acid.

| | | Percent Sesquioxides in soil free of $H_2O$, $CO_2$, & organic matter | | | Silica & Sesquioxide Ratios | | | |
|---|---|---|---|---|---|---|---|---|
| Soil Associate | Depth in inches | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $\frac{SiO_2}{R_2O_3}$ | $\frac{SiO_2}{Al_2O_3}$ | $\frac{SiO_2}{Fe_2O_3}$ | $\frac{Fe_2O_3}{Al_2O_3}$ |
| Phyto-morphic Prairie | 0--2" | 19.78 | 7.84 | 4.04 | 1.66 | 2.52 | 4.89 | .516 |
| | 2--8" | 24.48 | 11.15 | 5.40 | 1.48 | 2.20 | 4.54 | .484 |
| | 8-18" | 20.23 | 10.81 | 5.68 | 1.23 | 1.87 | 3.56 | .525 |
| | 18-28" | 20.97 | 10.29 | 5.83 | 1.30 | 2.04 | 3.60 | .566 |
| | 28"-- | 21.71 | 11.93 | 5.73 | 1.23 | 1.82 | 3.78 | .481 |
| Alkalin-ized phase | 0--3" | 22.40 | 8.04 | 5.23 | 1.69 | 2.79 | 4.28 | .650 |
| | 3-12" | 22.88 | 9.35 | 5.66 | 1.52 | 2.45 | 4.04 | .605 |
| | 12-18" | 23.71 | 9.22 | 5.52 | 1.61 | 2.57 | 4.29 | .599 |
| | 18-27" | 18.43 | 9.48 | 4.24 | 1.34 | 1.94 | 4.35 | .447 |
| | 27"-- | 19.09 | 9.22 | 5.35 | 1.31 | 2.07 | 3.57 | .581 |
| Degraded Alkalin-ized phase | 0--2" | Leaf Mat | | | Leaf Mat | | | |
| | 2--4" | 20.72 | 8.97 | 5.70 | 1.41 | 2.31 | 3.63 | .636 |
| | 4-24" | 29.19 | 11.84 | 6.36 | 1.60 | 2.47 | 4.59 | .537 |
| | 24"-- | 28.52 | 11.01 | 6.04 | 1.67 | 2.59 | 4.72 | .549 |
| Wooded phase | 0-1½" | Leaf Mat | | | Leaf Mat | | | |
| | 1½-2½" | 8.39 | 7.20 | 4.92 | 0.69 | 1.17 | 1.70 | .684 |
| | 2½-6½" | 18.81 | 7.78 | 4.97 | 1.48 | 2.42 | 3.78 | .639 |
| | 6½-15" | 31.60 | 9.94 | 5.80 | 2.01 | 3.18 | 5.45 | .584 |
| | 15-26" | 25.15 | 8.59 | 5.16 | 1.83 | 2.93 | 4.87 | .601 |
| | 26"-- | 24.96 | 9.36 | 5.46 | 1.68 | 2.66 | 4.57 | .583 |

# Chart No. 7
# Acid Soluble Silica and Sesquioxides, expressed as the ratio $SiO_2/R_2O_3$, in Red River Soils



In the phytomorphic prairie soil and the alkalinized soil the easily soluble silica is highest in the upper part of the profile, but high figures for soluble silica extend to a greater depth in the alkalinized soil profile. The degraded alkalinized soil and the phytomorphic wooded soils present a different picture in this regard. The soluble silica has decreased near the surface but is higher at greater depths in the profile. In the phytomorphic wooded soil the silica has reached a maximum in the $B_1$ horizon, decreasing again in the $B_2$ and $C_1$ horizons. It would thus appear that the silica has become more soluble in the surface horizons of the phytomorphic prairie and alkalinized soils, while in the degraded alkalinized and the phytomorphic wooded soils it has been made soluble and removed from the surface horizons and deposited lower in the profile.

The acid soluble bases, (calcium, magnesium, sodium and potassium). as determined by the Van Bemmelin-Hissink method (13) and listed in Table No. 21, vary greatly in these soils. In the phytomorphic prairie associate the easily soluble calcium is much in excess of the other soluble bases, while in the alkalinized and degraded alkalinized associates the acid soluble magnesium is greater than the calcium except in the carbonate horizon where the calcium is greater then the magnesium. The phytomorphic wooded soil varies somewhat from the latter named associates in that the easily soluble calcium is higher in the $A_1$ horizon than the magnesium, but is similar in that the calcium is lower in all the other horizons except the carbonate horizon.

## TABLE No. 21.

## BASES IN RED RIVER SOILS.

### As Dissolved by Hydrochloric Acid.

| Soil Associate | depth in inches | Bases Expressed in Milli-equivalents | | | |
|---|---|---|---|---|---|
| | | Ca | Mg | Na | K |
| Phyto-morphic Prairie associate | 0--2" | 108.6 | 66.7 | 22.2 | 17.0 |
| | 2--8" | --- | 87.2 | 7.4 | 17.4 |
| | 8-18" | 431.4 | 147.7 | 10.3 | 11.2 |
| | 18-28" | 321.1 | 150.8 | 15.2 | 13.4 |
| | 28"-- | 193.5 | 110.0 | 7.1 | 14.4 |
| Alkalin-ized phase | 0--3" | 46.6 | 62.6 | 7.7 | 30.6 |
| | 3-12" | 44.4 | 111.8 | 16.1 | 7.0 |
| | 12-18" | 42.6 | 87.2 | 9.7 | 24.0 |
| | 18-27" | 183.0 | 202.0 | 22.6 | 28.4 |
| | 27"-- | 226.0 | 212.3 | 35.2 | 20.2 |
| Degraded Alkalin-ized phase | 0--2" | Leaf Mat | Leaf Mat | | |
| | 2--4" | 33.2 | 49.2 | | |
| | 4-24" | 32.1 | 61.0 | | |
| | 24"-- | 48.5 | 71.3 | | |
| Phyto-morphic wooded phase | 0-1½" | Leaf Mat | Leaf Mat | | |
| | 1½-2½" | 63.9 | 41.5 | | |
| | 2½-6½" | 37.8 | 48.7 | | |
| | 6½-15" | 35.0 | 60.5 | | |
| | 15-26" | 37.8 | 58.5 | | |
| | 26"-- | 246.8 | 78.5 | | |

It is a very significant fact that the acid soluble calcium and magnesium in the carbonate free horizons of the alkalinized, degraded alkalinized and phytomorphic wooded soils approaches the exchangeable calcium and magnesium in quantity. This is especially true of the acid soluble calcium, and indicates that the easily soluble calcium compounds other than the exchangeable calcium have been weathered and removed to a much greater extent than the magnesium compounds. De Sigmond (11) finds that a characteristic of alkali leaching is the removal of calcium to a greater extent than magnesium, and an accumulation of large amounts of soluble silica. Sushko (58) believes that an accumulation of magnesium is an indication of the "solotization" of "Solonetz" soils. The large quantities of easily solbule silica and the low amount of easily soluble bases in excess of exchangeable bases noted in the alkalinized, degraded alkalinized and phytomorphic wooded soils indicate that severe weathering has taken place in these soils. On the other hand the phytomorphic soil does not indicate the same degree of weathering. This weathering probably took place, to some degree, previous to the time that the soil parent material was transported and laid down as lacustrine clay. The acid soluble mineral portion, exclusive of carbonates, is lower in the parent material of these soils than in the A and B horizons. This indicates that weathering has also taken place in "situ" and the development of the different soil types is due to the variations in this weathering.

Apparently this severe type of weathering and degradation has been more recently replaced in the alkalinized and degraded alkalinized soils by another process, which is increasing the exchangeable calcium in the upper horizons of the soil.

A probable explanation of the formation of different soil types on the extensive clay deposits which form the Red River association may be presented as follows:

As previously mentioned these soils have developed on lacustrine clay, the bed of Lake Agassiz. As the glacier which formed the northern boundary of the lake retreated, permitting the lake to drain towards the north, a swampy condition, which consisted of numerous ponds, was formed on the clay deposits due to the flat topography. These Small bodies of shallow water were prevented from draining by the low wave formed ridges which traverse the lake bed from a north northwest to south southeast direction. The phytomorphic prairie associate is the soil type that has developed upon the higher and therefore, the better drained portion. The low lying land or "pond phase" would become alternately dry and wet depending upon precipitation and upon water run-off from the higher lands to the south and west. The latter condition would be instrumental in bringing in large quantities of salt which, as the ponds dried up, would be deposited upon the surface and washed into the soil material causing saline conditions. Soil formed under these circumstances would be saline soil, or as more definitely described, magnesium saline soil. The assumption that large amounts (Gedroiz (56) ) of magnesium salts were present at that period of soil development is based upon the fact that there is a predominance of magnesium salts in the saline soils of the valley at the present time. The degraded alkalinized, the alkalinized and the phytomorphic wooded soils no doubt, had their origin in the salinized low lying lands of the "pond phase" and have become differentiated into different soil types by subsequent development. The higher land upon which the phytomorphic prairie associate was formed would not pass through this stage of salinization as any excess of soluble salts present would be washed out early in the development of the soil.

As the drainage systems developed and the valley became drier the low land became inundated with water from local precipitation rather than by drainage waters from higher lands. This surface water as it drained through the saline soil carried with it the soluble salts and in due course produced a soil low in soluble salts, and with an adsorption complex largely saturated with the predominating cation of the saline condition, namely magnesium. The continued leaching at this time caused the weathering and breakdown of silica compounds with the consequent movement of silica and calcium and the formation of an "alkali structure" in the soil.

Different degrees of alkalinization would take place depending upon the severity and length of time of leaching. This factor is no doubt the reason for the differentiation in soil type of the alkalinized, degraded alkalinized and the phytomorphic wooded soils. The alkalinized soil, due to its slightly higher position, was not under the influence of leaching to the extent that the degraded alkalinized and phytomorphic wooded soils were, and consequently the alkalinization of this associate as compared to the other two soils was somewhat curtailed.

De Sigmond (11) described the development of alkali soils in Hungary from swampy conditions, that is, a "pond phase" with alternate periods of humid and dry conditions. These conditions are similar to those occurring in the Red River valley. In Hungary, however, the soils after removal of the soluble salts were saturated with adsorbed sodium.

Rosov (50) studied several "Solonetz" soils and found that, "the morphological characteristics do not agree with the theory that "Solonetz" soils are the result of sodium saturation". The soils were morphologically "Solonetz" but the adsorbed sodium only included 1 - 5 per cent of the total adsorbed bases.

Thus it would appear that "Solonetz" soils have been formed in the Red River valley without the action of adsorbed sodium. This statement is further substantiated by the fact that in the saline soils of the valley at the present time sodium salts are insignificant in quantity compared to the divalent alkaline earth salts, Sodium carbonate also is rarely found.

After alkalinization, another phase in the development of some of these alkalinized soils,(i.e.,degradation) began.

The process of degradation would take place more intensively and rapidly in those soils in which alkalinization was more pronounced. The development of plants on these soils and continued leaching produced a hydrogen replacement of adsorbed magnesium and some calcium; magnesium being replaced to the greater extent than calcium, because of the greater percentage in the adsorbing complex. An increase in exchangeable hydrogen would occur, and this is noted in the degraded alkalinized and the phytomorphic wooded soil. (See Table No. 19). The percentage of adsorbed calcium would be increased in the upper horizons by ghd action of plants bringing calcium from the lower depths of the soil and depositing it in the surface where, on decomposition of the plants, it would again become adsorbed in the soil.

The process of degradation in the Red River soils with the increase of exchangeable hydrogen is accompanied also by an increase of exchangeable calcium and decrease of exchangeable magnesium in the surface horizons. The process of degradation seems to have advanced further in the phytomorphic wooded associate than in the degraded alkalinized associate. The increased hydrogen absorption and degradation of the phytomorphic wooded soil over that of the degraded alkalinized soil may be due somewhat to the better drainage that has developed recently in the first named soil type and also th the difference of vegetative growth, the vegetation of the wooded soil type being heavy woods while the degraded alkalinized type is covered by grasses or light brush as a recent invasion.

The soil structure of the B horizon of the wooded soil is described as hazel nut structure and differs quite markedly from the columnar, prismatic structure of the degraded alkalinized soil. This difference may be due either to the effect of plant roots or as suggested by Vilensky (63) who states: "The first stage of degradation is represented by the modification of the structure of the columnar horizon into a nutty one". In the light of this statement it is probable that the structure of the phytomorphic wooded soil has been modified by the process of degradation to a greater extent than the degraded alkalinized soil.

To summarize the above it may be stated that the degraded alkalinized soil and the phytomorphic wooded soil associates probably have passed through the soil forming processes of salinization, alkalinization and degradation. In the alkalinized soil associate these first two processes have operated to some degree, but not with the same intensity as in degraded soils. The phytomorphic prairie associate has developed as a chernozem--like soil.

## 6. EXPERIMENTAL - PHYSICAL PROPERTIES OF THE RED RIVER PHYTOMORPHIC, ALKALINIZED AND DEGRADED ALKALINIZED SOILS.

The phytomorphic prairie, the alkalinized and the degraded alkalinized associates were studied also in relation to their physical characteristics. Under normal conditions in the field, differences in physical condition is noted and the study was undertaken to determine the exact nature and degree of these differences.

## A. MECHANICAL ANALYSIS. (a) Method.

The mechanical analysis of these soils was determined by a combination of the method of United States Bureau of Soils (45) and the Sudan Method (35). The preliminary treatment with HCl and hydrogen peroxide was not necessary because sodium carbonate was used to insure dispersion. The soil sample was dispersed in 0.2 per cent sodium carbonate with the aid of shaking for two hours. It was then washed from the shaker bottles into Tyler sieves placed over the top of liter sedimentation cylinders. The separation of sand from silt and clay is effected by this means. The washing was performed by the use of .05 per cent sodium carbonate. The portion separated as sand by the Tyler sieves was removed and triturated thoroughly by a rubber policeman in a porcelain dish, to break up all aggregates. This was then washed back upon the Tyler sieve and final separation of the sand from the smaller particles made. The separation of the sands was effected by a nest of standard sieves. The sedimentation medium, namely .05 per cent sodium carbonate, was made up to volume (a litre) and the determination of the silt - .05 to .005 mm. - coarse clay,-.005 to .002 mm, - and the fine clay and colloids,-less than .002 mm.- was made by the pipette method of Robinson (48) in which Stokes formula for sedimentation is used, while the periods of sampling were those calculated by Engle and Yoder (19).

### (b) Results and Discussion.

The results are reported in Table No. 22, in which the fractions are expressed on a percentage basis. The moisture equivalents, also given in the same table, are taken from the Red River Survey Report. (16).

The mechanical analysis of the three soils shows one tendency common to all Red River soils, e.g., the texture became finer with depth. This change is not so pronounced in the degraded alkalinized soil, as the texture of this soil is more uniform throughout the profile than in the other two soils. The clay and colloidal fractions are extremely high in the three soils, the colloids and fine clays amounting to as high as seventy-eight per cent. This is one very important reason why the good physical properties of these soils are so hard to maintain. The sand content is low throughout, and the silt content, although rather high in the surface horizons of the phytomorphic prairie and the alkalinized soils, is generally low, and decreases with depth in the profile.

The variation in texture throughout the profiles is probably due to the textural differences of the deposits when they were laid down, although it may be possible that the high silt content of the A horizon of the phytomorphic prairie and the alkalinized soils is due in part to mechanical removal of the clay. The alkalinized and phytomorphic prairie associa-tes apparently have been formed where a somewhat coarser textured layer was superimposed upon a finer textured deposit. These two soils differ in this respect from the degraded alkalinized soil which is fairly uniform throughout, and the difference is no doubt due to their higher position.

The mechanical analysis of these soils would indicate that no appreciable movement of fine colloidal material downward has been effected. The moisture equivalents also indicate that no marked illuviation has taken place, except in the degraded alkalinized soil. However, the chemical analysis points to a movement of highly weathered material downward and since the increase in solubility of silica does not correspond with increased clay content there must have been a movement of more easily soluble material downward in these soils. The reason for this process of illuviation not being indicated in the mechanical analysis results by a zone of accumulation is due (1) to the original heterogenity of the soil, and (2) to the fine textured material in which separation by size is almost impossible, thus covering up any evidence of the movement of material.

The difference in texture of these soils does not apparently account for the difference in their physical properties, and so the variation must be due almost entirely to chemical differentiation and the influence of adsorbed ions on the fine textured material.

## TABLE No. 22.

## MECHANICAL ANALYSIS AND MOISTURE EQUIVALENT OF TYPICAL RED RIVER ASSOCIATES.

| Soil Associate | Depth in inches | per cent Moisture | per cent fine clay and colloids less than .002 mm | per cent coarse clay .002 to .005 mm | per cent total clays less than .005 mm | per cent silt .005 to .05 mm | per cent sand | Moisture Equivalent |
|---|---|---|---|---|---|---|---|---|
| Phyto-morphic Prairie | 0--2" | 3.40 | 28.73 | 21.46 | 50.19 | 35.54 | 10.86 | 43.7 |
|  | 2--9" | 3.11 | 49.57 | 20.26 | 69.83 | 22.18 | 4.87 | 43.7 |
|  | 9-19" | 2.56 | 53.98 | 22.07 | 76.05 | 17.86 | 3.53 | 42.0 |
|  | 19-29" | 2.84 | 75.11 | 9.19 | 84.30 | 8.79 | 4.08 | 40.5 |
|  | 29"-- | 3.70 | 78.83 | 11.04 | 89.85 | 3.67 | 2.76 | 41.2 |
| Alkalin-ised | 0--3" | 4.97 | 32.90 | 4.34 | 37.23 | 47.86 | 9.93 | 45.0 |
|  | 3-12" | 5.31 | 40.84 | 19.04 | 59.88 | 27.09 | 7.72 | 41.7 |
|  | 12-18" | 5.22 | 40.67 | 21.83 | 62.50 | 23.64 | 8.65 | 42.0 |
|  | 18-27 " | 4.54 | 59.07 | 10.89 | 69.96 | 17.18 | 8.32 | 34.9 |
|  | 27"-- | 4.28 | 62.65 | 10.86 | 73.51 | 17.12 | 5.08 | 35.9 |
| Degraded Alkalin-ised | 0--2 | Leaf | Mat | Leaf | Mat | Leaf | Mat |  |
|  | 2--4" | 6.36 | 58.94 | 12.38 | 71.32 | 16.38 | 5.93 | 50.5 |
|  | 4-10" | 7.20 | 57.28 | 12.38 | 71.39 | 15.12 | 6.28 | 49.7 |
|  | 10-24 | 7.80 | 59.88 | 13.66 | 73.54 | 14.27 | 4.39 | 60.5 |
|  | 24"-- | 7.68 | 62.71 | 14.25 | 76.96 | 10.18 | 5.19 | 59.1 |

## B. PERCOLATION STUDY.

### (a) Method

The phytomorphic prairie, alkalinized and degraded alkalinized associates were studied in relation to the rate of water percolation. The upper three horizons of each of the soils were passed through a 2 mm. sieve and each horizon tamped into separate cylinders, 2 inches in diameter. A soil column six inches long was used and percolation induced under a water head of two inches. Percolation was continued for 253 hours.

### (b) Results and Discussion.

The results are summarized in Table No. 23 and expressed graphically in Chart No. 8.

The percolation through the phytomorphic prairie soil was more rapid than through the alkalinized soil. No percolation occurred through the degraded alkalinized soil after a period of 253 hours, hence it provided no data which could be included in Table and Chart. This emphasises the very impermeable nature of the alkalinized soil compared to the phytomorphic soil. The effect of the influence of organic matter on maintaining aggregation is plainly seen in this study. The two upper horizons of the phytomorphic prairie and alkalinized associates show an increased rate of percolation at the beginning of the experiment over the lower horizons because of better aggregation, but later, the rate of percolation slows down until it equals the slower percolation of the lower horizons, due to the peptization of the slighlty better aggregated material and the movement of fine material which stoppers all the water passages.

## TABLE No. 23.

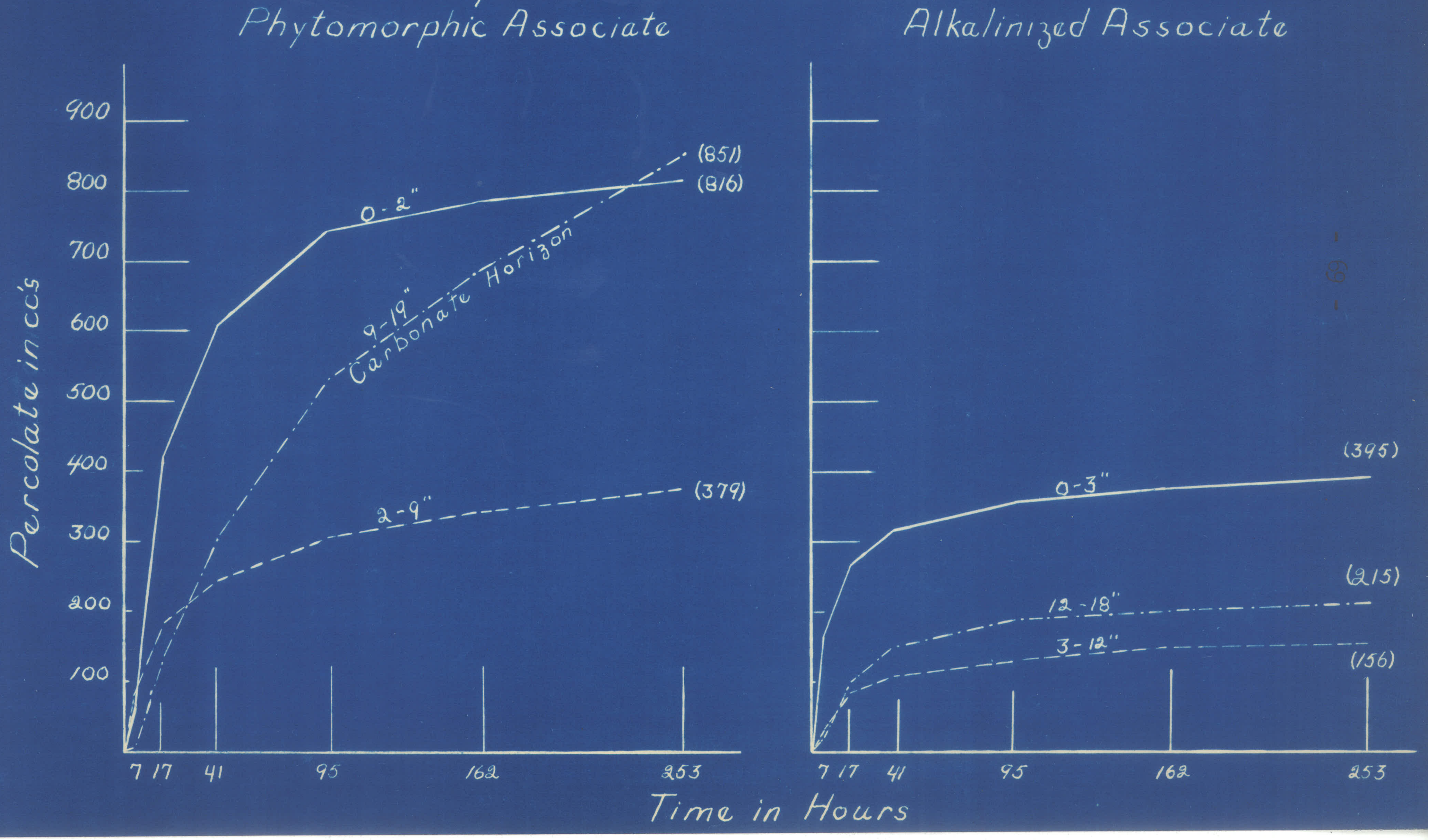
## PERCOLATION STUDY OF RED RIVER PHYTOMORPHIC AND ALKALINIZED ASSOCIATES.

| Soil Type | Depth inches | Rate of Percolation in ccs. per hour by periods. | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0--7 hours | 7-17 hours | 17-41 hours | 41-95 hours | 95-162 hours | 162 to 253 hours |
| Phyto-morphic Prairie | 0--2" | 10.0 | 35.0 | 8.0 | 2.4 | 0.6 | 0.4 |
| | 2--9" | 12.0 | 10.0 | 2.5 | 1.2 | 0.5 | 0.4 |
| | 9-19" | 1.0 | 13.0 | 7.0 | 4.3 | 2.3 | 1.8 |
| Alkalin-ized | 0--3" | 23.0 | 11.0 | 2.0 | 0.7 | 0.3 | 0.2 |
| | 3-12" | 3.0 | 5.0 | 1.0 | 0.4 | 0.3 | 0.1 |
| | 12-18" | 3.0 | 8.0 | 2.0 | 0.7 | 0.2 | 0.2 |

The influence of carbonate can be noticed in the third horizon of the phytomorphic prairie soil. The rate of percolation in this horizon was rather slow at the beginning of the experiment because of the lack of aggregation and absence of organic matter, but later percolation proceeded at a faster rate than in the other horizon of the same soil. This no doubt was due to the solubility of the carbonate which insured the flocculation of the fine material and the opening of new water channels where the carbonate had been dissolved out.

# Chart No.8

## Percolation Study of Some Soils of the Red River Association



The permeability of the phytomorphic prairie, the alkalinized and degraded alkalinized soils vary a great deal. This difference is due in some degree to variations in the organic content and in texture, but these factors are not sufficient to account for the marked variation in rate of percolation. Sokolovsky (56) found that permeability of the soil was decreased as the Ca ions were removed and stated that the decreased permeability of the soil indicates increased deflocculation. In the fine textured soils of the Red River Valley it is probable that flocculating agents such as adsorbed Ca and the divalent soluble salts,as well as organic matter,are necessary to promote permeability. Variation in amount of any of these factors will produce changes in percolation rates which is indirect evidence of the physical condition of the soil.

## C. THE ATTERBERG CONSTANT AND SHRINKAGE VALUES OF RED RIVER SOILS.

### (a) Methods.

To study further the physical properties of these soils the Atterberg constants, which include the upper and lower plastic limits, the plastic number and the scouring point, were determined. The methods followed were those outlined by Russel and Wehr (54). The results are given in Table No. 24, and shown graphically in Chart No. 9. The shrinkage values of these soils also were determined.

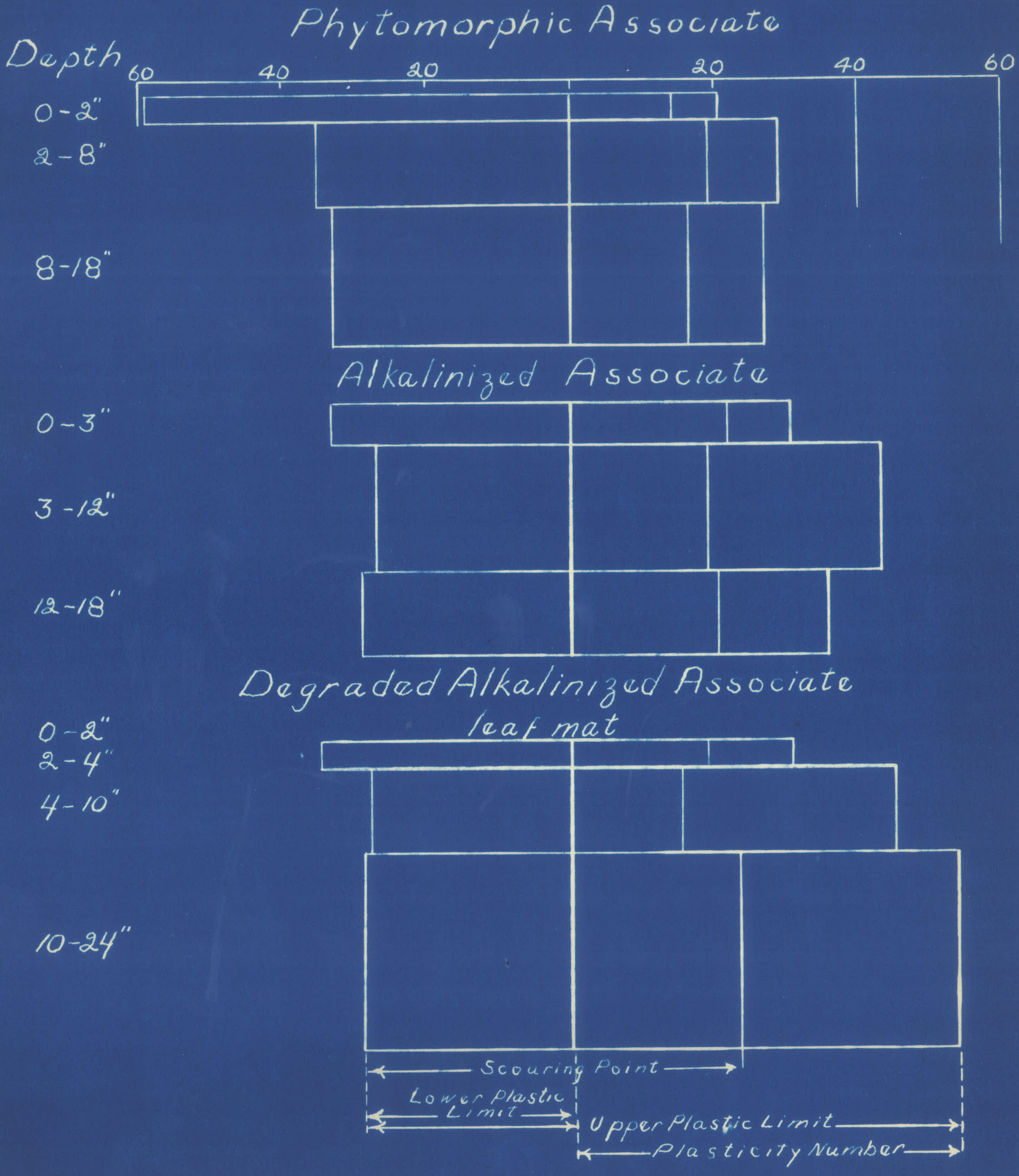
## TABLE No. 24.

## ATTERBERG CONSTANTS AND SHRINKAGE VALUES OF THE RED RIVER PHYTOMORPHIC PRAIRIE, ALKALINIZED AND DEGRADED ALKALINIZED SOILS.

| Soil Associate | depth inches | Upper plastic limit | Lower plastic limit | Plasticity number | Scouring number | Shrinking percent |
|---|---|---|---|---|---|---|
| Phyto-morphic Prairie | 0--2" | 79.5 | 58.8 | 20.7 | 73.1 | 21.2 |
| | 2--8" | 64.0 | 35.2 | 28.8 | 54.7 | 32.7 |
| | 8-18" | 60.2 | 33.1 | 27.1 | 49.3 | 32.0 |
| Alkalin-ized | 0--3" | 63.8 | 33.6 | 30.2 | 55.3 | 32.0 |
| | 3-12" | 69.8 | 26.7 | 43.1 | 45.4 | 31.5 |
| | 12-18" | 64.9 | 29.3 | 35.6 | 49.6 | 30.9 |
| Degraded Alkalin-ized | 0--2" | | Leaf Mat | | Leaf Mat | |
| | 2--4" | 68.9 | 34.2 | 34.7 | 53.1 | 15.6 |
| | 4-10" | 72.8 | 28.0 | 44.8 | 43.1 | 27.5 |
| | 10-24" | 82.3 | 28.5 | 53.8 | 51.7 | 33.4 |

# Chart No. 9

## Atterberg Constants of Soils of the Red River Association



The results obtained show the change in volume of the respective soil in shrinking from the moisture equivalent to oven dry, and are expressed as per cent shrinkage from the moist condition. (See Table No. 24 and Chart No. 9.)

### (b) Results and Discussion.

A study of the results given in Chart No. 9 brings out some important differences in the respective plasticity constants, both between associates and between the different horizons of each associate. It is noticed that the plastic constants of the upper horizon in each associate are shifted to higher values and the plastic numbers are less in comparison to other horizons, indicating some influence of lighter textured material or organic matter. Baver (5) found however, that organic matter does not influence the plasticity number of a soil, but rather shifts the limits to higher values. The difference therefore in the plasticity numbers of the upper horizons of these soils is probably due to differences in textural composition rather than to variations in organic matter.

The comparison of the three associates shows that the plasticity numbers of the phytomorphic prairie are the lowest while that of the degraded alkalinized soil are the highest. Outside of the upper horizons the lower plastic limit does not vary greatly, the variation being chiefly in the upper plastic limit which apparently in this case has more influence than the lower plastic limit in causing plasticity differentiation in these soils.

In the phytomorphic prairie soil the plasticity numbers are the highest in the horizon (2" - 8") and in the alkalinized soil at about the same depth (3" - 12"), decreasing below this depth in both cases. In the degraded alkalinized soil, however, the plasticity number in the horizon (4" - 10") equals the alkalinized soil at this depth, but in the horizon below, the plasticity increases still further, differing from the two other associates in this respect. Therefore the factors influencing plasticity seem to be developed to a greater depth and to a greater degree in the degraded alkalinized soil than in the other two soils.

The work of Baver (5) brings out the fact that there is a high relationship between clay content of a soil and its plasticity number.

A comparison of the clay content of these soils with the plasticity numbers however makes it quite clear that the clay content is not producing a predominating influence on plasticity. Therefore we must look to other soil characteristics for the cause of variation. Baver (5) found that the plasticity number of a soil was influenced by the $Sio_2/R_2O_3$ ratio, a high ratio being correlated with high plasticity values. Plasticity also is determined to some extent by the nature of the exchangeable cations. Baver (5), (4) reports that in comparison to the original soil the plasticity number is lowered when the soil is saturated with potassium cations, raised when saturated by calcium or magnesium cations, and raised still further by saturation with sodium cations. Joseph and Oakley, (34) also report a variation in the plasticity of a soil due to the exchangeable cations. They found that when a soil is saturated with magnesium it had a plasticity number corresponding to 52; when saturated with sodium, a number of 60; when saturated with calcium, a number of only 42; and when saturated with potassium, an number of only 22. Joseph and Oakley go a step beyond Baver's work, finding that a difference exists in the plasticity of soils depending upon whether the soil is saturated with sodium or magnesium.

Therefore it may be expected that a variation of plasticity numbers in the Red River soils will be caused by this latter condition, since the ratio between absorbed calcium and magnesium varies a great deal from the low value for magnesium in the phytomorphic prairie soil to the high value in the degraded alkalinized soil. The plasticity numbers as already noted are lowest in the phytomorphic prairie soil and highest in the degraded alkalinized soil which would indicate that the chief cause of the increase in plasticity is due to the increase of magnesium and decrease of calcium in the exchange complex.of these soils. The influence of the increased silica sesquioxide ratio, (See Table No. 22), in the accumulation horizons, due to decreased movement of silica from badly weathered horizons also may have some influence in determining the higher plasticity numbers of the degraded alkalinized horizons and to some degree in those of the alkalinized horizons.

The variation in the scouring point value, although small, changes in inverse manner to the plasticity numbers, a high scouring point value corresponding to a low plasticity number. The shrinkage values also vary as the plasticity numbers within the profiles of the phytomorphic prairie and degraded alkalinized associates, but not within the alkalinized profile. There appears to be no relationship between shrinkage values and the plastic constants of the soil associates studied. Thus it would appear that the scouring point is dependent on similar factors which influence the plasticity numbers.

The shrinkage values (See Table No. 26) are quite high in these soils and remarkably consistent in all horizons, save in the A horizon of the phytomorphic prairie and degraded alkalinized associates. In the case of the phytomorphic prairie associate this decrease in shrinkage value is due probably to a high organic matter content and in the case of the degraded alkalinized associate to the presence of leached and weathered soil material. The lower shrinkage value in the A horizon of the latter soil is probably an indication of the amount of weathering that has taken place and the subsequent removal of the more easily soluble material. The shrinkage values do not seem to be dependent upon the same factors which influence the plasticity constants. Joseph and Oakley (34) report a variation of shrinkage, depending upon the cation adsorbed, but although quite marked differences are apparent between adsorbed sodium and calcium or magnesium the difference between magnesium and calcium is small. In the Red River soil the shrinkage values however do not seem dependent upon the variation in the kind of ion adsorbed.

Baver (5) suggests that the degree of plasticity as measured by the Atterberg constants is an index to the friability of the soil. Referring this to the plasticity of the Red River soils it may be stated that the phytomorphic prairie associate is the more friable soil and the degraded alkalinized associate the least friable soil in this soil group, the alkalinized associate being intermediate. This conclusion is similar to that reached in the field work on these soils, and in a study of their morphological characteristics.

## D. SEDIMENTATION STUDY.

### (a) Review of Literature.

Reviewing the physical characteristics of the soils of the Red River association, with special reference to the permeability and plasticity studies, it is apparent that wide differences exist in these soils. The differences are too great to be accounted for by changes in texture and would appear to be due to chemical composition differences. These differences are noted chiefly in the amounts of easily soluble silica and the percentage of magnesium in the adsorbing complex. Magnesium when present as an adsorbed cation does not have the same effect on the physical properties of a soil as calcium does. As previously mentioned, Joseph and Oakley (34) found that a magnesium saturated clay had a much greater influence on the plasticity of a clay than had calcium.

Sokolowski and Lukaschewitsch (57) report differences in the resistance to pressure and to the rise of water in soils saturated with different cations:

| Saturated with | Fe | H. | Ca | Mg | $NH_4$ | Na | Normal Chernozem |
|---|---|---|---|---|---|---|---|
| Resistance to pressure | 22 | 30 | 70 | 180 | 440 | 440 | 100 |
| Rate of water rise of 3 cms. | min | min | min | min | hr. | month | |
| | 2 | 2 | 3.5 | 5.5 | 10 | 1 | |

These results indicate a marked difference in the influence of magnesium and calcium upon the physical properties of the soil. Aarnio (1) reports Weigner's theory on adsorption in which he states that if the cations present as exchangeable ions in the soil are highly hydrated as magnesium or sodiom the soil becomes converted in the wet state into a dense impervious mass which is coagulated with difficulty. Such soils are tough and are tilled only with difficulty.

Gedroiz (25) found that a magnesium saturated soil remained in suspension for a longer time than either a calcium or a potassium saturated soil. His results are given in the following table, the weight of clay given in the results being the quantity of clay contained in a 10 cc. aliquot taken from the centre of the 100 cc. cylinder after the suspension had stood for 24 hours:

| Clay saturated with the cation. | Weight of clay in grams. |
|---|---|
| Na | 1.980 |
| $NH_4$ | .716 |
| K | .319 |
| Mg | .365 |
| Ca | .195 |
| Ba | .011 |
| H | .232 |

Baver (4) in studying the influence of adsorbed ions on the flocculation of a Toledo silty clay, reports that magnesium has not the flocculating power of calcium, althogh this is not true for lighter textured soils. Thomas (59) also found that adsorbed magnesium had a greater influence than calcium on the peptization of soil suspensions.

(b) Method

The difference between the flocculating power of adsorbed calcium and magnesium in clay may be reflected in the speed of the flocculation of a magnesium saturated clay as compared to a calcium saturated clay. As the chief adsorbed ions in the Red River soils are calcium and magnesium an experiment was conducted to determine the relative flocculating power of the two ions on the Red River heavy clay soils. The cations sodium, potassium and hydrogen were also used as adsorbed ions in this experiment for comparison purposes. The second horizon of the Red River phytomorphic, alkalinized and degraded alkalinized soils were selected and studied similarly to the method outlined by Gedroiz in his investigation. Ten grams of dry soil was saturated with the respective cations by leaching with the corresponding chloride salt, and the excess chlorides were removed by washing with water. In each series an original soil sample was used which was prepared by washing out the water soluble salts. The soils were then shaken in distilled water for three hours, and washed into a litre sedimentation tube which was made up to volume. The suspension was then stirred vigorously for two minutes and the first sample taken immediately, by means of a pipette at a 10 cm. depth. The sampling was continued at intervals for a two week period. The results are reported in Table No. 25, 26 and 27, and Chart No. 10, 11 and 12). The results in the tables are expressed as per cent of the original weight of oven dry soil, while in the charts they are expressed as per cent of material in suspension at the end of ten hours.

### (c) Results and Discussion.

The sodium cation as expected, had a very much higher peptizing influence on the soil suspensions than any of the other cations, the order of the series being Na K Mg Ca H. Potassium had not the peptizing power of sodium and indeed did not vary a great deal in this respect from the divalent cations. In the three soils studied magnesium had, as other workers have found, a greater peptizing effect than calcium, but the difference was not as marked as that found by Gedroiz (25). The series was also different to the series of Gedroiz which was in the following order: Na K H Mg Ca.

## TABLE No.25.

## PER CENT OF SOIL REMAINING IN SUSPENSION AT DIFFERENT INTERVALS DURING SEDIMENTATION WHEN SATURATED WITH DIFFERENT CATIONS.

Red River Phytomorphic Prairie Associate, Horizon 2"-8"

| Time in hours | Soil Saturated With | | | | | Untreated Soil. |
|---|---|---|---|---|---|---|
| | Na | K | H | Mg | Ca | |
| 0 | 97.7 | 40.40 | 25.70 | 27.30 | 24.60 | 26.30 |
| 2 | 95.2 | 23.40 | 9.27 | 12.80 | 11.00 | 10.60 |
| 4 | 70.1 | 20.00 | 7.76 | 9.38 | 8.52 | 9.16 |
| 6 | 67.2 | 17.20 | 6.47 | 8.84 | 7.55 | 6.90 |
| 10 | 62.7 | 14.80 | 5.17 | 6.90 | 6.36 | 5.71 |
| 14 | 61.2 | 13.80 | 4.96 | 6.90 | 6.14 | 5.39 |
| 23 | 57.4 | 13.00 | 4.31 | 5.93 | 4.20 | 4.10 |
| 30 | 56.5 | 11.60 | 4.10 | 5.93 | --- | --- |
| 48 | 53.0 | 9.38 | 2.80 | 4.53 | 3.77 | 3.56 |
| 54 | 53.0 | 8.84 | 2.59 | 4.20 | 3.56 | 3.45 |
| 71 | 51.0 | 7.76 | 2.48 | 3.56 | 3.02 | 3.23 |
| 96 | 47.9 | 6.25 | --- | 2.37 | 2.16 | 1.62 |
| 144 | 46.9 | 6.14 | 1.51 | 2.16 | 1.51 | 1.40 |
| 168 | 46.9 | 5.61 | 1.51 | 1.83 | 1.51 | 1.40 |

## TABLE No. 26.

## PER CENT OF SOIL REMAINING IN SUSPENSION AT DIFFERENT INTERVALS DURING SEDIMENTATION WHEN SATURATED WITH DIFFERENT CATIONS.

Red River Alkalinized Associate, Horizon 3"--12"

| Time in hours | Soil Saturated With | | | | | Untreated Soil |
|---|---|---|---|---|---|---|
| | Na | K | H | Mg | Ca | |
| 0 | 96.7 | 74.90 | 31.20 | 48.00 | 43.60 | 40.80 |
| 3 | 75.6 | 31.50 | 7.57 | 17.60 | 15.70 | 17.70 |
| 6 | 72.4 | 25.80 | 6.08 | 14.70 | 12.60 | 15.00 |
| 10 | 68.8 | 21.10 | 5.01 | 12.60 | 11.30 | 12.70 |
| 25 | 64.9 | 14.60 | 3.62 | 9.28 | 8.53 | 9.38 |
| 31 | 63.40 | 13.40 | 3.09 | 7.46 | 7.25 | 8.52 |
| 48 | 59.4 | 10.30 | --- | 5.36 | 4.90 | 6.72 |
| 72 | 58.4 | 8.74 | 2.56 | --- | --- | 4.90 |
| 120 | 56.2 | 8.42 | 2.24 | 5.12 | 4.26 | --- |
| 144 | --- | 8.21 | 1.28 | 4.80 | 4.26 | 4.58 |
| 168 | 54.0 | 7.25 | --- | 3.84 | 3.52 | 4.16 |
| two weeks | 51.2 | 5.01 | 1.17 | 1.92 | 1.49 | 1.92 |

## TABLE No. 27.

## PER CENT OF SOIL REMAINING IN SUSPENSION AT DIFFERENT INTERVALS DURING SEDIMENTATION WHEN SATURATED WITH DIFFERENT CATIONS.

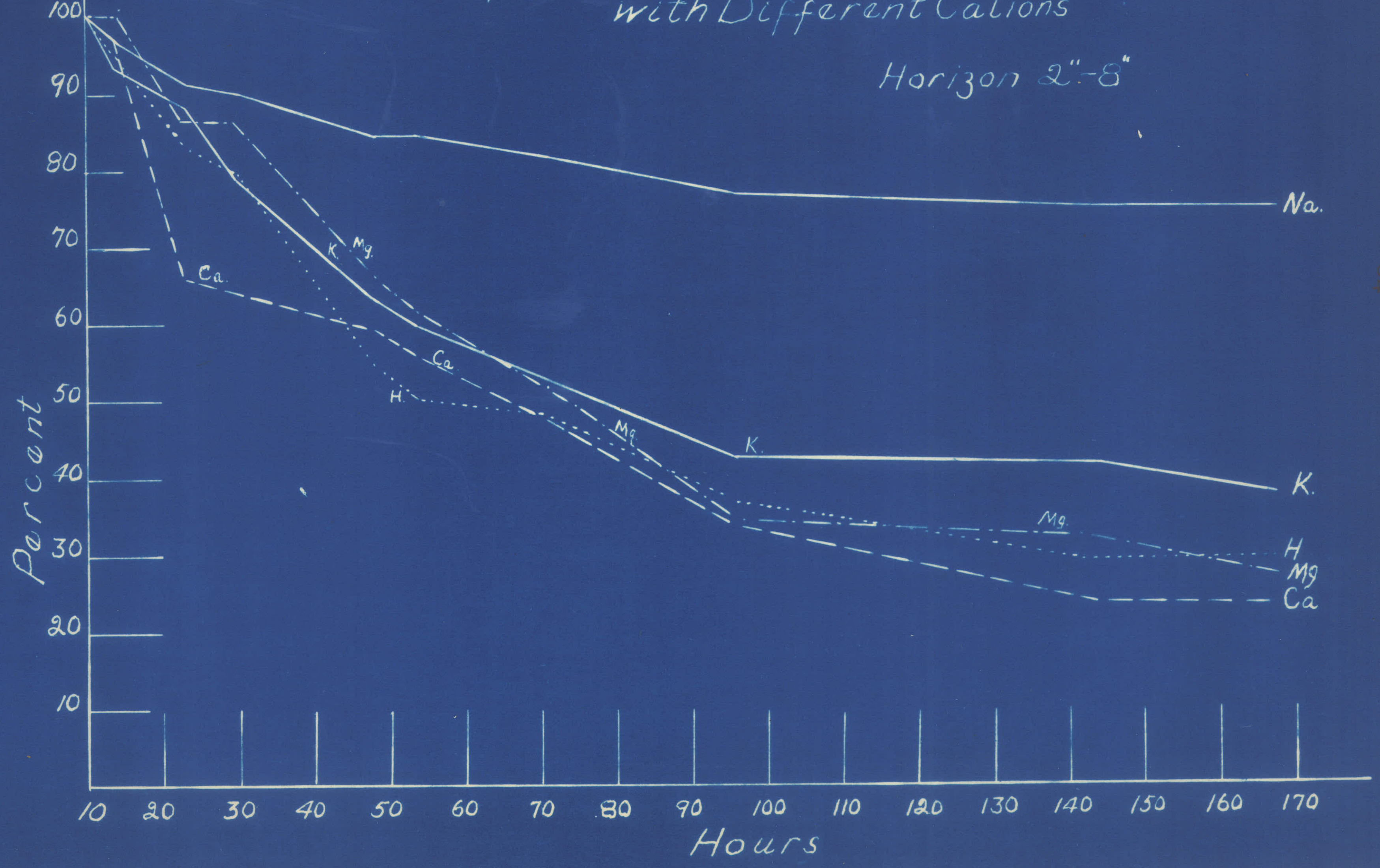
Red River Degraded Alkalinized Associate, Horizon 4"--10"

| Time in hours | Soil Saturated with | | | | | Untreated Soil |
|---|---|---|---|---|---|---|
| | Na | K | H | Mg | Ca | |
| 0 | 93.0 | 60.60 | 48.50 | 48.30 | 46.40 | 43.60 |
| 2 | 73.2 | 28.60 | 16.60 | 18.20 | 17.90 | 17.60 |
| 4 | 71.5 | 24.30 | 14.10 | 15.80 | 16.10 | 15.70 |
| 6 | 71.0 | 21.90 | 12.20 | 12.40 | 13.40 | 13.20 |
| 10 | 64,20 | 18.40 | 10.60 | 11.90 | 11.20 | 11.20 |
| 14 | 61.1 | 16.20 | 8.79 | 9.96 | 9.11 | 9.96 |
| 24 | 57.5 | 13.90 | 6.64 | 8.68 | 8.36 | 8.14 |
| 31 | 54.5 | 12.80 | 6.43 | 8.04 | 8.04 | 7.61 |
| 48 | 47.9 | 10.80 | 6.00 | 7.39 | 6.86 | 6.54 |
| 72 | 46.6 | 6.32 | 2.89 | 4.29 | 3.54 | 3.86 |
| 121 | 42.6 | 6.00 | 2.57 | 3.64 | 3.21 | 3.00 |
| 144 | 42.0 | 5.36 | 2.36 | 3.54 | 2.46 | 2.36 |
| 168 | 40.9 | 5.04 | 1.50 | 3.11 | 2.46 | 1.61 |
| two weeks | 39.0 | 4.29 | 0.86 | 1.93 | 2.14 | 0.86 |

## Chart No. 10

Sedimentation Study of the Red River
Phytomorphic Associate Saturated
with Different Cations

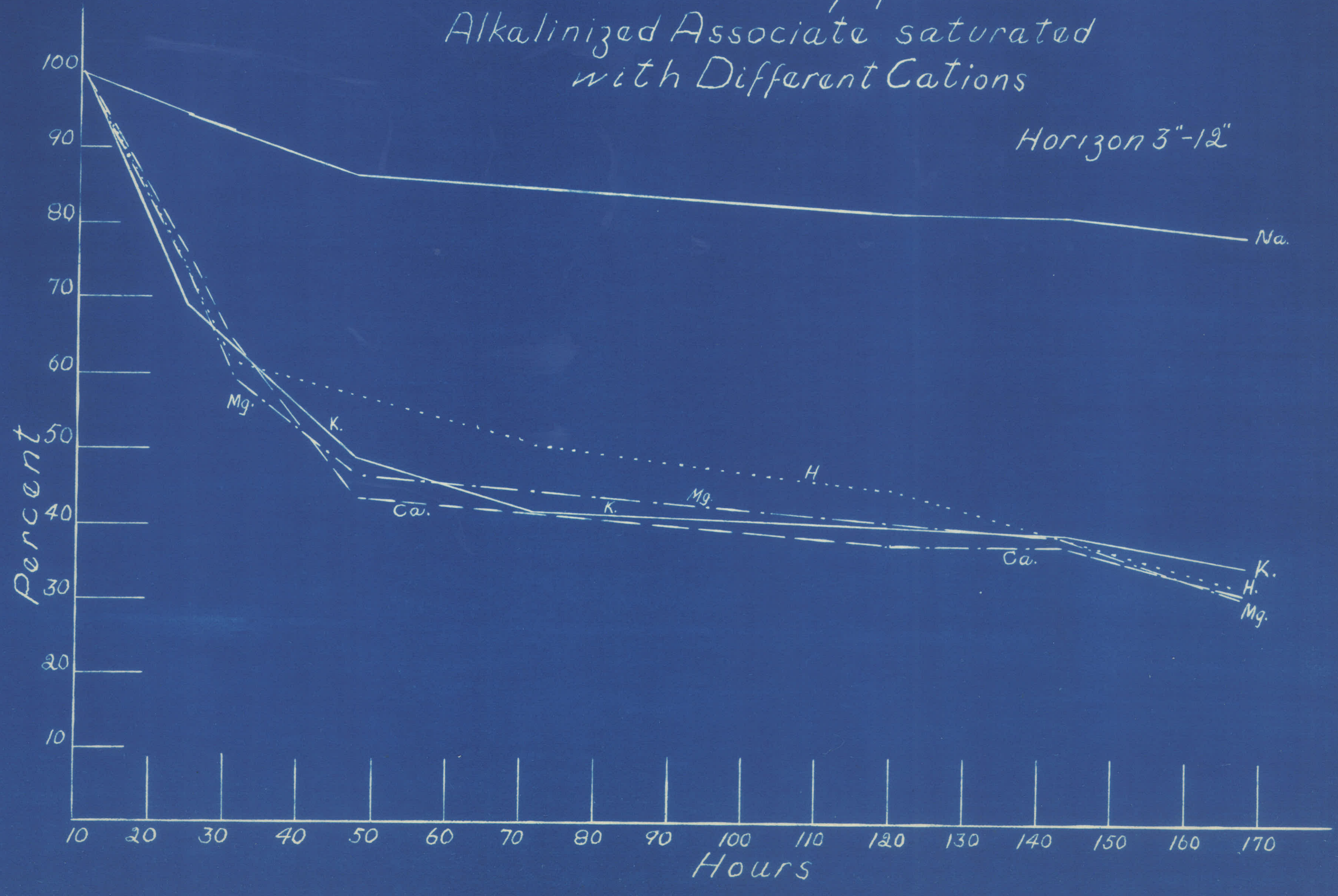
Horizon 2"-8"



# Chart No.11

## Sedimentation Study of the Red River Alkalinized Associate saturated with Different Cations

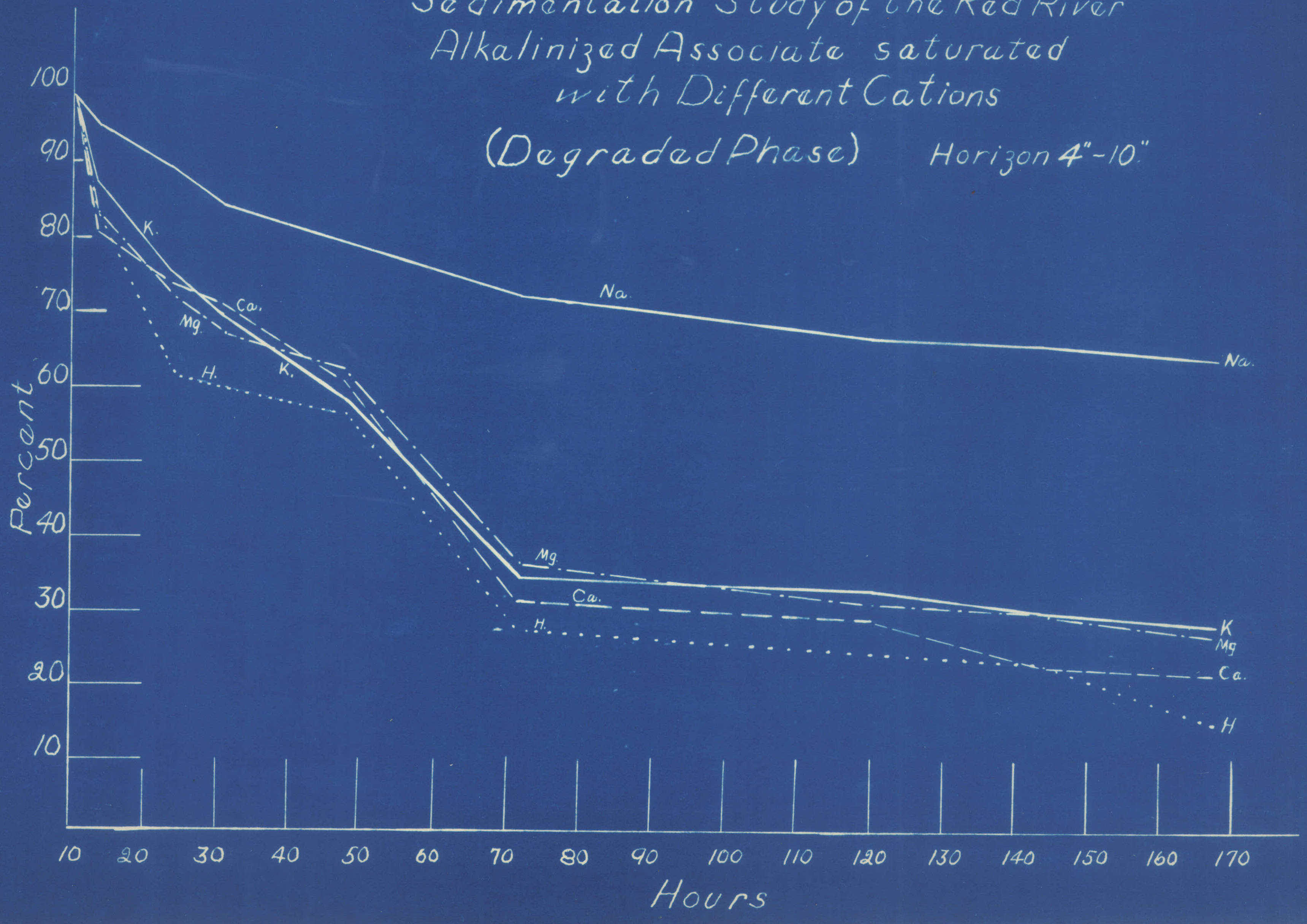
Horizon 3"-12"



# Chart No. 12

## Sedimentation Study of the Red River Alkalinized Associate saturated with Different Cations

## (Degraded Phase) Horizon 4"-10"



The reason for the change in position of Hydrogen is not clear.

In Table No. 28 a comparison is made of the different degree of peptization of the three soils studied under the influence of the different cations at three sampling periods.

At the commencement of the experiment sodium had a greater peptizing influence on the phytomorphic prairie associate, potassium on the alkalinized associate and the other cations upon the degraded alkalinized associate. After a period of ten hours all the cations, except hydrogen, showed a greater peptizing effect upon the alkalinized associate. After one hundred and sixty-eight hours a similar relationship existed as that found at the ten-hour period, except in the case of hydrogen. This would indicate that the degree of aggregation was much stronger in the phytomorphic prairie associate, and weakest in the alkalinized associate.

The data indicate that the sodium cation has a greater dispersing effect upon the soil aggregates than the other cations. This is shown by the small degree of variation apparent in the sedimantation values of the sodium saturated soils compared to the sedimentation values of the three soils saturated with other cations. However, the degree of aggregation has some influence on sodium peptization effects. This is noted in a comparison of the phytomorphic prairie and the alkalinized associates. At the beginning of sedimentation the peptizing influence is one per cent greater in the phytomorphic prairie associate, in ten hours it is 6.1 per cent greater, and in 168 hours it is 7.1 per cent greater than in the alkalinized associate. This indicates some increase in the number os small particles produced by sodium peptization in the alkalinized soil compared to the phytomorphic soil.

The greater stability of the aggregation of fine particles in the phytomorphic prairie associate as compared with the other two associates is produced or influenced by three factors, namely, (a) organic matter, (b) the water soluble salts which act as electrolytes, and (c) the nature of the adsorbed cation. The organic matter in the phytomorphic prairie soil is much higher than in the alkalinized and degraded alkalinized soils, (See Table No. 1), which probably explains in part the better degree of aggregation in the former soil.

In regard to the presence of electrolytes in the soil solution it is found by refering to Table No. 2 that the amount of water soluble salts in the phytomorphic prairie associate, (2" - 8" ) is 1872 parts per million, in the alkalinized associate, (3" - 12") it is 912 parts per million, and in the degraded alkalinized associate it is 879 parts per million. The water soluble salts in the latter two profiles therefore are only half of the quantity of the quantity occurring in the phytomorphic prairie soil. The water soluble salts in the alkalinised and degraded alkalinized soils are less than the electrolytic limit for flocculation as given by Gedroiz (26).

# TABLE No. 28.

## A COMPARISON OF THE QUANTITY OF SOIL REMAINING IN SUSPENSION OF THE THREE RED RIVER SOILS WHEN SATURATED WITH DIFFERENT CATIONS.

Samples taken at three intervals during sedimentation.

| Soil saturated with | Period of Sedimentation in Hours. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 10 | | | 168 | | |
| | Phytomorphic Prairie | Alkalinized | Degraded Alkalinized | Phytomorphic Prairie | Alkalinized | Degraded Alkalinized | Phytomorphic Prairie | Alkalinized | Degraded Alkalinized |
| Na | 97.7⊠ | 96.7 | 93.0 | 62.7 | 68.8⊠ | 64.2 | 46.9 | 54.0⊠ | 40.9 |
| K | 40.4 | 74.9⊠ | 60.6⊠ | 14.8 | 21.1⊠ | 18.4 | 5.61 | 7.25⊠ | 5.04 |
| H | 25.7 | 31.2 | 48.5⊠ | 5.17 | 5.01 | 10.6⊠ | 1.51⊠ | ---- | 1.50 |
| Mg | 27.3 | 48.0 | 48.3⊠ | 6.90 | 12.6⊠ | 11.9 | 1.83 | 3.84⊠ | 3.11 |
| Ca | 24.6 | 43.4 | 46.4⊠ | 6.36 | 11.3⊠ | 11.2 | 1.51 | 3.52⊠ | 2.46 |
| Original | 26.3 | 40.8 | 43.6⊠ | 5.71 | 12.7⊠ | 11.2 | 1.40 | 4.16⊠ | 1.61 |

The flocculation of suspended material then would take place in the phytomorphic prairie soil but not in the other two soils at this electrolytic concentration. The degree of aggregation in the former soil therefore is more stable under the influence of leaching by water comparatively free from electrolytes as Gedroiz (26) states: "The capacity of the soil to attain this or that structure and preserve it for longer or shorter periods of time will eventually depend upon the stability with which the smallest soil particles form aggregates under the influence of these or other electrolytes, and with the degree of counteractions of the aggregates obtained to the disintregating action of water, for example, in the periods of large quantities of atmospheric deposits. Therefore the soils of the same mechanical composition may possess a different structure and a different stability of structure".

Galay (20) states: "The calcium soil differs from all soils, artificial as well as natural, through its greater sensitivity to electrolytes"

Therefore according to Galay's statement the alkalinized and degraded alkalinized soils are not as sensitive to electrolytes as the phytomorphic prairie soil because they contain large quantities of adsorbed magnesium instead of calcium, and so are more difficult to hold in a stable condition. Theoretically also the alkalinized and degraded alkalinized soils have not sufficient water soluble salts present to hold the aggregates stable, and under the influence of water these soils become a colloidal impermeable mass which hardens and becomes compact as the soils dry.

As has been shown previously, magnesium has not quite the flocculating power of calcium. Sokolovsky (56) found that drying produced a more stable form of aggregation in the soil, which resisted peptizing action to a greater degree than possessed by the original soil, i.e., a portion of the colloids become "irreversible". With this in mind an experiment was conducted on the alkalinized associate to see what influence the effect of drying the soil would have upon the relative peptizing strength of the adsorbed ions calcium and magnesium.

## E. SEDIMENTATION STUDY ON THE RED RIVER ALKALINIZED SOIL BEFORE AND AFTER DRYING.

### (a) Method.

The water suspensions of the calcium and magnesium saturated alkalinized soil used in the previous sedimentation study was evaporated to dryness and the clay dried at a temperature of 50 to 60° C. The residue was then taken up with water and dispersed by shaking for three hours in a shaker. Sedimentation was conducted in litre sedimentation cylinders, the sampling of the suspension being made by use of a pipette as outlined in the previous sedimentation experiment.

### (b) Results and Discussion.

The results obtained are tabulated in Table No. 29 and illustrated graphically in Chart No. 13. The degree of peptization before drying is given as a comparison. In the Chart the percentages are based upon the total weight of oven dry soil as 100 per cent.

## TABLE No. 29.

## SEDIMENTATION STUDIES OF SOIL OF THE RED RIVER ALKALINIZED ASSOCIATE BEFORE AND AFTER DRYING.

(Saturated with Ca or Mg. ions.)

| Time in hours | Ca saturated soil | | Mg saturated soil | |
|---|---|---|---|---|
| | After drying per cent 1/ | Before drying, percent 1/ | After drying per cent | Before drying, percent |
| 0 | 51.81 | 43.6 | 64.65 | 48.0 |
| 3 | 7.12 | 15.7 | 11.57 | 17.6 |
| 7 | 7.12 | 12.6 | 10.16 | 14.7 |
| 20 | 4.86 | --- | 6.92 | -- |
| 27 | 3.35 | 8.53 | 5.08 | 9.28 |
| 44 | --- | 4.90 | 4.76 | 5.86 |
| 68 | 2.70 | --- | 4.11 | --- |
| 92 | --- | --- | 3.57 | --- |
| 140 | 1.94 | 4.26 | 3.24 | 4.80 |
| 164 | .86 | 3.52 | 2.39 | 3.84 |

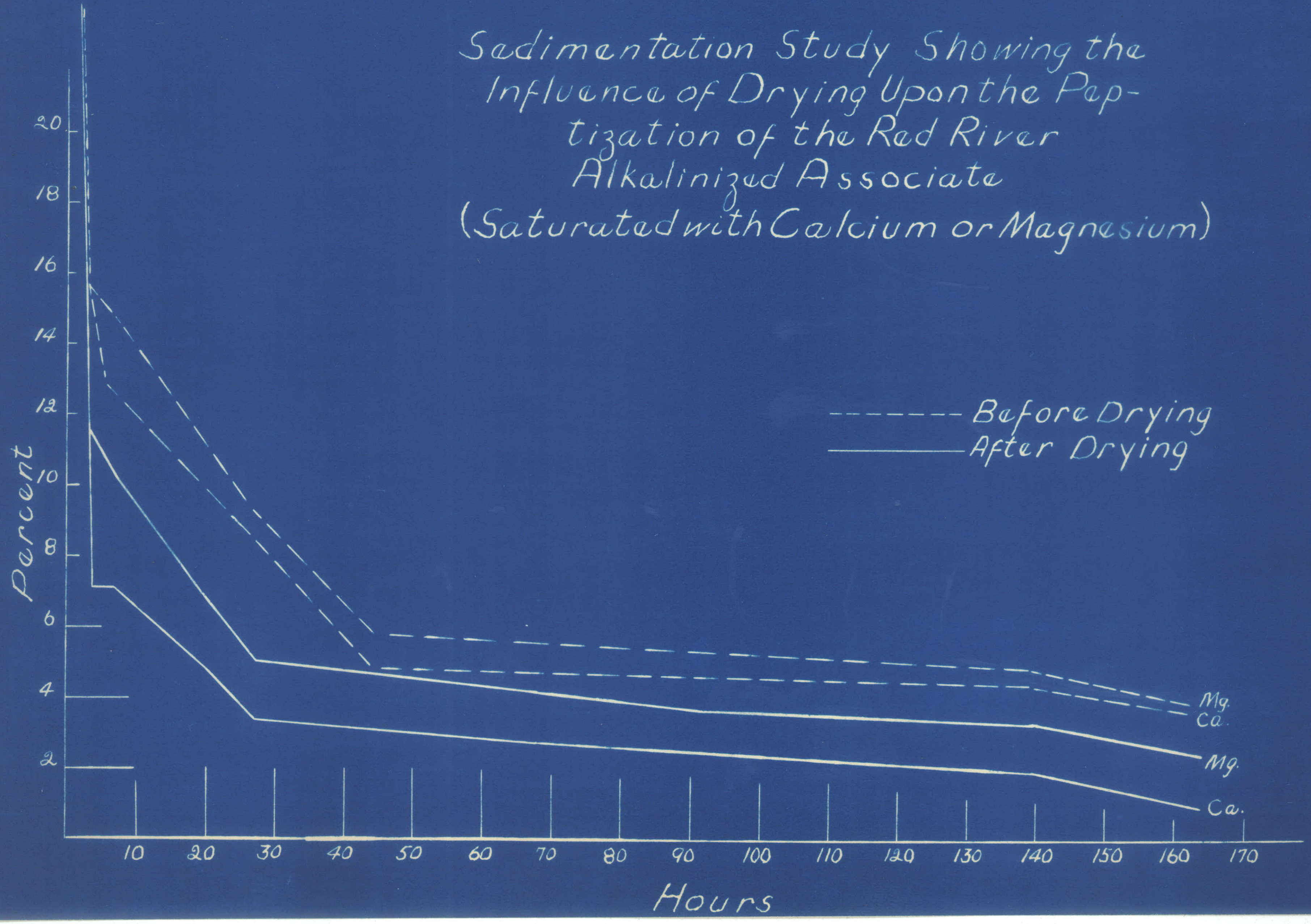
1/ Percentage expressed as percent of total soil.

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

The drying decreased the peptization of this soil to a considerable extent as indicated by results of all sampling periods except the first sampling. The peptizing influence of magnesium is increased to 1½ to 2 times as great as calcium in this soil after drying. It thus appears that as the colloidal material is made more difficult to peptize the influence of magnesium is increased over that of calcium, indicating a greater peptizing influence of magnesium.

# Chart No. 13

## Sedimentation Study Showing the Influence of Drying Upon the Peptization of the Red River Alkalinized Associate (Saturated with Calcium or Magnesium)



Under normal soil conditions of wetting and drying it would appear that a clay soil containing appreciable quantities of adsorbed magnesium would have a tendency to become more deflocculated than if it was saturated with calcium, and this difference would become more marked with continued wetting and drying of the soil.

Therefore it is to be expected that Red River soils under field conditions will be deflocculated to a greater extent when containing adsorbed magnesium than when containing adsorbed calcium. As the Red River alkalinized and degraded alkalinised soils contain an excess of adsorbed magnesium their soil aggregates will be very much less stable then the Red River phytomorphic calcium soil.

## 7. SUMMARY OF THE DATA FROM THE EXPERIMENTAL WORK.

The deflocculated and poor physical condition existing in the alkalinised soil of the Red River Valley is due apparently to several causes, first, lower organic content, thus reducing the aggregation caused by such material in the soil; second, to a low concentration of electrolytes in the soil; and third, to the presence of large quantities of adsorbed magnesium in the soil.

In the field the peptising action of water upon the soil aggregates tends to form a colloidal suspension of the small particles, when sufficient electrolytes are not present in the soil solution ot provide a stabilising influence upon the aggregates. This action of deflocculation results in a sticky impervious soil that in drying forms hard prismatic or columnar structures rather than granular aggregates. Adsorbed magnesium has a greater influence on deflocculation of a soil than has calcium. A magnesium soil also requires large quantities of electrolytes to insure the flocculation of the fine particles and the stability of the aggregates than a calcium soil. Therefore it may be expected that a magnesium saturated soil would develop at least feebly the characteristic structure and physical condition of a deflocculated soil.

The study of the physical properties of Red River soils shows that some types in this group develop structure and physical conditions very similar to sodium saturated soils or "Solonetz" which are commonly known as alkali soils. In the Red River soils the "Solonetz-like" condition is due, (a) to the small quantities of electrolytes in the soil solution; (b) to the presence of adsorbed magnesium, and (c) to the low organic matter content. Sodium has had no part in the development of these soils.

The term "Solonetz" is used to define the morphological appearance of structure forming soils, and they have generally been assumed to form under the influence of sodium. It has been shown in this study that soils possessing typical "Solonetz-like" structure exist, which contain large amounts of adsorbed magnesium but no appreciable quantities of sodium. Hence the "Solonetz" soil type should be divided into two subtypes, namely "sodium Solonetz" and "magnesium Solonetz"

Sokolovsky (56) states that the structure formation in a soil is but the morphological evidence of the physical characteristics of that soil, and is a function of the colloidal material. Gedroiz (66) also states that the manifestation of soil structure is due to the influence of electrolytes upon the colloidal portion of that soil. The better type of soil structure is the crumbly granular structure, (Sokolovsky (56). The soils of this structural type are very friable and permeable to water. This structural type is found in chernozems where the humus content of the soil is high. Tumin (37).

The development of soil structure is dependent upon the presence of flocculated colloidal material. The agents of flocculation are, (1) electrolytes; (2) drying; (3) freezing; (4) the presence of opposite charged colloids. (Gedroiz (66) ). In the production of the better type of structure in soil, namely the crumbly granular structure, the adsorptive ions must consist chiefly of adsorbed calcium. Sufficient organic material must be present to have a cementing influence upon the aggregates. (Sokolovsky (56) and Tumin (66) ).

Therefore the production of better structure, which is indicative of a better physical condition, in the alkalinized and degraded alkalinized associates of the Red River soils could be expected by the use and interaction of three agencies, (a) increasing the electrolytic content of these soils; (b) saturating the base exchange complex with calcium; and (c) increasing the organic matter content.

## 8. AMELIORATION OF THE RED RIVER ALKALINIZED SOIL.

### (a) Review of Literature.

In Europe, the United States of America and other parts of the world, many sodium saturated soils with their accompanying poor physical condition are being ameliorated by the use of gypsum. Gedroiz (29), Sigmond (11) and Kelly and Thomas (40). The application of gypsum however, must necessarily be very heavy and the cost is high. Kelly and Thomas (40) found in California that uniform results were obtained only after an application of ten tons of gypsum per acre, while Sigmond (11) mentions the heavy cost of such treatment. Kelly (38) states that heavy textured alkali soils are hard to reclaim, but that lighter textured soils may be reclaimed by the use of gypsum or sulphur.

Other workers have undertaken investigations in reclaiming alkali soils by removing the sodium and flocculating the highly dispersed colloidal material by use of soluble compounds of high flocculating capacity, such as ferrous sulphate, aluminium sulphate, tannic acid, etc. Kelly Thomas (40) found that relatively large amounts of ferric sulphate was required to produce noticeable results. Joffre and McLean (33) mention the improvement of the permeability of an alkali soil by the use of alum but do not consider it as a scientific treatment of alkali soils. C. W. Botkin (8) studied several compounds in relation to their ability to increase the permeability of a soil as measured by the flocculating power of these compounds. The permeability after treatment was indicated by the length of time required for six inches of water to penetrate a foot column of soil. The time required for percolation through the original soil was 36 hours, while the soil when treated with .5 per cent $Al_2(SO_4)_3$ required 4 hours, that with .3 per cent tannic acid 15 hours, with .5 per cent calcium acid phosphate 17 hours, with .5 per cent magnesium sulphate 20 hours, with 1 per cent manure 22 hours, and with gypsum 23 hours. Under these conditions aluminium sulphate is the most effective agent used in flocculating these soils.

Lewis and Marmoy (41) in England found that aluminium sulphate and ferrous sulphate produced aggregation in heavy clay soils as measured by the dispersion co-efficient. The action of calcium chloride was less marked than was the action of the iron and aluminium salts. However these workers make the statement that the permanent improvement was too small to be economical at the present time.

The use of lime in moderate quantities on soils of the burn-out areas of Saskatchewan, which are very hard to till, due to poor physical condition, produced no marked improvement, possibly due to insufficient quantity. Russell and Keen (53) effected a reduction of 11 per cent in draft of plows in heavy clay soils by the addition of 20 loads of fine chalk per acre.

## (b) Conclusions.

From a review of the experimental evidence at hand it would appear that the alkalinized heavy clay soils in the Red River Valley which are in poor physical condition probably could be ameliorated somewhat by chemical means, but under the present system of extensive farming it is commercially impossible to apply the large amounts that would be required.

A large amount of literature has been written on the subject of the influence of organic matter upon improving the physical condition of heavy clay soils by increasing their permeability and aggregation. (Keen (36) ). Botkin (8) shows that organic matter increases the permeability of an alkali soil by 33 per cent, while Noll (44) reports that the plow draft, which is one indication of the physical condition of the soil, varied inversely to the percentage of organic matter. Dudley and Jones (15) however, report that the plow draft was slightly increased in a silt loam treated with manure.

It therefore appears that the addition and maintenance of the organic matter in the heavy clays of the Red River Valley is the best practical method of amelioration. This is especially applicable in the case of the alkalinized associates which included quite a large acreage of cultivated land in this area. The organic matter of a soil, however, can only be increased and maintained economically by use of a system of rotation which would include the grasses and clovers or by the application of barnyard manure.

## 9. GENERAL SUMMARY.

The soils studied in this investigation are the major soil associations of the Red River soil Combinations, namely, the Red River, Emerson and Altona associations.

The parent material of the Red River association is deep lacustrine clay, that of the Emerson association is delta and shallow lacustrine deposits, and that of the Altona association is littoral and shallow lacustrine deposits.

The relatively light textured soils of the Emerson and Altona associations are good agricultural soils, although small areas of saline soils are included in these areas.

The good agricultural soils of the Red River association include only those in the Red River phytomorphic associate which is only about 20 per cent of the total area of the association. The other soil associates all have some problem or problems such as periodical flooding, drainage, and the maintenance of a good physical condition in soils which have been subject to the soil processes of alkalinization and degradation.

The soil forming process in the Emerson and Altona associations is a chernozem-like soil process operating in the surface horizons of the soil while the lower part of the profile is under the influence of ground water.

In the Red River association the soil processes are:- the chernozem-like soil process in the phytomorphic associate; salinity, alkalinization and degradation processes taking place in the hydromorphic, alkalinized, degraded alkalinized, and phytomorphic wooded associates, respectively.

A study of the water soluble salts of the soils in the Red River combination show that calcium and magnesium sulphates and bicarbonates are the predominating salts. Sodium carbonate is practically absent and the chlorides are low inquantity.

The exchangeable divalent ions calcium and magnesium comprise the greater portion of the total exchangeable cations in all the soils studied, while the exchangeable sodium is insignificant in quantity. The exchangeable calcium exceeds the exchangeable magensium in the Emerson and Altona soil associations and in the hydromorphic and phytomorphic associates of the Red River association. In the alkalinized and degraded alkalinized soils of the Red River association however, the exchangeable magnesium exceeds the exchangeable calcium in many horizons and hydrogen has been absorbed in appreciable amounts.

The alkali and degraded alkali soils of the Red River association have developed from saline soils, high in magnesium salts. As the natural drainage of the valley improved, the salt content of the soil was removed and the development of alkali structure began. This was followed in some soils by a process of degradation. The alkali soils studied have been formed therefore from saline soils that have contained large quantities of magnesium salts rather than sodium salts and the typical "Solonetz-like" structure has been developed without the strong peptizing effect of sodium.

The physical properties of the Red River phytomorphic, alkalinized and degraded alkalinized soils are markedly different. The mechanical analysis of these soils indicates that they are composed of fine textured material, the clay and colloidal fractions being very high. The texture does not remain constant throughout the profile, becoming finer textured with depth, in the soils studied.

Percolation studies and a determination of the Atterberg constants show that as alkalinization of the soil develops it becomes more impervious to water, more sticky and compact. These changes in physical characteristics are due to the lowering of the organic matter of the soil and to the character of the exchangeable cations adsorbed by the fine textured soil.

Sedimentation studies on the Red River phytomorphic, the alkalinized and degraded alkalinized soils brought out the relationship between the exchangeable cations and the flocculation of the soil particles. A soil saturated with adsorbed magnesium is more easily deflocculated in water than a soil saturated with adsorbed calcium and the difference becomes more marked after the soil has been dried at 50° to 60° C. The alkalinized soils are more easily deflocculated than the phytomorphic soil. The deflocculation of all the Red River soils may be accomplished, to some extent at least, if the electrolyte and organic matter content is low. This process may be hastened by the substitution of adsorbed magnesium for calcium in the exchange complex.

The presence of considerable magnesium in the exchange complex, low electrolyte content and low organic matter content in the Red River soils promotes the development of "Solonetz-like" soil structure. Therefore a "Solonetz" soil may be formed without the assisting action of sodium, but with magnesium acting in the place of sodium. "Solonetz" soils may be classified then as "sodium Solonetz" or "magnesium Solonetz" soils depending upon the adsorbed ion.

At the present time the amelioration of these soils is economically possible only by a judicious system of crop rotation which includes the growing of grasses and clovers, and by the frequent application of barnyard manure.

## 10. CONCLUSIONS.

1. The alkalinized soils in the Red River Valley have developed from saline soils rich in magnesium salts.

2. The "Solonetz-like" structure in the Red River soils is formed in soil which contains large amounts of adsorbed magnesium but no appreciable quantities of adsorbed sodium.

3. The development of this structure has been aided by a low electrolyte and organic matter content of the soil.

4. In the classification of the "Solonetz" soil type it should be divided into two sub-types, namely, "Sodium-Solonetz" and "Magnesium-Solonetz" soils. The alkalinized soils in the Red River Valley would than be classified as "Magnesium-Solonetz" soils.

5. The addition of organic matter to the Red River alkalinized soils offers the most practical solution of the amelioration of their prevailing bad physicl condition.

## 11 BIBLIOGRAPHY.

1. Aarnio, B. (1927)

Proceedings of the First International Congress
of Soil Science, Vol. II, P. 65

2. Afansiev, J. N. (1927)

Russian Pedalogical Investigations, No.5, Table,
No. VI. Academy of Sciences of the U.S. S. R.

3. Analytical Methods of Association of Official Agricultural Chemists, (1925)

4. Baver, L. D. (1928)

"The Relation of Exchangeable Cations to the Physical Properties of Soils".

Journal of American Society of Agronomy, Vol.20, P.921.

5. Baver, L. D. (1930)

"The Atterberg Consistency Constants".

Jour. Amer. Society of Agronomy, Vol.22, P. 935

6. Biilman, E, and Tovborg-Jensen, S.

Transactions of Second Commission of International
Society of Soil Science, Vol. B, Page 236.

7. Bobko, B. W., and Askinasi, D. L. (1925)

"Zeitschrift Pflanzenernahrung Dungung"

6 A, P. 99.

8. Botkin, C. W.

"Some Factors Affecting the Impermeability of Soil".

Paper read before New Mexico Associate of Science,
November, 1924. Abstract; Proceedings of the International Society Soil Science, Vol.I, Page 242.

9. Chapman, H. D. and Kelly, W. P. (1930)

Soil Science, Vol. 30, Page 391

10. Gonrey, G. W. and Schollenberger, C. J. (1928)

"The Effect of Weathering on Exchangeable Bases as Shown in the Clermont Silt Loam Profile."

Proceedings of the First International Congress of Soil Science, Vol. II. Page 212

11. De Sigmond, Dr. Alexis A. J. (1927)

"Hungarian Alkali Soils and Methods of their Reclamation".

Special Publication - University of California Agricultural Experimental Station.

12. De Sigmond, Dr. Alexis A. J. (1928)

"The Chemical Characteristics of Soil Leaching"

First International Congress of Soil Science, Vol. I. Page 60

13. De Sigmond, Dr. Alexis A. J. (1928)

First International Congress Soil Science, Vol. I. Page 197.

14. De Sigmond, Dr. Alexis A. J. and Di Gleria, T. (1928)

"The Different Degrees of Saturation of the Absorbing Complex, Jumus Zeolites, of the Soil, and Method for their Determination".

Prodeedings of the First International Congress of Soil Science, Vol. II, Page 155.

15. Dudley, F. L. und Jones, M. M. (1926)

Effects of Soil Treatments upon the Draft of Plows".

Soil Science, Vol. 21. Page 277

16. Ellis, J. H.

Red River Soil Survey Report".

Unpublished Data. Soils Division, Department of Agronomy, University of Manitoba.

17. Ellis, J. H. (1932)

"A Field Classification of Soils for use in the Soil Survey".

Scientific Agriculture, Vol. 12. Page 338

18. Emerson, P. (1925)

"Soil Characteristics". Page 93.

McGraw Hill Book Co.

19. Engle, E. B. and Yoder, D. R. (1926)

"Application of the Robinson Method to the Determination of Clay".

Journ. of the Amer. Soc. of Agronomy. Vol.18. Page 1016

20. Gallay, R. (1924)

"Contribution a l'etude de la Coagulation de l'argile". Page 47

21. Gedroiz, K. K. (1918)

Contribution to the Method of Determining the Zeolitic Bases in the Soil".

Communication I , Chemical Laboratory of Forestry Dept. People's Commissariat of Agriculture. Agriculture Scientific Committee, Petrograd.

22. Gedroiz, K. K. (1923)

"The Hydrochloric Acid Method for Determining in the Soil the Cations Present in an Adsorbed Condition".

Soil Science, Vol. 16, Page 473.

23. Gedroiz, K. K. (1918)

"Contribution to the Method of Determining the Zeolitic Bases in the Soil".

Communication I, Chemical Laboratory of Forestry Department, People's Commissariat of Agriculture, Agriculture Scientific Committee, Petrograd.

24. Gedroiz, K. K. (1925)

"The Soil Absorbing Complex and the Absorbed Soil Cations as a Base of Genetic Soil Classification".

Nossov Agric. Exp. Station, Paper No.28
People's Commissariat of Agriculture, Leningrad

25. Gedroiz. K. K. (1924)

"Ultrachemical Composition of Soils and its Dependence on the Nature of the Cations Present in the Soil in an Absorbed Condition".

Journal Experimental Agronomy, Vol.22, P. 41

26. Gedroiz. K. K. (1915)

"The Action of Electrolytes on Clay Suspensions".

Communication XXIV from Bureau of Agriculture and Soil Science of the Scientific Committee of the Main Department of Land Organization and Agriculture. Page 1.

27. Gedroiz, K. K. (1912)

Journal of Experimental Agronomy, Vol 13.

28. Gedroiz, K. K. (1918-19)

"Contribution to Our Knowledge of the Absorption Capacity of the Soils".

Journal Experimental Agronomy. Vol. 20, Page 54.

29. Gedroiz, K. K. (1917)

"Saline Soils and Their Improvement".

Journal of Experimental Agronomy. Vol.18, Page 122.

30. Glinka, K. (1914)

Die Typen der Bodenbildung.
Verlag von Gebruder Borntraeger Page 189.

31. Hilgard, E. W.

Soils, 1905. McMillan Book Co. New York.

32. Hissink, D. J. (1923)

Soil Science, Vol. 15, Page 269

33. Joffre, J. S. and McLean, H. C. (1924)

"Origin of Alkali Soils and the Physical Effects of Treatment."

Soil Science, Vol. 18. Page 13.

34. Joseph, A. F. and Oakley, H. B. (1929)

"Soil Containing Different Exchangeable Bases".

Journ. of Agric. Science, Vol. 19, Page 121.

35. Joseph, A. F. and Martin, F. J.

The Determination of Clay in Heavy Soils."

Journ. of Agric. Science, Vol. II, page 293.

36. Keen, B. A. (1927)

"Some Physical and Physio-Chemical Effects of Organic Matter".

Journ. of the American Society of Agronomy, Vol. 19. Page 362.

37. Kelly, W. P. (1926)

"A General Discussion of Base Exchange in Soil".

Journ. Amer. Soc. of Agronomy, Vol. 18, Page 450

38. Kelly, W. P. (1932)

"American Alkali Soils, with Special Reference to Mode of Formation and Methods of Reclamation".

Second International Congress of Soil Science, Vol. 5. Page 355.

39. Kelly, W. P. and Brown, S. M. (1924)

University of California Agric. Exp. Sta. Bull. No. 15.

40. Kelly, W. P. and Thomas, E. E. (1928)

"Reclamation of the Fresno Types of Black Alkali Soils"

University of California College of Agriculture, Experimental Station Bull. No. 455.

41. Lewis, A. H. and Marmoy, T. B. (1933)

"Jeolotts Hill Agricultural Research Bulletin, Vol. II. No. 3. Page 150

42. McGeorge, W. T. (1930)

"The Base Exchange Property of Organic Soils."

Arizona Agric. Exp. Sta. Tech. Bull. No. 31

43. Nikiforoff, C. C. (1930)

"Sohonetz and Solenchak Soils of the Red River".

Report of Tenth Meeting of American Soil Survey Association, Page 141.

44. Noll, E. F.

"Effect of Fertilizers on Soil Structure as Indicated by the Draft of a Plow.

Pennsylvania Agricultural Experimental Station Report, 1913-14, Pages 36 to 46.

45. Olmstead, L. B, Alexander, L.T., and Middleton, H. E. (1930)

"A Pipette Method of Mechanical Analysis of Soil Based on Improved Dispersion Procedure".

United States Department of Agriculture, Technical Bulletin No. 170.

46. Page, H. J., and Williams, W. (1925)

Proceedings of the International Society of Soil Science, Rome, Vol. I. Page 172.

47. Parker, F. W. (1928)

"Methods for the Determination of the Amount and Acidity of Exchangeable Hydrogen in Soils".

Proceedings of the First International Congress of Soil Science, Vol. II. Page 164.

48. Robinson, G. W. (1922)

"A New Method for the Mechanical Analysis of Soils and Other Dispersions".

Journal Agricultural Science, Vol. 12. Page 306

49. Robinson, G. W., McLean and Williams. (1929)

"The Determination of Organic Carbon in Soils."

Journal of Agricultural Science, Vol. 19. Page 315.

50. Rosov. L. P.

"Solonetsous Processes at Amelioration".

Transactions of Sixth Commission of International Society of Soil Science, Russia, Part Vol. A. P. 30.

51. Rost, C. O., and Aetterburg, J. (1932)

Soil Science, Vol. 33. Page 249.

52. Russell, Sir John, (1932)

Soil Conditions and Plant Growth, Pages 185--186.

Longman Green and Company.

53. Russell, E. J. and Keen, B. A.

"The Effect of Chalk in the Cultivation of Heavy Land".

Journal of Min. Agric. (Great Britain).
Vol. 28, P. 419.

54. Russel, J. C. and Wehr, F. M. (1928)

"The Atterberg Consistency Constants".

Journal Amer. Society of Agronomy, Vol. 20, Page 354.

55. Shanks, L.

Uppublished Date of Dept. of Engineering.
University of Manitoba.

(Private Communication to Author)

56. Sokolovsky, A. N. (1932)

"To the Problems of Soil Structure".

Second International Congress of Soil Science,
Vol. I. Page 94.

57. Sokolowski, N. N. and Lukaschwitsch, E. S. (1925)

"Contribution to the Knowledge of the Physical
Properties of Soils.".

Abstract in Proceedings of the International
Society of Soil Science, Vol. 2. Page 165,(1926)

58. Sushko, S. Y. (1933)

"Chemis. Social Agriculture".
No. 3. 217-220

59. Thomas, M. D. (1928)

"Replaceable Bases and Dispersion of Soil in
Mechanical Analysis".

Soil Science, Vol. 25, Page 419.

60. Tjurin, Prof.

Russian Journal Pedology, 1927, No. 1

61. Tjurin, Prof. (1928)

Proceedings First International Congress Soil Science,
Vol. I. Page 231.

62. Tumin, G. M. (1932)

"Chernozem Soils of the European Part of the U.S.S.R.

Proceedings of the Second International Congress of
Soil Science, Vol. 5, Page 261.

63. Vilensky, Prof. D. G. (1927)

"Alkali Soils of Ukraine".

Report to the First Int. Congress of Soil Science,
Washington, Page 107.

Published by Pedological Section. Kharkov, 1927.

64. Vilensky, D. G. (1928)

"Some Data About Alkali Soils of Russia."

Soil Research, Vol. I. No. I. Page 50.

65. Vilensky, D. G. (1932)

"Brief History and Principal Summary of Investigations of Saline and Alkali Soils in U. S. S. R."

Second International Congress of Soil Science, Vol. 5, Page 309.

66. Zakharov, S. A.

"Achievement of Russian Science in Morphology of Soils".

Russian Pedological Investigations, No. 2. (1927)