HALOMORPHISM IN MANITOBA SOILS

A THESIS

Submitted to The Faculty of Graduate Studies and Research
of The University of Manitoba

By

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In Partial Fulfillment of the Requirements for
the Degree of:

MASTER OF SCIENCE

April, 1952.

ACKNOWLEDGEMENT

The writer wishes to express his indebtedness to Professor J.H. Ellis of the Soils Department, University of Manitoba, who suggested the problem and under whose supervision the investigation was conducted.

Acknowledgement is also made to Dr. R.A. Hedlin, Assistant Professor of Soils, University of Manitoba, for supervision in the course of laboratory experimentation; to Mr. W.M. Ward, Chief Chemist, Manitoba Department of Health and Public Welfare, for information on well water analysis; to Mrs. L.B. Kerr, Stratigrapher, Manitoba Department of Mines and Natural Resources, for geological information; to Mr. J. Cunningham, Physicist, Board of Grain Commissioners, for construction of special conductivity cell; and to members of the staff of the Botany Department, University of Manitoba, for identification of plant specimens.

TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGURES

HALOMORPHISM IN MANITOBA SOILS

I. INTRODUCTION:

The occurrence of areas in Manitoba where the productivity of soil is impaired by the presence of excessive amounts of soluble salts has been known since the time of the early settlers. The distribution and extent of these areas has been determined over most of the agricultural portion of the province through the operations of the Manitoba Soil Survey. The mapping of saline soils by this survey has been based on morphological features expressed in the soil profiles, such as pseudo-mycelium and crystalline gypsum, together with observations of native vegetation or crop growth. Investigations to determine the amount and composition of the soluble salts have been limited mainly to areas of special interest and to soil samples submitted to the Soils Laboratories of The University of Manitoba by farm operators.

In order to gain a more comprehensive understanding of halomorphism in Manitoba soils, the investigations herein recorded were undertaken to ascertain the nature of the salts in different parts of the province and the concentrations at which they occur. Arising from these studies, some theories are advanced concerning the possible origin of these salts based on a consideration of their composition and of the geology of the areas.

II. REVIEW OF LITERATURE:

A. Nature, Origin and Classification of Saline Soils

It has long been known that the ability of some soils to support the growth of useful vegetation was appreciably lowered by the presence of excessive amounts of soluble substances. However, a clear understanding of the origin and nature of soluble salts in soils was not attained until recent years. One of the first acceptable scientific theories for the formation of saline soils was advanced in 1912 by Hilgard (14). He separated the continental alkali lands from those in which the salts were clearly derived from past or periodic flooding by sea water, and attributed the salinization of these to the dry climate in which they exist. He contended that the accumulation of salts in the upper horizons of the soil was due largely to the downward movement of water being insufficient to leach out those salts which were continually being formed through the weathering of the soil minerals.

De Sigmond (6), of Hungary, recognized the importance of Hilgard's work but found that under the climatical conditions prevailing in the region of the Hungarian Plain, an impervious subsoil was a necessary supplement to the dry climate for the formation of saline soils. He considered that three factors took part in the evolution of szek (saline) soils; (i) the arid climate, (ii) the impermeable subsoil, and (iii) meteorological conditions which bring the soil periodically under the influence of excessive moisture. He states, "Wherever such conditions have existed or now exist there were and will be formed sooner or later szek soil."

In their recent publication on saline and alkali soils, the staff members of the California Salinity Laboratory (15) substantially agree with de'Sigmond's conclusions. They attribute the salinization of soils to one or a combination of three principal factors--arid climate, poor drainage, and irrigation. They state that poor drainage conditions are an essential prerequisite to this process and that restricted drainage of soils may be due to the presence of a high water table, to low permeability of the soil, or to a combination of both factors.

The classification of alkali soils has developed along somewhat different lines in different parts of the world. Hilgard differentiated continental saline soils into two groups on the basis of the chemical composition of the salts and the surface appearance of the soil. Soils containing appreciable amounts of sodium carbonate were named "black alkali soils", because of the brown or black crust on their surface formed through the dissolving action of carbonate of soda on the soil humus. Opposed to these were "white alkali soils", so called because of the white efflorescence of salts which appeared when the surface of the soil dried.

In Hungary and Russia, the division of alkali soils has been based on their chemical and morphological nature. De Sigmond (6) separated the alkali soils of the Hungarian Plain into two chief groups: (i) Szek soils; (ii) Szik soils. This classification is very similar to that set up by the Russian scientists Sibirtsev and Glinka. The Solonchak soils of Russia and Szek soils of Hungary are soils containing appreciable amounts of soluble salts, particularly the carbonate and chloride of soda, and having no characteristic morphology, other than the common occurrence of salt efflorescences on the surface. They are formed simply by the accumulation of soluble salts in the upper horizons of poorly drained soils. The Szik soils of de'Sigmond and the Solonetz soils of Glinka are characterized by a high content of exchangeable sodium and a particular type of profile, in which a leached "A" horizon of 0.1-20.0 cm or more is underlain by a heavy textured, dark colored, columnar "B" horizon.

These two systems of classification result in some instances in similar divisions, but there are distinct differences. Kelley of the University of California (17) compared the methods by stating, "black alkali denotes soil which contains Na_2CO_3 while solonetz has a twofold significance: namely, morphological and chemical; that is, it refers to certain morphological features of the soil profile and to the presence of absorbed sodium. Since soils which contain Na_2CO_3 probably always contain more or less absorbed (replaceable) sodium, black alkali is equivalent to solonetz in a chemical sense but not necessarily so in a physical sense. Solonchak denotes structureless alkali soil containing a high concentration of soluble salts. White alkali (saline)soils are usually classified as solonchak but solonchaks sometimes contain Na_2CO_3 as well as neutral salts".

In recent years a system of classification has been developed in the United States (15, 22) based on the concentration of soluble salts in the soil, as determined by conductivity measurements on their saturation extracts, and the percentage of sodium on the exchange complex of the soil. In this system, salinized and alkalinized soils are grouped under three headings: (i) Saline soils; (ii) Saline--alkali soils; (iii) Nonsaline--alkali soils.

The term saline soils is used to denote soils for which the conductivity of the saturation extract is more than 4 millimho/cm* and the exchangeable - sodium - percentage is less than 15. Ordinarily the pH is less than 8.5. These soils correspond to Hilgard's "white alkali" and to the "solonchaks" of the Russians. They are often identified by the presence of white crusts of salt on the surface or by streaks of salt within the soil. They may develop from normal soils having distinctly developed profile characteristics or on undifferentiated soil material such as alluvium, in which case soil horizon and profile characteristics may be only feebly developed.

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* Millimho/cm. is the common way in which electrical conductivity is expressed. It is equivalent to mho/cm.$X10^3$ where mho/cm. is the reciprocal of the resistence measure ohm/cm.

Saline - alkali soils are soils for which the conductivity of their saturation extract is greater than 4 millimho/cm. and the exchangeable - sodium - percentage is greater than 15. As long as excess salts are present the soil's appearance and properties are generally similar to those of saline soils, but if these are leached downward, the properties of these soils may change markedly and become similar to those of nonsaline - alkali soils.

The term nonsaline - alkali soils is applied to soils for which the exchangeable - sodium - percentage is greater than 15 and the conductivity of the saturation extract is less than 4 millimho/cm. The pH values generally range between 8.5 and 10. The soils correspond to Hilgard's "black alkali" soils and in some cases to the solonetz soils of the Russians. They are formed directly from saline-alkali soils through drainage and leaching in the absence of gypsum or other sources of soluble calcium.

The investigations reported in this thesis were conducted on soils containing soluble salts and hence on those which belong to the first two categories of this classification; namely saline and saline - alkali soils.

B. Review of Information on Salinity in Manitoba Soils

The principal source of information on the distribution of saline soils in Manitoba is the maps of the Manitoba Soil Survey. These maps were made during a reconnaissance survey of the soils and cover a large portion of the agricultural area of the province. Wherever saline soils were observed in the field in the course of this survey their occurrence was recorded on the field maps and the extent of the larger areas shown by boundaries. At the time the soils were mapped in the field the degree of salinity was estimated through observations on the species and vigor of native plants and growing crops within the areas, and the results were shown by the use of symbols denoting slightly saline, saline and strongly saline soils. These maps were studied and used in the selecting of sample areas for the investigation reported in this thesis.

Quantitative analyses to determine the kind of salts present in the saline soils of the province have been few in number. Those that have been conducted have indicated that the sulphates of calcium, magnesium and to a lesser extent sodium are the chief constituents of the soluble salts in most areas, but that high concentrations of chlorides occur in some regions. This has been supported by the qualitative tests made on a large number of samples of saline soil which farmers have sent to the Soils Department of The University of Manitoba over a period of twenty-five years.

The absence of appreciable amounts of soluble carbonates in nearly all of the saline soils that have been tested and the lack of significant amounts of exchangeable sodium in the solonetzic soils of the Red River Valley, as determined by Ellis and Caldwell (8), has lead to the general conclusion that high concentrations of sodium carbonate are not common in Manitoba. This has been supported by the field observations of the Manitoba Soil Survey. In their report on the solonetzic soils of the Red River Valley, Ellis and Caldwell (8) suggested that the structure of these soils, which closely resembles the solonetz soils described by Glinka and de'Sigmond (6), has been formed through the action of magnesium rather than sodium and they suggested that solonetz soils be considered as a group which should be subdivided into sodium-solonetz and magnesium-solonetz. This is in accordance with the views subsequently expressed by other soil scientists and would explain the occurrence of large areas of soils exhibiting the characteristic structural profile of Glinka's so-called "sodium solonetz soils" but containing no appreciable amount of absorbed sodium on their exchange complex.

C. Salt Deposits and Saline Ground Waters of Manitoba

The soluble salts in the soils of Manitoba appear to have been derived mainly from the decomposition of minerals on which the soils are developed. These minerals originally came from the rock formations, which now underlie the surface deposits, and were transported to their present sites by glacial and glacio-fluvial action. Therefore a review of the evidence of salt deposits and saline waters in these rock formations is pertinent to a study of soil salinity.

Manufacture of salt by evaporation of brines issuing as springs in the area of Dawson Bay on Lake Winnipegosis, was begun around 1820 by James Monkman. These operations were visited in 1889 by J.B. Tyrrell, whose descriptions and analytical data on saline springs found scattered along the west shore of Lake Winnipegosis were published by Cole (4). Tyrrell thought that these springs arise in the porous dolomites of late Silurian or early Devonian age and that the salts originate through the leaching of numerous salt crystals which were observed to occur in these formations. Cole also reported the occurrence of saline wells in the Westbourne and Winnipeg areas and that strong flows of brine were encountered at depths of 1,225 and 1,455 feet in a deep government well drilled at Neepawa for the purpose of obtaining gas.

Wallace (27) examined some 80 saline springs in Manitoba and collected data on numerous saline wells. On the basis of this information he described the brine-containing area as being about 50 miles wide (from the Manitoba escarpment to the West shore of Lake Winnipeg) and 400 miles long (from the north end of Lake Winnipegosis to Grand Forks in North Dakota). Concerning the origin of these brines he stated (28), "The evidence points to their originating by the leaching of isolated salt crystals in the Paleozoic strata", and also that, "whenever the Dakota sandstone (Swan River formation) is tapped at any considerable depth in Manitoba a strong flow of brine is obtained". He advanced the theory that the volume of flow of saline waters originates in the Dakota sandstone but, due to the impervious shales capping this sandstone, the water which enters by the lateral seepage penetrates downward into the Devonian limestone, travels laterally through the fissures and openings which characterize these formations and reaches the surface wherever outcrops occur.

Wallace concluded that there are four salt water horizons in Manitoba: (i) in the Winnipeg sandstone; (ii) in the Upper Mottled limestone (approximately); (iii) in the gypsum zone of the Silurian (approximately); and (iv) in the Devonian strata. He believed that there is no genetic relationship between these salt brines and the gypsum deposits which occur in the rock formations. He based this assumption on the presence of a fresh water horizon between the gypsum beds and the brines and the absence of other salts in the sulphate waters of the gypsum zone.

At the Neepawa Salt Plant, now being operated by the Canadian Industries Limited, brine is being pumped out of two wells from the Silurian limestones from a depth of about 1,400 feet. This source of brine has been continuously tapped since 1933 and no appreciable change has occurred in its composition. The percentage of sodium chloride in the brine averages around 15.4 and smaller amounts of calcium chloride, sulphate and bicarbonate; magnesium, potassium and lithium chloride; and sodium bromide are also present (23).

Gypsum deposits in the rock formations of Manitoba have been reported on by Wallace (27, 28) and by Cole (5). Wallace noted that the important deposits lying at or near the surface occur in three areas: Gypsumville area; Leifur district; Dominion City, Arnaud, St. Pierre district. He advanced the theory that these gypsum deposits represent precipitation of successive layers of gypsum and anhydrite in closed or partially closed inland seas during Silurian times. Cole described the surface deposits at Gypsumville, where the rock has been quarried since 1901, as comprising an area of about 56 square miles. Gypsum layers also have been encountered in rock formations of Jurassic and Devonian age in deep wells in the western part of the province.

Examination of any data on well water analysis reveals that the ground waters over a large portion of Manitoba contain high concentrations of soluble salts (24, 16, 12). This is particularly the case in the western portion of the Red River Valley, the Westbourne-Gladstone area and the Whitewater Lake area of south-western Manitoba. The composition of these saline waters varies somewhat in different areas and at different depths within the same areas. This will be discussed in more detail in another portion of this thesis.

III. INVESTIGATIONAL PROCEDURE

A. Field Observations and Collection of Samples.

During the summer and fall of 1950 the author made a number of field trips covering, in all, most of the agricultural area of Manitoba. The purpose of this was to obtain first hand information on the intensity and distribution of halomorphism in different parts of the province, and to make a collection of samples from representative areas for subsequent laboratory investigations. Prior to this, a set of Land Classification maps of the areas which have been covered by the Manitoba Soil Survey were marked with all available information on the distribution of salinized and alkalinized soils and these were used as a guide during the field trips.

The procedure followed was to select areas of similar soil type and examine them individually. The location of the salinized soils within each area was first determined from the prepared maps. Following this, traverses were made through the area by car to facilitate observations on the general distribution of salinized soils with respect to the topography and the apparent intensity of salt concentration as indicated by its effect on native vegetation and cultivated crops. The location of areas in which the salts appeared to be most highly concentrated was noted and one or more of these was finally selected for sampling.

A four-foot auger was used to obtain the samples. At each location composite samples from four or five points within a local area were taken from the following depths (in inches):

0 to 6; 6 to 12; 12 to 24; 24 to 36; and 36 to 48. A detailed description of the sample site was recorded, with particular attention paid to: textural changes within the soil, soil moisture conditions and ground water level, and the topographical position of the site sampled. The native plants growing on and around the sample area were noted and specimens of any unfamiliar species were obtained for future identification. In some districts the samples were taken from bare spots in cultivated fields, in which case observations were made on: the condition of the surrounding crop, the type of weeds present, and the vegetation on adjacent road allowances. Photographs showing saline vegetation and salt efflorescences were taken at a number of locations.

In all, sixty-one areas were sampled in this manner. The number of samples taken from each general soil area was based on the extent of the area and the degree of salinization of the soils within it. These samples were transported to the Soils Laboratories where they were air dried and stored for subsequent studies.

B. Laboratory Investigations

1. Chemical Analysis

After the samples had become air-dry, they were ground to pass through a 2 m.m. mesh sieve. Composite samples of the borings from each sample site were prepared by mixing together 200 grams of sieved soil from each of the five sampled depths. The subsequent analyses were conducted on these composite samples rather than on the individual depth samples because the time that could be spent on analytical work was limited and the primary aim of the investigation was to obtain information on the kind of salts in these soils and not their distribution within the soil profiles, which is subject to variation with changes in soil moisture conditions. Thirty-six of these samples were analysed quantitatively for soluble salts.

The analysis was done on water extracts made from the composite samples by the following procedure:

> Equal parts of soil and water (by weight) were placed in quart sealers, agitated in a mechanical shaker for 20 minutes, and allowed to stand over night. The salt solution was then extracted by suction filtering through Buchner funnels. Pulped filter paper was used to speed filtration of the fine textured samples. The moisture content of the air-dry samples was determined by drying them at 105-108°F and this was used to calculate the exact water to soil ratio of the extracts.

These extracts were analysed for: Calcium, magnesium, sulphates, chlorides, carbonates, bicarbonates, nitrates, and total solids. The alkali cations were determined by difference and expressed as sodium. The methods used for this analysis were as follows:

<u>Calcium</u>

The calcium was precipitated as calcium oxalate and titrated against N/10 potassium permanganate. The size of the aliquots of the extracts used in the analyses was 50 c.c.

<u>Magnesium</u>

Analysis for magnesium was conducted on the filtrate from the calcium determinations by precipitation with sodium ammonium phosphate. The precipitate was dissolved in a measured quantity of N/10 sulphuric acid and this was titrated against N/10 sodium hydroxide. Methyl orange was used as the indicator.

Alkali cations (Na and K)

The milli-equivalents of alkali cations were calculated by subtracting the m.e. of calcium and magnesium from the total m.e. of the anions. In the calculation of p.p.m. the alkali cations were expressed as sodium.

Sulphates

The sulphates were determined gravimetrically by precipitation with barium chloride. The size of the aliquots used in the analysis was 25 cc.

Carbonates, Bicarbonates and Chlorides

The analysis for carbonates, bicarbonates, and chlorides was carried out on the same aliquots of the extracts by a method outlined in the United States Regional Salinity Laboratory Publication (15). First the carbonates and bicarbonates were determined by titration with .05 N sulphuric acid, using phenolphthalein and methyl orange as indicators. Then the chlorides were determined by titration with .05 N. silver nitrate, using potassium chromate as a secondary indicator.

Nitrates

The extracts were analysed for nitrates by Harper's modification of the colorimetric, phenoldisulphonic acid method. The size of the aliquots used in the analysis was 10 cc.

Total Solids

The total solids were determined by evaporation to dryness of 10 cc aliquots of the extracts at 100°C.

An estimation of the relative amounts of sulphates and chlorides in the composite samples which were not analysed quantitatively was obtained through the use of the quick tests outlined by Morgan (19).

The reaction of all the composite samples was measured with a Coleman Model 3 pH Electrometer. The measurements were done on soil pastes, using a standard glass electrode of the penetration type.

2. Conductivity Tests

Conductivity tests were carried out on the samples with two objectives in mind: (i) to obtain a graph of the conductivity of typical Manitoba saline soils plotted against their salt concentration, as ascertained by chemical analysis; (ii) to estimate the total salt concentration in the samples which were not analysed chemically. The conductivity measurements on the thirty-six composite samples which had previously been analysed, were made on the same extracts that had been used in the analysis. The tests of the other samples were conducted on saturation extracts in order to obtain closer correlation with soil solution concentrations as they exist in the field.

A RC-12c-1 model Conductivity Bridge was used for these measurements. Because of the difficulty involved in obtaining large volumes of saturation extracts and the high concentration of salts in most of the extracts to be tested, a special conductivity cell with a small volume and a high cell constant was required. This was obtained by the construction of a pipette type of cell as outlined in the United States Regional Salinity Laboratory Publication (15).*

Platinum electrodes, 0.5 cm. square, were placed approximately 0.5 cm. apart in the bulb of the cell. These were subsequently platinized by the method outlined in the Operating Manual for Type R.C. Conductivity Bridge, Industrial Instruments Inc. This was necessary to obtain sharp balance points with highly concentrated extracts, without the use of external condensers. With this cell, tests could be made on samples of less than 5 cc and sharp balance points could be obtained with concentrations of over 60,000 parts per million. The cell constant was determined by obtaining the measured resistance, in ohms, of 0.01 normal solution of KCl and multiplying this by the specific conductance of the solution, in mhos/cm., as given in the "Handbook of Chemistry and Physics." It was found to be .53.

The procedure followed in the determination of conductivity of the extracts was as follows:

The measured resistance of the extract was obtained from the conductivity bridge and was converted to specific resistance by dividing it by the cell constant. The

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* The cell was constructed by Mr. J. Cunningham, Physicist, Board of Grain Commissioners.

reciprocal of this gave the specific conductance of the solution, which was converted to the standard temperature of 25°C. by multiplying by the appropriate factor as given in the United States Regional Salinity Laboratory Publication (15).

IV. FIELD AND LABORATORY DATA AND DISCUSSION OF RESULTS

A. Field Observations and Chemical Analysis

For the purpose of this discussion the agricultural portion of Manitoba may be divided into four main physiographic areas:

1. Western Upland area.
2. (a) Souris Basin and (b) Assiniboine Delta area.
3. Agassiz Basin and Lowland area.
4. Eastern Upland area.

The location of these areas is shown on the accompanying map (in pocket), together with some subdivisions based on differences in the kind of soil parent material and the dominant soil forming processes as reflected in the vegetation. Also shown on this map are the field locations of the samples studied in the laboratory, and the location of a number of saline springs. A cross section through the underlying rock formations of Manitoba, together with a map showing the areas of surface contacts of these formations, is also included (in pocket) and will be referred to during the discussion of these physiographic areas which follows.

1. Western Upland Area

The Western Upland area of Manitoba consists of the land lying to the west of the Manitoba escarpment, excluding the river channels, river and lake terraces, and the lacustrine and delta deposits which constitute the Souris Basin and Assiniboine Delta area. Over most of this area the soils are developed on mixed boulder till containing a considerable amount of shale in some parts. Shallow deposits of lacustrine and deltaic material over the till occur within this area, notably in the valley of the Swan River between the Porcupine and Duck Mountains, the broad valley between the Duck and Riding Mountains, and the "basinal" area to the north of the Turtle Mountain.

As a consequence of climatic and vegetational differences, variations exist in the dominant soil-forming processes operative in different parts of this area. Over a large part of the northern portion and on the higher land of the Turtle Mountain and Tiger Hills in the southern portion, the climate is somewhat cooler, and the soil climate more humid than in the rest of the area, and the soils have developed under woods. Grey-black and grey-wooded soils are the dominant types, and the associated hydromorphic soils are usually peaty meadow or organic soils. In the less elevated portion of the region, the conditions under which the soils have developed are somewhat drier, due to a warmer climate, and grassland soils are the dominant types.

In the forest regions of this area, which are denoted as [1a(1)] on the accompanying map, saline soils do not commonly occur. The soluble salts which result from the weathering of the soil minerals do not accumulate in the upper portions of the profile, but are leached downward and carried away by the drainage waters. The only sample taken in this region was from a very heavy shale clay soil in the Swan River valley, south of Minitonas, where due to impeded drainage a small area of salinized and alkalinized soils occur. The soil here is developed on decomposed shale which appears to have been washed down from the north slope of the Duck Mountain. Its origin is probably in the dark grey shale of the Ashville formation in which narrow bands of bentonite have been noted to occur (18). The soil is quite similar to the Gretna clay soils which are developed on shale outwash from the escarpment in southern Manitoba, and the parent materials are probably from the same shale stratum. The results of the analysis of the soil sample (No. 36) are shown in Tables No. 1 and 2, along with the samples from other regions in the Western Upland area. The indication is that sulphates of sodium, magnesium and calcium are the dominant salts. Only a small amount of chlorides were present. The salinization of the soil appears to be due to the impermeable clay subsoil and the periodic flooding of the area by runoff and seepage water from the mountain .

The boulder till area of the aspen grove and grassland region, denoted on the map as [1a(2)], is made up of four main soil zones or sub-zones; (1) northern black-earth soils (Newdale association); (2) blackearth soils (Oxbow association); (3) dark brown-blackearth soils (Waskada association); and (4) blackearth soils of the Manitou-Clearwater prairie area (Darlingford, Manitou and Snowflake associations). These soils have been grouped together for discussion because, although there are considerable differences between the well drained members of these associations, the appearance and distribution of their hydromorphic salinized associates are quite similar.

Table No. 1

WESTERN UPLAND AREA

RESULTS OF ANALYSIS OF 1:1 EXTRACTS, EXPRESSED IN P.P.M. OF OVEN DRY SOIL.

Sample No.	Parent Material of Soil	CATIONS Ca	Mg	Na*	ANIONS SO_4	Cl	HCO_3	CO_3	NO_3	Sum of Salts	Total Solids
(a) Areas of Mixed Boulder Till											
(1) Forest Region											
36	Shale Clay	472	297	1,275	4,656	115	202	-	-	7,017	7,197
(2) Aspen Grove and Grassland Regions											
1	Mixed Boulder Till	362	269	1,852	5,307	2,948	97	-	T	10,935	12,838
2	" " "	466	1,389	2,487	11,346	183	266	-	-	16,137	18,947
3	" " "	515	1,239	1,995	8,825	989	173	-	T	13,736	15,041
4	" " "	481	1,840	598	9,235	130	336	-	-	12,620	14,153
5	" " "	472	1,295	2,061	9,168	920	183	-	-	14,099	15,510
6	" " "	443	615	3,118	9,383	312	259	-	-	14,130	14,439
7	" " "	1,848	2,409	1,896	17,765	26	153	-	-	24,097	26,469
8	" " "	460	540	1,308	5,702	72	217	-	-	8,299	9,041
11	" " "	375	502	2,531	5,804	43	256	T	T	8,523	9,526
12	Shaly Boulder Till	476	660	2,411	8,557	18	262	-	-	12,384	12,835
13	" " "	593	221	325	2,773	29	210	-	T	4,151	5,258
(b) Shallow Lacustrine Clay Deposit											
9	Lacustrine Clay	612	670	7,472	19,250	147	355	-	-	28,506	29,604
10	" " "	476	938	5,647	16,000	363	197	-	T	23,621	24,814

* Alkali cations determined by difference and expressed as sodium.

Table No. 2

WESTERN UPLAND AREA

CATION AND ANION MILLI-EQUIVALENTS, EXPRESSED AS PERCENTAGES OF THEIR RESPECTIVE TOTALS.

Sample No.	Parent Material of Soil	CATIONS			ANIONS					Total # Cations	pH
		Ca	Mg	Na*	SO_4	Cl	HCO_3	CO_3	NO_3		
(a) Areas of Mixed Boulder Till											
(1) Forest Region											
36	Shale Clay	23	23	54	94	3	3	-	-	103.44	7.05
(2) Aspen Grove and Grassland Region											
1	Mixed Boulder Till	9	16	75	57	42	1	-	-	195.08	8.60
2	" " "	9	47	44	96	2	2	-	-	245.64	8.25
3	" " "	12	48	40	86	13	1	-	-	214.36	8.60
4	" " "	12	75	13	95	2	3	-	-	201.38	8.35
5	" " "	11	48	41	87	12	1	-	-	219.72	8.60
6	" " "	11	24	65	94	4	2	-	-	208.31	8.75
7	" " "	25	53	22	99	0	1	-	-	372.96	8.40
8	" " "	19	36	45	96	2	2	-	-	124.26	7.95
11	Shaly Boulder Till	15	33	52	95	2	3	-	-	126.60	8.20
12	" " "	13	30	57	97	1	2	-	-	182.89	8.10
13	" " "	48	29	23	93	1	6	-	-	61.97	8.10
(b) Shallow Lacustrine Clay Deposit											
9	Lacustrine Clay	8	13	79	98	1	1	-	-	410.58	8.65
10	" " "	7	22	71	96	3	1	-	-	346.45	8.65

* Alkali cations determined by difference and expressed as sodium.

Total cations expressed as milli-equivalents per 1000 grams of soil.

Characteristic of this region is the occurrence of undrained depressional areas varying from small potholes and sloughs in the undulating portions to large meadows and intermittent lakes in the smoother areas. These depressional areas act as local catchbasins for runoff water and subsurface lateral seepage from the surrounding higher land. In wet springs and periods of heavy rainfall, they are flooded by water and, because of a high water table or impeded internal drainage, the percolation of this water into the soil is retarded and a large portion of it evaporates, leaving behind the soluble salts it has derived from the minerals in the soils of the surrounding area. This concentration may be supplemented in some cases by upward movement of ground water in dry seasons.

It is in this manner that most of the saline soils of this region have been formed. Their distribution therefore is of a scattered nature. In the areas where the rough topography has resulted in the formation of numerous small sloughs and potholes, the salinized soils often occur as narrow borders around these hydromorphic areas. In the portion of the region where the topography is somewhat smoother, salinized soils often occur over larger areas.

These salinized soils usually have the profile characteristics of the hydromorphic members of the soil associations in which they occur. The solum generally consists of a shallow A horizon of mucky clay loam which grades into the boulder till parent material at from 3 to 12 inches. The soils are alkaline in reaction throughout the profile and usually effervesce strongly with acid at the surface. White encrustations of salts commonly occur in patches on the surface (see Figure No. 1). Where these efflorescences are found the area is usually barren of vegetation and is surrounded by soil on which only the very salt tolerant plants, such as Distichlis (alkali grass) Salicornia (glasswort) and Suaeda (sea blite) grow. Where the areas occur in cultivated fields they appear as bare spots which were either too wet to be seeded in the spring or the seeds failed to germinate or were killed shortly after germination.

Figure No. 1. Saline soil in the Oxbow association, south of Elkhorn. (Photo by Prof. J. H. Ellis.)

Eleven composite profile samples from this region were analysed for soluble salts. The results of these analysis are given in Tables No. 1 and 2. From these results it would seem that the dominant anion in the saline soil solutions in this region is invariably the sulphate ion. Chlorides are usually present but, with three exceptions, are in very low concentrations. Carbonates or nitrates were not found in measurable quantities in any of the samples tested. Bicarbonates usually made up 1 or 2 percent of the anions, being present in amounts varying from about 100 to 350 parts per million. Some variation existed in the proportions of the cations present. Magnesium was dominant in six of the samples and the alkali cations in the other five.

The total salts present in these composite samples ranged up to 24,097 p.p.m. Higher concentrations would have been found had the various sample depths been tested individually. The reaction of the samples varied from 7.95 to 8.75.

A number of other samples from this area were tested for total salts, pH and qualitatively for sulphates and chlorides. These results are given in Table No. 3, and are in accordance with the results obtained from the samples that were analysed quantitatively.

As was stated earlier (on page 24), the general source of the soluble salts which occur in the poorly drained soils in this region is the soil minerals in the surrounding higher land. A possible exception to this is the salinized soils which occur in the long, continuous, shallow draws running south-westerly in the Newdale soil area. These draws were formed

Table No. 3

Total Salts, pH, and Relative Amounts of Sulphates and Chlorides in Supplementary Soil Samples from Mixed Boulder Till Area.

Sample No.	Total Salts*	pH	Sulphates	Chlorides
38	11,214	8.25	High	Low
37	8,127	8.25	Very High	Very Low
41	1,620	7.75	"	"
44	13,845	8.05	"	"
43	600	7.80	"	"

* Total salts expressed in p.p.m. of saturation extracts.

by the runoff waters from the south slope of the Riding Mountain and the salts in the salinized soils which are often found in these channels may have been carried in by this run-off water. More detailed work in this area is required before any definite statement can be made in this regard.

The area of shallow lacustrine clay deposit surrounding Whitewater Lake, which lies to the north of Turtle Mountain, is denoted on the map as area [1(b)]. This area was once covered by a large lake which extended from Township 3, Range 20 to Township 2, Range 24. In this lake, sediments were deposited over the glacial till. As the lake receded to the boundaries of the present intermittent Whitewater Lake, soils were developed on these lacustrine and alluvial deposits which have been designated as the Whitewater soil association. The Whitewater soils are a complex of immature soils showing varying degrees of profile development in the process of transition from hydromorphic through salinized to well drained soils.

This area acts as a catch basin for the runoff water from the Turtle Mountain. The internal drainage of the soils is very slow and large areas of strongly salinized soils were observed to occur (see Figure No. 2).

Figure No. 2. Scene showing patchy growth of vegetation due to salinization of Whitewater clay soils, east of Deloraine. (Photo by Prof. J. H. Ellis.)

Two samples from this region were analysed for the cations and anions in their water extracts and the results are given in Tables No. 1 and 2. These analyses indicate that sodium sulphate forms a large part of the soluble salts in the soil of this area. Chlorides and bicarbonates were present in small amounts. The samples did not contain any carbonates or nitrates. The cations consisted of about 70 to 80 percent "sodium" and small amounts of magnesium and calcium. The total salts ranged from about 23 to 28 thousand parts per million and the soil reaction was 8.65 with both composite samples. One other sample was tested for total salts, reaction and qualitatively for sulphates and chlorides and the results correlated closely with those of the other two samples. The sample was very high in sulphates and low in chlorides. The total salt content was 26,980 p.p.m. of the saturation extract and the reaction was 8.60.

The high concentration of salts in these impervious clay soils is easily understandable. The area is the catch-basin for surface runoff and lateral seepage from the Turtle Mountain and the ground water in the boulder till and rock formations of that area is known to be high in soluble salt content. This is shown by the following table taken from the Geological Survey Water Supply Paper for that aréa (12).

Table No. 4

Analysis of Water Samples from various Aquifers in the Turtle Mountain Area. (All figures in p.p.m.)

	Turtle Mtn. Formation	Boissevain Sandstone	Riding Mtn. Shale	Gravel	Till
Tot. Solids	1,042	1,719	2,637	1,442	2,305
Ca	143	220	71	167	181
Mg	70	85	26	81	109
Na	63	208	834	169	224
Cl	11	16	995	45	60
SO_4	306	824	471	606	927
HCO_3	459	427	606	405	345

From this information it is clear that the salinization of the Whitewater clay soils is due to the periodic surface flow and undergpound seepage of waters high in soluble salts into this area and the capillary rise and surface evaporation of water resulting from the impermeable nature of the soil. The preponderance of sulphates over chlorides in the soil samples analysed is in accordance with their proportions in the waters from the Turtle Mountain shale and Boissevain sandstone, which are the underlying rock formations of the Turtle Mountain (see chart in pocket).

2. Souris Basin and Assiniboine Delta Area

As the continental ice sheet, which at one time had covered the entire area of Manitoba, retreated toward the north-east, glacial lakes were formed by the melting waters from the ice and the drainage waters from the west and south. Enormous amounts of sediments were carried into these lakes by the drainage waters flowing into them from the west and south. These sediments were laid down as delta and lacustrine deposits and formed the parent materials on which the soils were developed after the water had receded. The sandy and medium textured lacustrine deposits of the so-called Lake Souris merge in the north-east with the sandy deltaic deposits of the western portion of Lake Agassiz and these, together with the eroded channels and river terraces of the Assiniboine River and Lake Souris outlet, comprise the area shown on the accompanying map as the Souris Basin and Assiniboine Delta area.

Table No. 5

SOURIS BASIN AND ASSINIBOINE DELTA AREA

RESULTS OF ANALYSIS OF 1:1 EXTRACTS, EXPRESSED IN P.P.M. OF OVEN DRY SOIL.

Sample No.	Parent Material of Soil	CATIONS Ca	Mg	Na*	ANIONS SO_4	Cl	HCO_3	CO_3	NO_3	Sum of Salts	Total Solids
A.	Lacustrine and Delta Deposits										
18	Silty Deltaic Material	385	296	69	2,046	43	171	-	-	3,026	3,459
B.	River and Lake Terraces										
14	Gravelly Modified Till	462	637	613	4,694	69	153	-	-	6,628	7,224
17	Shale Clay	136	105	217	892	44	284	T	-	1,690	1,753
C.	Eroded River Channels										
15	Shale Clay	481	263	886	3,766	44	280	-	-	5,720	6,042
16	Shale Clay	472	556	3,252	7,026	2,126	280	-	-	13,712	14,010

* Alkali cations determined by difference and expressed as sodium.

Table No. 6

SOURIS BASIN AND ASSINIBOINE DELTA AREA

CATION AND ANION MILLI-EQUIVALENTS, EXPRESSED AS PERCENTAGES OF THEIR RESPECTIVE TOTALS

Sample No.	Parent Material of Soil	CATIONS			ANIONS					Total # Cations	pH
		Ca	Mg	Na*	SO_4	Cl	HCO_3	CO_3	NO_3		
A.	Lacustrine and Delta Deposits										
18	Silty Deltaic Material	41	52	7	91	3	6	-	-	46.59	7.80
B.	River and Lake Terraces										
14	Gravelly Modified Till	23	51	26	96	2	2	-	-	102.14	8.25
17	Shale Clay	27	35	38	76	6	18	T	-	24.85	7.95
C.	Eroded River Channels										
15	Shale Clay	29	26	45	93	2	5	-	-	84.22	7.26
16	Shale Clay	11	22	67	70	28	2	-	-	210.70	8.00

* Alkali cations determined by difference and expressed as sodium.

Total cations expressed as milli-equivalents per 1000 grams of soil.

Table No. 7

Total Salts, pH, and Relative Amounts of Sulphates and Chlorides in Supplementary Soil Samples from Souris Basin and Assiniboine Delta Area.

Sample No.	Total Salts*	pH	SO4	Cl
A. Lacustrine and Delta Deposits				
47	1,359	8.20	Very high	Very low
45	4,875	8.15	"	"
B. River and Lake Terraces				
46	22,600	8.80	Very high	Very low
59	17,466	8.70	"	"
40	19,000	8.35	"	"

* Total salts expressed in p.p.m. of saturation extracts.

With the exception of some areas of mixed woods, the soils of this region have been developed under grassland and aspen grove vegetation and the well drained members of the soil associations exhibit blackearth profile characteristics. For the purpose of a discussion of the salinized soils, this area has been subdivided into three sections on the basis of the general parent materials of the soils. These are:

(1). Lacustrine and delta deposits
(2). River and lake terraces
(3). Eroded river channels

Considerable variations exists in the soils developed on the lacustrine and delta deposits of this area. This variation is due to differences in the texture and depth of the surface deposits, to the height at which the ground water normally occurs, and to the action of water and wind subsequent to the deposition of the materials. Over a considerable portion of this area the soils have been developed on light textured sandy deposits and, even though the water table is within a few feet of the surface in many regions, these soils are almost invariably free of high concentrations of soluble salts. The high permeability of these soils is undoubtedly an important factor contributing to this absence of salinization, but also, a study of well records reveals that the water in these sandy deposits is normally very low in soluble salts (24, 16, 12). As a good deal of seepage water enters this area from the surrounding boulder till regions, there must be a continuous movement of water in the substrata, otherwise salts would accumulate.

Only one sample was taken from the sandy soils of this region. This was from a poorly drained area in the Almasippi soil north-east of MacGregor. This area is shown as being slightly saline on the soils map, but there was only 186 p.p.m. of soluble salts in the composite profile sample so no further analysis was attempted.

Salinization has occurred over small acreages in the medium textured soils of the Souris Basin. These soils, which have been designated as the Carroll Association (10), are black-earth soils developed on very fine sandy loam to clay loam lacustrine sediments and are normally well drained, but small local areas of saline and alkalinized soils do occur. Wherever such areas were examined in the field it was found that the internal drainage was being impeded by a heavier textured substratum of heavy clay loam or silty clay lacustrine material or heavy loam boulder till. Samples were taken from three of these areas. One composite profile sample was analysed for soluble salts and the other two were tested for total salt content, pH, and type of salts present. The results of these analyses are given in Tables No. 5, 6 and 7. These results, combined with the field observations, indicate that although salinization has occurred in some areas of the Carroll soils, the concentration of soluble salts is low compared with that found in the saline soils of the surrounding boulder till area. The salts seemed to consist mainly of calcium and magnesium sulphate. The pH of the soils ranged from 7.80 to 8.20 and the total salt content from about 1,000 to 5,000 p.p.m.

The soluble salts of this area are probably local in origin and accumulate only in those depressional areas where the internal drainage is impeded by a heavier textured sub-soil. The well records that were examined indicate that, although water is usually difficult to obtain in this area because of the deep lacustrine clay substratum, wherever it is found it is of low salt content.

On the terraces which occur in the broad valleys of the Souris and Assiniboine rivers, in the wide channel of the Lake Souris outlet and along the north side of the Tiger and Pembina Hills, the soils have been developed on an assortment of materials. These terraces were originally cut in the mixed boulder till, and stony water-worked till forms the parent materials of the soils in some places. Elsewhere, the soils were developed on thin deposits of overwash gravel and sand and outwash shale clay which were laid down over the water-worked till. The topography of these terraces is usually flat to depressional and salinized soils are found in the lower positions where the internal drainage is impeded by a change in the textural profile.

Five samples were taken from widely scattered sites on these terraces. Samples from the Heaslip soil of the Lake Souris outlet (No. 14) and Oliver soil of the lake terrace north of the Tiger Hills (No. 17) were analysed for soluble salts and the results are given in Tables No. 5 and 6. Samples from the Hecla soil of the lake terrace (No. 46) and from the stony phase Oxbow (No. 59) and Lenore soils (No. 40) of the Assiniboine river terrace were tested for total salts, pH and qualitatively for sulphates and chlorides. These results are shown in Table No. 7.

As might be expected, these samples showed a wide variation in their total salt content, but similarity does appear in the kind of salts present. In each of the two samples analysed quantitatively, the anions were found to be largely sulphates and this correlated with the qualitative tests of the other samples. Calcium, magnesium and alkali cations were all present in substantial amounts in the Oliver and Heaslip samples. Trace amounts of carbonates were found in the samples of the Oliver and Oxbow soils, while all soils gave negative tests for nitrates.

These river and lake terraces are somewhat depressed in relation to the surrounding lands and therefore receive the runoff waters from them, so that in areas where the internal drainage is impeded by a heavy textured or impervious substrata, the accumulation of excessive amounts of soluble salts is likely to occur. This accumulation has been so severe in some places, as was indicated by the samples analysed, that extensive tracts of land are of very little agricultural value.

Subsequent to the formation of the river terraces dealt with above, deep river channels were cut through the boulder till and into the underlying shale. In the central and western channels of the Souris River south of Melita and in the broad valley of the Lake Souris outlet, soils have been developed on clay deposits from weathered shale. These soils are highly impervious to water and, because of their low position, are subject to swamping. Consequently they have been salinized or alkalinized throughout their extent. On these areas the native vegetation consists almost entirely of salt tolerant species of plants and the land is useful only for grazing purposes (See Figure No. 3).

Two samples were taken to represent these soils. The first (No. 15) was obtained from the Chesterfield soil in the central blind channel of the Souris river; the second (No. 16) was taken in the Lake Souris outlet at the west end of Bone Lake. At each sample site an impervious clay pan was encountered at

Figure No. 3. View of central blind channel of the Souris River, showing native vegetation on Chesterfield salinized and alkalinized clay soil. (Photo by Prof. J. H. Ellis.)

about 40 inches below the surface. The results of the analysis of these samples are given in Tables No. 5 and 6. From these results it would appear that although the dominant salts in both cases are the sulphates of sodium, magnesium and calcium, a high concentration of sodium chloride is present in the soils surrounding Bone Lake. This difference in the kind of salts present in these two similar soils is a reflection of the difference in their drainage conditions, particularly of the very sluggish movement of water in the valley which formed the outlet of glacial Lake Souris. The average fall here is only about one foot per mile (11) and there is no perennial stream draining this valley. Three more-or-less stagnant lakes, which receive their water from surface runoff from the surrounding areas, occur and in dry seasons the level of these lakes is lowered by evaporation and extensive areas of saline flats appear. These conditions are ideal for the accumulation of even the most soluble salts and afford an explanation for the high concentration of chlorides found in the sample from this area.

3. Agassiz Basin and Lowland Area

The area commonly referred to as the Manitoba Lowlands is the broad extent of land between the Manitoba Escarpment on the west and the Eastern Upland area of Precambrian rock outcrop. This is the area that formed the basin of glacial Lake Agassiz during the recession of the continental ice sheet. The surface deposits on which the soils have been developed vary considerably and for this reason the area has been divided into a number of sections as shown on the accompanying map. These are:

(i) West Lake Section
(ii) Interlake Section
(iii) Transitional Section
(iv) Red River Plain
(v) South-East Lowland Section

(i) West Lake Section

The parent material of the soils within the Agassiz Basin in the areas west of lakes Winnipegosis and Manitoba consists mainly of high-lime boulder till which was subjected to severe wave action in the shallow waters of Lake Agassiz and is consequently somewhat modified and very stony. This boulder till was deposited by the continental ice sheet before it reached the surface contact areas of the Cretaceous shales and therefore consists mainly of material derived from the Devonian, Silurian and Ordovician limestone formations. (See chart showing surface contacts of rock formations). The reworking of this till by the waters of Lake Agassiz resulted in the ridge and swail topography which is characteristic of this and the Interlake area. Shallow deposits of lacustrine sediments are often found to cover the till in the depressional areas. The high lime content of these parent materials has resulted in the soils of this area being generally of the rendzina type. Adjacent to the Manitoba escarpment the boulder till is often covered by deltaic and lacustrine deposits which were carried in by the streams from the higher land to the west and in many areas alluvial material has been superimposed over these deposits in more recent times.

In the northern portion of this area, where the climate is somewhat cooler, the soils have been developed under woods and some degradation has occurred. In this region, which is denoted as [3A(1)] on the map, the well drained soils are degraded rendzinas and their poorly drained associates are mainly organic or peaty meadow soils. Saline soils are not of general occurrence here, because soluble salts do not tend to accumulate in the upper horizons of the soils developed under these conditions. In the portion of this region

Table No. 8

AGASSIZ BASIN AND LOWLAND AREA

RESULTS OF ANALYSIS OF 1:1 EXTRACTS, EXPRESSED IN P.P.M. OF OVEN DRY SOIL.

Sample No.	Parent Material of Soil	CATIONS			ANIONS					Sum of Salts	Total Solids
		Ca	Mg	Na*	SO_4	Cl	HCO_3	CO_3	NO_3		
A. WEST LAKE SECTION											
(1) Forest Region											
21	Lacustrine Sediments	1,424	857	12,604	3,582	21,535	519	-	-	40,521	42,673
(2) Aspen Grove and Grassland Region											
19	Lacustrine Sediments	423	623	1,694	5,005	1,345	244	-	-	9,334	9,786
20	Alluvium	668	1,840	3,561	8,302	5,739	311	-	-	20,421	21,792
22	High-Lime Mod. Till	124	284	1,324	742	2,439	181	-	T	5,094	5,051
23	High-Lime Mod. Till	286	201	78	1,490	26	151	-	-	2,232	2,212
B. INTERLAKE SECTION											
(1) Forest Region											
24	Lacustrine Sediments	143	212	147	1,086	128	290	-	-	2,125	2,232
(2) Aspen Grove and Grassland Region											
25	High-Lime Mod. Till	597	1,035	1,378	4,689	2,620	214	-	-	10,533	11,449
26	High-Lime Mod. Till	510	1,028	4,179	8,505	3,973	172	-	-	18,367	20,604
C. TRANSITIONAL SECTION											
27	Lacustrine Clay	1,124	834	2,733	419	8,290	85	-	-	13,489	15,707
29	Lacustrine Clay	285	254	575	1,604	807	266	-	-	3,791	3,854
30	Lacustrine Clay	609	850	615	2,911	1,968	125	-	-	7,095	8,344
31	Lacustrine Clay	678	1,278	1,742	4,885	3,915	171	-	T	12,669	14,396
D. RED RIVER PLAIN											
(1) Central Clay Basin											
32	Lacustrine Clay	453	949	500	5,537	49	355	-	-	7,843	9,510
33	Lacustrine Clay	491	391	88	2,713	35	156	-	T	4,011	4,271
(2) Clay Outwash from Cretaceous Shales											
28	Shale Clay	354	334	1,468	3,063	1,498	187	-	-	6,904	7,350
(3) Lacustrine, Delta and Recent Alluvial Deposits											
34	Silty Deltaic Deposit	202	160	55	429	451	244	-	-	1,541	1,755
35	Sandy Deltaic Deposit	626	877	494	3,393	1,865	107	-	T	7,362	8,204

* Alkali cations determined by difference and expressed as sodium.

Table No. 9

AGASSIZ BASIN AND LOWLAND AREA

CATION AND ANION MILLI-EQUIVALENTS, EXPRESSED AS PERCENTAGES OF THEIR RESPECTIVE TOTALS.

Sample No.	Parent Material of Soil	CATIONS Ca	Mg	Na*	ANIONS SO_4	Cl	HCO_3	CO_3	NO_3	Total # Cations	pH
A. WEST LAKE SECTION											
(1) Forest Region											
21	Lacustrine Sediments	10	10	80	11	88	1	-	-	689.28	7.05
(2) Aspen Grove and Grassland Region											
19	Lacustrine Sediments	14	35	51	72	26	2	-	-	146.05	8.25
20	Alluvium	10	44	46	51	47	2	-	-	339.54	7.85
22	High-Lime Modified Till	7	27	66	18	79	3	-	T	87.11	7.95
23	High-Lime Modified Till	42	48	10	91	2	7	-	-	34.22	8.00
B. INTERLAKE SECTION											
(1) Forest Region											
34	Lacustrine Sediments	23	56	21	73	12	15	-	-	30.96	8.35
(2) Aspen Grove and Grassland Region											
25	High-Lime Modified Till	17	49	34	56	42	2	-	-	174.90	8.00
26	High-Lime Modified Till	9	29	62	61	35	4	-	-	291.73	8.55
C. TRANSITIONAL SECTION											
27	Lacustrine Clay	23	28	49	3	96	1	-	-	243.63	7.75
29	" " "	24	35	41	55	38	7	-	-	60.47	7.85
30	" " "	26	52	23	51	47	2	-	-	118.07	7.95
31	" " "	16	49	35	47	51	1	-	T	214.74	8.05
D. RED RIVER PLAIN											
(1) Central Clay Basin											
32	Lacustrine Clay	19	64	17	94	1	5	-	-	122.43	7.75
33	Lacustrine Clay	41	53	6	93	2	4	-	T	60.51	7.90
(2) Clay Outwash from Cretaceous Shales											
28	Shale Clay	16	25	59	58	39	3	-	-	109.02	7.85
(3) Lacustrine, Delta, and Recent Alluvial Deposits											
34	Silty Deltaic Deposit	39	51	9	35	50	15	-	-	25.63	7.80
35	Sandy Deltaic Deposit	25	58	17	57	42	1	-	T	124.90	8.10

* Alkali cations determined by difference and expressed as sodium.
# Total cations expressed as milli-equivalents per 1000 grams of soil.

Table No. 10

Total Salts, pH, and Relative Amounts of Sulphates and Chlorides in Supplementary Soil Samples from Agassiz Basin and Lowland Area.

Sample No.	Total Salts*	pH	Sulphates	Chlorides
C. Transitional Section				
51	8,400	7.85	High	Low
52	1,570	7.80	Very high	Very low
D. Red River Plain				
(1) Central Clay Basin				
53	1,944	7.55	Very high	Very low
54	890	7.70	High	Low
55	856	7.95	High	Low
(2) Clay Outwash from Cretaceous Shales				
50	5,184	7.80	Very high	Very low
(3) Lacustrine, Delta and Recent Alluvial Deposits				
56	422	7.55	High	Low
57	796	8.10	Very high	Very low

* Total salts expressed in p.p.m. of saturation extracts.

adjacent to Lake Winnipegosis and Swan Lake numerous small areas of very strongly salinized soils do occur as a result of saline springs. These springs, which originate in the Devonian limestone underlying the till, are thought by Wallace (28) to have obtained their high salt content through the leaching of isolated salt crystals in these strata.

The land is generally flat or gently sloping towards the lake in these areas and is continually being swamped by the salty water issuing from the springs. The soil is usually bare of vegetation except for a patchy growth of Salicornia sp. and white incrustations of salts are often found around the edges of the areas (see Figure No. 4).

The location of a number of these saline springs is shown on the accompanying map (in pocket). These locations were obtained from Cole's publication (14) and represent only a few of the springs which are known to occur. A soil sample was taken from the land surrounding one of these springs on the west shore of Dawson Bay at the point where the Red Deer River enters the lake. This is the general area in which salt manufacture from the water of these springs has been conducted periodically since 1820. Figure No. 5 shows brine bubbling from a pipe which had been sunk 30 feet into the ground at the site of one of these springs. Recovery of sodium chloride from this brine by evaporation in open vats had continued until recent years.

Figure No. 4. View of saline spring area on the shore of Dawson Bay, Lake Winnipegosis, showing sparse growth of Salicornia spp. and salt incrustations.

Figure No. 5. Salt brine flowing from a pipe sunk at the site of a saline spring in the Dawson Bay area.

The results of the analysis of the soil sample (No. 21) are given in Tables No. 8 and 9 and indicate that the principal salt here is sodium chloride with minor amounts of calcium and magnesium sulphates and bicarbonates. These results are in accordance with the results of the analysis of brines issuing from the saline springs in this area as reported by Cole (4). The salinization of these soils is of little agricultural significance because even the non-saline soils in this area are sub-marginal due to stoniness and low fertility.

Saline soils are known to occur over an extensive tract of land in The Pas area between the Carrot and the Pasquia Rivers. The author was not able to visit this area but Ellis et al (9) report that bare spots up to an acre in size are common here.

A set of depth samples taken from one of these areas showed a concentration of over 70,000 p.p.m. of total salts in the surface six inches. The concentration decreased with depth. Both sulphates and chlorides were found to occur in high concentrations and nitrates were also present. This area is subject to periodic flooding by overflow waters from the rivers and it would appear that the salts are being carried in by these waters and accumulating in the soil as a result of the poor drainage of the area. No indication of the source of the nitrates is given in the report.

In the southern portion of the West Lake section, where the climate is somewhat warmer, the better drained soils are rendzinas and usually effervesce with acid at the surface. In this region, denoted as [3A(2)] on the map, the poorly drained soils are often found to be salinized to some degree; this is particularly true in the area bordering the south shore of Lake Dauphin where shallow deposits of silty lacustrine material cover the heavier textured boulder till, and in the Big Grass Marsh area north of Gladstone. Here runoff waters from the Riding Mountain are ponded and the salts carried in by these waters accumulate through evaporation. Saline springs occur in the Winnipegosis area and cause local areas of strongly salinized soils.

Four sets of samples were taken in this region: No. 23 from the high lime boulder till soil in the Big Grass Marsh area; No. 20 from recent alluvial soil north-east of

Dauphin; No. 19 from a soil developed on lacustrine sediments north of Ochre River; and No. 22 from a saline spring area south of the town of Winnipegosis. The composite profile samples from all these locations were analysed for soluble salts and the results of the analysis are given in Tables No. 8 and 9. From these results it appears that the saline soils bordering the south edge of Lake Dauphin are high in both sulphate and chloride salts, while the salts in the boulder till soil of the Big Grass marsh area are largely sulphates. The sample from the saline spring area at Winnipegosis showed about the same high proportion of chlorides to sulphates as was found in the soil from a similar area on the shore of Dawson Bay. None of the samples contained measurable amounts of carbonates. A trace of nitrates was found in the Winnipegosis sample.

The water obtained from the boulder till in the Dauphin district is commonly high in soluble salts. This is shown in Table No. 11, which gives the analysis of a number of well water samples from this area obtained from the records of the Department of Health and Public Welfare.*

These analyses show that the ground water in this area is high in sulphates and chlorides. In the low lying land bordering Lake Dauphin this ground water is usually very near the surface and the accumulation of soluble salts in these

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* Courtesy of Mr. W.M. Ward, Chief Chemist, Manitoba Department of Health and Public Welfare.

Table No. 11

Analysis of Well Water Samples from Dauphin Area. (All figures in p.p.m.)

Location	Depth of Well	SO4	Cl	Ca	Mg	Total Solids
1 mile S.E. of Dauphin	12 Feet	662	270	91	95	2010
12-28-19	28 "	812	317	89	69	2030
29-28-19	20 "	2580	165	470	406	5250
Sifton	53 "	346	232	143	140	2250
Dauphin Creamery	20 "	164	150	212	68	1190
Ste. Rose		726	1400	157	53	3690

soils can occur through the capillary rise and evaporation of this water. An additional source of salts is the runoff water from the Riding Mountain which is carried into this area by numerous small rivers flowing from the mountains into Lake Dauphin. During the spring thaw these rivers often overflow their banks and flood the surrounding land. In the area where the internal drainage is slow due to a heavy textured subsoil, this water does not percolate through the soil but evaporates leaving behind its soluble salts.

The Big Grass Marsh area north of Gladstone is the catch basin for a large portion of the runoff water from the west slope of the Riding Mountain . This water has been continually ponded here by the higher land bordering Lake Manitoba and the soils in this area are largely peaty meadow soils. In recent times a number of open ditches have been installed here and the water table has been lowered. In areas where the peat was subsequently burnt off, white incrustations of lime carbonate and soluble salts cover the surface. The low chloride content of the sample from this area, as compared with those from the Dauphin area, might be due to this improved drainage. No well records are available for the area.

(ii) Interlake Section

The surface deposits in the area between the lower portion of Lake Winnipeg and Lake Manitoba consist mainly of a thin depth of highly calcareous, lake-washed boulder till. In some areas the Paleozoic limestones outcrop at the surface, while in others only a few feet of till cover the bedrock. The ridge and swail topography which is characteristic of this land was formed as a result of wave action during the time when glacial Lake Agassiz extended over this entire area and shallow deposits of lacustrine sediments are often found in the depressional areas. A narrow strip of heavy lacustrine deposits occurs along the west side of Lake Winnipeg, below the 850 foot contour, as far north as the Icelandic River and extends along the banks of this river to its head.

As in the West Lake Section, this section can be divided into two regions on the basis of the dominant soil forming processes operative in these regions. This division is shown on the accompanying map. In the northern portion, [3B(1)], the soils have been developed under woods and degradation has occurred in the well drained sites. While in the southern portion, [3B(2)], the native vegetation is tall-prairie-grasses and aspen-groves and the well drained soils are rendzinas.

As was found in the other areas where the soils were developed under woods, salts do not generally accumulate in the soils in the northern portion of this area. The area has not been covered by the Manitoba Soil Survey and therefore detailed information is not available, but an extensive field trip was made through the region in the course of this investigation and, with the exception of the Gypsumville district, no large tracts of salinized soils were observed. A sample (No. 49) taken from a meadow soil at Arborg at a site where a high soluble salt concentration might be expected to occur, gave only 732 p.p.m. of total salts on analysis. Qualitative tests on this sample showed that chlorides were the dominant salts and a trace of carbonates was present.

At Gypsumville, where an extensive surface deposit of gypsum and anhydrite covers about 56 square miles, an area of soils developed on lacustrine deposits is being farmed. At several places in this area the soils in the slightly depressed positions were observed to be more or less salinized. A sample (No. 24) was taken from one of these areas and the results of the analysis are given in Tables No. 8 and 9. These results indicate that the dominant salts in this soil are sulphates of calcium and magnesium. The reason for the accumulation of these salts is undoubtedly the capillary rise of ground water which is high in sulphates due to the gypsum deposits of this region.

In the aspen-grove and grassland region of the Interlake area, denoted as [3B(2)] on the map, the well drained soils are rendzinas and the poorly drained soils in the depressional areas are often slightly salinized. Saline soils are particularly common along the east shore of Lake Manitoba where the topography is flat and the ground water close to the surface. Samples of the high lime boulder till soils (No.'s 25 and 26) were taken from two sites in this region and the results of their analysis are given in Tables No. 8 and 9. These results indicate that the salinized soils in this region are high in both sulphates and chlorides. Some variation exists in the proportion of the cations in these samples; magnesium being dominant in one and "sodium" in the other. A corresponding difference in the pH of the soils was found; the one which was high in alkali cations has a more alkaline reaction than the other. Carbonates and nitrates were absent in both samples.

The nature of the occurrence of salinized soils in this region indicates that the salts originate from the weathering of the soil minerals of the surrounding higher land. The parent material of these soils is boulder till derived from the Devonian, Silurian and Ordovician limestone formations. Numerous layers of gypsum and anhydrite are known to occur in these formations (18, 1, 2) as well as salt water horizons. Therefore it is not surprising if the soils developed on this material should be salinized in areas where the internal drainage is impeded by an impervious subsoil or high water table.

(iii) Transitional Section

North of the Assiniboine River the heavy clay deposits of the Red River Plain form a shallow covering over the high lime boulder till of the Interlake and West Lake areas. This is a transitional belt between these two types of surface deposits and is distinguished from the main portion of the Red River Plain in this study because it receives drainage waters from the north as well as from the west and south. In parts of this area, particularly in the district known as the Portage Plains, a shallow depth of lighter textured lacustrine and deltaic materials has been deposited over the heavy clay and the soil developed on them. These soils are highly fertile and are usually free of salinization because of their good internal drainage, but over most of the area the soils are developed on the heavy clay deposits and salinization is very common in the depressional areas.

The topography of this area is generally flat with some micro-relief. Because of the very slow internal drainage, the soils in the low lying areas are frequently covered with water for long periods in the spring and after heavy rains. A large volume of the water does not percolate into the soil but evaporates from the surface leaving behind its soluble salts. This accumulation of soluble salts in the slightly depressed portion of the land causes the characteristic unevenness of the crops in this area. This is especially noticeable in drier seasons when the salts are concentrated near the surface through the high capillary rise of ground water in these clay soils.

Samples were taken from six locations in this section. These sample sites were selected to be representative of the most saline proportions of the section and four of them were analysed for soluble salts (No.'s 27, 29, 30 and 31). The other two samples (No.'s 51 and 52) were tested for total salts, pH, and type of salts. The results of these analyses are given in Tables No. 8, 9 and 10.

From the analyses of these samples it would appear that the saline soils in this area are high in both sulphates and chlorides. A particularly high concentration of chlorides was found in the sample from the Westbourne area (No. 27), in which they made up 96 per cent of the total anions. Calcium, magnesium and alkali cations were found in high concentrations in all the samples. Trace amounts of carbonates were present in two samples and one gave a slight positive test for nitrates. The total salt content varied from about 1,500 to 15,700 p.p.m. The pH determinations indicated that the saline soils in this area are not as alkaline in reaction as those in the western part of the province.

The high salt content of the ground water in this area is shown by the analysis of well water samples from numerous wells, given in Table No. 12. These analyses were obtained from the records of the Department of Health and Public Welfare.*

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* Courtesy of Mr. W.M. Ward, Chief Chemist.

Table No. 12

Analyses of Well Water Samples from Northern Portion of Red River Plain. (All figures in p.p.m.)

Location	Depth of Well	SO4	Cl	Ca	Mg	Total Solids
Lockport	200 feet	356	311	116	135	1,590
Selkirk	250 "	198	398	87	88	1,380
Old Kildonan	65 "	194	254	86	71	1,140
St. Charles	145 "	952	1050	296	130	3,960
St. Vital	60 "	1510	450	746	232	4,040
Transcona	72 "	616	165	140	129	1,550
Rosser	39 "	86	13	74	78	720
N.W. 36-11-8		2100	580	800	920	11,400
Newton		1310	1140	430	179	4,700

Although these wells are all deep and the water is often obtained from strata below the clay on which the soil is developed, the presence of high concentrations of chlorides and sulphates in this ground water indicates that the water entering this area is commonly saline. This water is derived mainly from the high-lime boulder till deposits and the limestone rock formations of the Interlake and West Lake areas. This may be the reason for the difference between the kind of salts in the saline soils of this area and of the clay basin area south of the Assiniboine River.

(iv) Red River Plain

The area of Manitoba commonly referred to as the Red River Valley or Plain is the broad level plain east of the Manitoba Escarpment on which blackearth soils are developed on the clay, silt and sand deposits of glacial Lake Agassiz. The heavy clay soils of the Red River Association cover the major portion of this region and the area which they occupy is denoted on the map as [3D(1)]. The soils on a narrow strip of land adjacent to the escarpment are developed on clay outwash from the Cretaceous shales of the Pembina Hills, and this area has been separated on the map and designated [3D(2)]. East of these shale clay soils there is a broad extent of land on which the lacustrine clay deposits of Lake Agassiz are covered by a variable depth of coarser textured lacustrine, delta and recent alluvial deposits which were carried in from the west subsequent to the deposition of the clay. This area is denoted as [3D(3)].

Over a large portion of the clay basin area in the Red River Plain, the soils were developed under conditions of poor drainage and accumulation of soluble salts in the surface horizons was bound to occur. However, since the days of early settlement the drainage of these soils has been greatly improved through the installation of an extensive system of artificial drains. As a consequence of this improvement in drainage, the soils over a large part of the area have become desalinized, alkalinized, and in some places solodized. However, slightly salinized hydromorphic soils still occur in the depressional areas. The nature of the alkalinized and solodized soils has been investigated by Ellis and Caldwell (8), Caldwell (3), and Poyser (21) and they have found that the dominant cation on the exchange complex is magnesium rather than sodium.

Five areas of salinized soils at widely scattered points in this section were sampled during the investigation being reported in this thesis. Two of these samples (No.'s 32 and 33) were analysed for soluble salts and the other three (No.'s 53, 54 and 55) were tested qualitatively. The results indicate that the main constituents of the saline soils in this area are sulphates of magnesium and calcium. Chlorides were not found in high concentrations in any of the samples. The alkali cations were low in both analysed samples and the relatively low pH of the other samples indicated a similar condition. This is in agreement with the findings of the previous investigations on the alkalinized soils of this area. A trace amount of carbonates was present in two of the samples. The highest concentration of soluble salts in the composite profile samples tested was 7,843 p.p.m.

The low concentration of chlorides in this area as compared with the salinized soils in the region north of the Assiniboine River may be due to the improved drainage in this area which allows the very soluble chlorides to be leached out of these soils. Another possibility is the difference in the source of the drainage waters which flow into these areas. More detailed study is necessary before any definite conclusions can be reached in this regard.

An examination of well water records for this area shows that the ground water is invariably quite high in soluble salt content. This is often due to the wells being bored into the underlying Jurassic shales which contain numerous layers of gypsum and anhydrite and salt water horizons (27, 28). This high salt content of the ground water is a source of great inconvenience to the farmers of this area, because it is usually impossible for them to obtain domestic supplies of good quality water. Saline ground water has also created a problem in the past by attacking the concrete aqueduct of the Greater Winnipeg Water District in an area east of the city of Winnipeg. In order to prevent the sulphates in the ground water from causing a rapid deterioration of this aqueduct, it was necessary to install sub-surface drainage along the pipeline to lower the salt content of the ground water in its vicinity.

Most of the soils which have been developed on the clay outwash from the Cretaceous shales of the escarpment are salinized or alkalinized, depending on their drainage conditions. These soils which were mapped as the Gretna and Benton associations (11) contain a high percentage of bentonite clay, derived from the bentonite layers in the shale formations, and are therefore very impervious to water. As they occur in an area which is continually subject to seepage water from the adjacent higher land, the accumulation of salts in the depressional areas is easily understandable. Two samples were taken from these soils. A sample from the Gretna clay (No. 28) was analysed for soluble salts and the results, given in Tables No. 8 and 9, indicate that the salts in this soil are high in both sulphates and chlorides. "Sodium" was the dominant cation; calcium and magnesium were present in relatively small amounts.

The results of the tests conducted on the other sample (No. 50) are given in Table No. 10 and indicate a somewhat lower content of chlorides than was found in the analysed sample. Neither samples contained carbonates nor nitrates.

The high salt content of the drainage waters from the Pembina Hills is further shown by the salinity of the water in shallow wells and dugouts in this area. Department of Health analysis of well water and water from the Prairie Farm Rehabilitation dam at Morden show appreciable amounts of both sulphates and chlorides. The sulphates are usually in much higher concentrations. This water comes from seepage out of the acid shales of the Morden member of the Vermilion River formation and is often very acid in reaction.

In the area where the soils are developed on lacustrine, delta and recent alluvial deposits over the Red River clay, salinized soils are found where the internal drainage is impeded by a heavy textured subsoil. This commonly occurs in the Schoenwiese Association and in the heavy textured phase of the Emerson Association (7). In the rest of the area the soils are generally well drained and soluble salts have not accumulated in the upper horizons of the profiles.

Four locations were sampled in this area; three samples were taken from the Emerson soil and one from the Schoenwiese. The Schoenwiese sample (No. 35) and one of the Emerson samples (No. 34) were analysed for soluble salts and the results are given in Tables No. 8 and 9. Here again the soils were found to contain high concentrations of both sulphates and chlorides. The cations were dominantly magnesium and calcium; the alkali cations were present in relatively small amounts. The tests on the other two samples of Emerson soil (No.'s 56 and 57) showed only low concentrations of salts which appeared to be mainly sulphates.

These analyses, combined with observations made in the field, indicate that wherever conditions of impeded internal drainage exist in these sandy and silty deltaic deposits both sulphates and chloride salts will accumulate in the upper horizons of the soils. The possibility exists that the ground water in this area is influenced by saline flowing wells which are known to occur particularly in the Emerson district. The well records for the area show high chlorides as well as sulphates, and a sharp increase in the chloride content of the Red River at Emerson, as compared with the chloride content of the river further south, is reported by Wallace (29).

(v) South-East Lowland Section

The soils in this area have been generally developed under forest vegetation as a result of a somewhat cooler and more humid climate than exists in the lower portions of the Agassiz Basin and, as was found under similar conditions in other areas, the poorly drained soils are not often salinized. Artesian water which occurs in this area, particularly in the Sprague-Piney district, was tested for soluble salts and found to be free of significant concentrations. This artesian water comes from the Winnipeg sandstone which underlies the surface deposits in most of this region.

4. Eastern Upland Area.

The Eastern Upland area of Manitoba represents a portion of the Laurentian Shield and is characterized by large areas of granitoid rock outcrop. Where glacial material and lacustrine sediments occur over the rocks, podzolic soils have been developed under an acid leaching process. These soils are the result of a more humid climate than that which is responsible for the formation of grey-wooded soils in other parts of the province, and the mature soils lack the lime carbonate horizon which occurs in the lower part of the grey-wooded soil profiles. Therefore it is reasonable to expect that saline soils will not be found under these conditions.

B. <u>Conductivity Measurements:</u>

The results of the conductivity tests made on the 1:1 extracts which had previously been chemically analysed for soluble salts, are shown in Table No. 13. In expressing these results use is made of the method advanced by Whittles and Schofield-Palmer (30). In an attempt to gain uniformity in the method of expressing electrical conductivity of saline soils they suggested that the term pC be used for the common co-logarithm of the specific conductivity of extracts or suspensions of soils. They also proposed that the term pS be used for the common co-logarithm of the salt concentration expressed as grams weight per milliliter or p.p.m. x 10^{-6}.* This, when converted into a gram-equivalent concentration as gram-equivalents per liter, produces a third term, pN, for the common co-logarithm of the normality as usually understood. It was found that this method of expression has the distinct advantage over the usual methods in that by using these terms the relationship between the conductivity of the extracts and their total salt content,

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* The following is an example of the calculation of pC from the specific conductivity of a solution. Assume that the solution has a conductivity of 30 mho/cm. x10^{-5}. Then its specific conductivity is .00030 mho/cm. or 3 x 10^{-4} mho/cm. and the pC or common co-logarithm of the specific conductivity is calculated as follows:

$$3 \times 10^{-4} = 10^{+.48} \times 10^{-4}$$
$$= 10^{-3.52}$$
$$\therefore pC = 3.52$$

The pS values are similarily obtained from the salt concentration in p.p.m. x 10^{-6}. It will be noted that these calculations are analogous with the calculation of pH values from the hydrogen ion concentration in mols. per liter.

Table No. 13

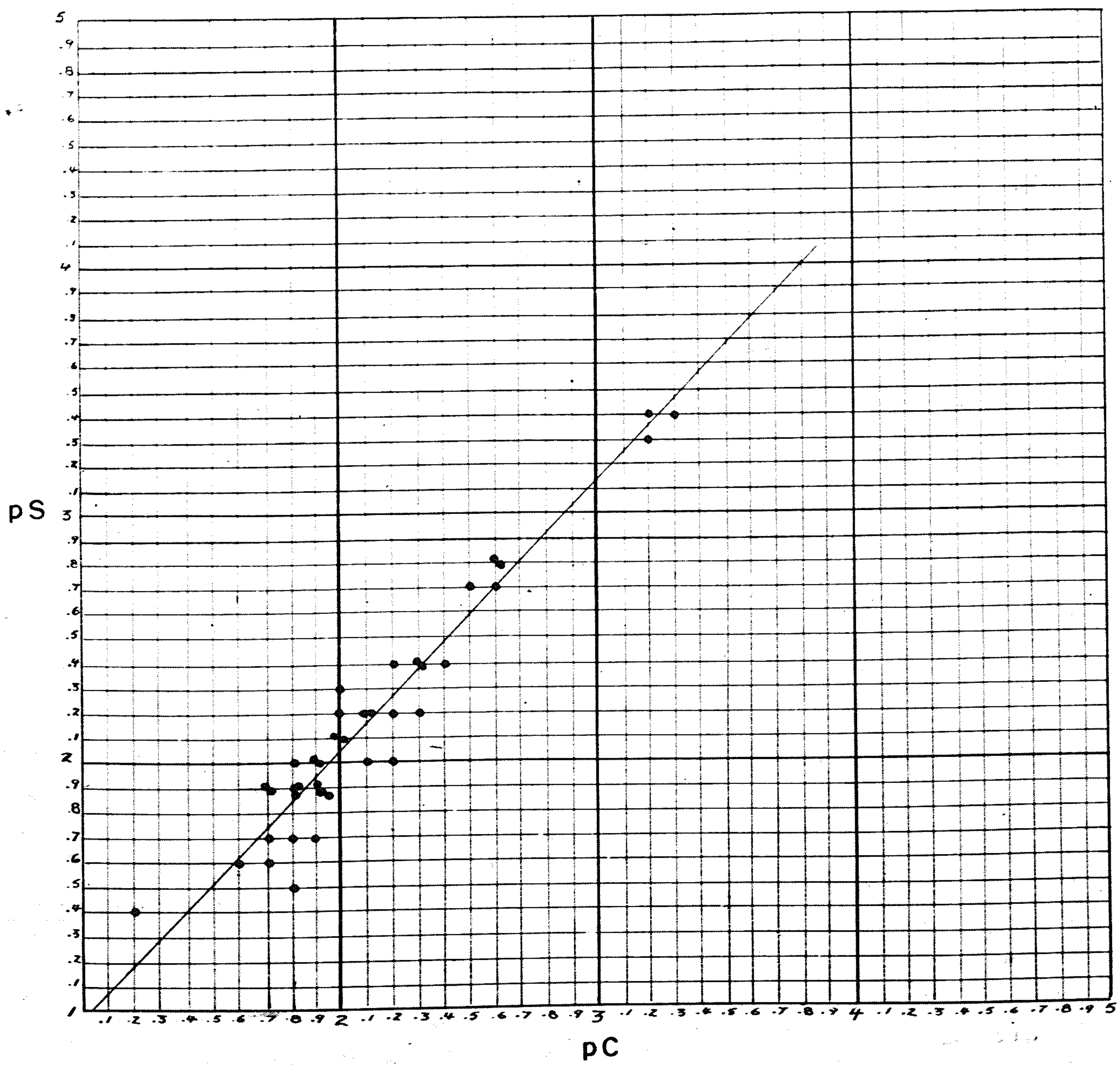
RELATIONSHIP BETWEEN CONCENTRATION OF SALTS AND CONDUCTIVITY OF 1:1 EXTRACTS, EXPRESSED BY MEANS OF pS AND pC VALUES.

Sample No.	Conductivity in Millimho's/cm @ 25° C	pC	Concentration in p.p.m. of Soil	pS
1	17.9	1.76	10,935	1.96
2	14.5	1.84	16,137	1.72
3	15.5	1.81	13,736	1.86
4	12.0	1.92	12,620	1.90
5	13.6	1.87	14,099	1.85
6	15.9	1.80	14,130	1.85
7	19.6	1.71	24,097	1.62
8	8.2	2.09	8,299	2.04
9	14.5	1.84	28,506	1.53
10	28.4	1.55	23,621	1.63
11	10.0	2.00	8,523	2.07
12	13.6	1.87	12,384	1.91
13	5.8	2.24	4,151	2.38
14	7.1	2.15	6,628	2.18
15	7.8	2.11	5,720	2.24
16	19.3	1.71	13,712	1.86
17	2.5	2.60	1,690	2.77
18	4.0	2.40	3,026	2.42
19	13.6	1.87	9,334	2.03
20	13.1	1.88	20,421	1.69
21	60.0	1.22	40,521	1.39
22	10.4	1.98	5,094	2.29
23	2.8	2.55	2,232	2.65
24	3.1	2.51	2,006	2.67
25	13.8	1.86	10,533	1.98
26	21.4	1.67	18,367	1.69
27	21.7	1.66	13,489	1.87
28	4.6	2.34	6,904	2.16
29	4.6	2.34	3,791	2.41
30	9.5	2.02	7,095	2.15
31	17.6	1.75	12,669	1.90
32	6.9	2.16	7,843	2.02
33	4.9	2.31	4,011	2.40
34	2.5	2.60	1,541	2.79
35	10.0	2.00	7,362	2.13
36	7.4	2.13	7,017	2.15

Figure No. 6

Concentration of 36 1:1 extracts in pS values as related to conductivity in pC values.

(Approximate average line drawn in for reference)



as determined by analysis, can be shown graphically without the use of log-log paper. The relationship is shown in Figure No. 6.

From these results it is apparent that there is a direct relationship between the conductivity of extracts from saline soils in Manitoba and their total salt content, also that this relationship varies, within certain limits, with different soils. This variation is to be expected because the soils vary considerably in the kind of salts present, particularly in their proportions of sulphates and chlorides, and, as is pointed out in the publication of the United States Regional Salinity Laboratory (15), the conductivity of solutions of chloride salts is higher than that of solutions containing equal amounts of sulphate salts. Therefore in order to obtain a reliable estimation of the total salt content of soils from the measurement of the electrical conductivity of their extracts, it is necessary to use a graph based on representative samples from the area being studied.

The results of the conductivity tests made on the saturation extracts of the samples which were not analysed chemically are given in Table No. 14. In this table, the specific conductivity of the sample extracts are given in millimho's/cm and in their pC values. The pS values shown were obtained by means of the graph presented in Figure No. 6, and the concentration of salts in p.p.m. of the saturation extracts were calculated from these pS values. The concentrations were used

Table No. 14

RESULTS OF CONDUCTIVITY TESTS ON SATURATION EXTRACTS OF A NUMBER OF MANITOBA SALINE SOILS

Sample No.	Conductivity in Millimho's/cm @ 25°C	pC	pS	Concentration in p.p.m. of Sat. Extract
37	9.8	2.01	2.12	7,590
38	24.2	1.62	1.70	20,000
39	17.5	1.76	1.86	13,900
40	17.5	1.76	1.86	13,900
41	2.6	2.59	2.78	1,660
42	19.2	1.72	1.82	15,200
43	1.1	2.96	3.15	710
44	15.9	1.80	1.90	12,600
45	5.2	2.28	2.40	4,000
46	11.2	1.95	2.05	9,000
47	14.5	1.84	1.95	11,300
48	0.5	3.30	3.50	320
49	1.0	3.00	3.20	630
50	5.6	2.25	2.40	4,000
51	12.0	1.92	2.02	9,550
52	1.9	2.72	2.90	1,260
53	2.4	2.62	2.80	1,590
54	1.2	2.92	3.10	630
55	0.8	3.10	3.30	500
56	0.5	3.30	3.50	320
57	2.2	2.66	2.85	1,420
58	9.6	2.02	2.12	7,590

as estimations of the total salt content of the samples in the proceeding discussion of saline soils by physiographic areas. Saturation extracts of the samples were used in the determinations because they are more representative of field moisture conditions and bear a closer relationship to the water holding capacity of the soils than do the 1:1 extracts. This is particularly significant in Manitoba because of the common occurrence of the relatively insoluble salt calcium sulphate. Although it is very difficult to obtain sufficient extract from a saturated soil sample on which to conduct chemical analysis, without the use of special equipment, the small amount required by the specially constructed conductivity cell may be easily obtained with the use of a Buchner suction funnel.

C. Vegetation as an Indicator of Halomorphism:

The native plants found growing on saline soils in Manitoba are given in the following list.* The relative tolerance of these plants, as indicated by their grouping in the list, is based on the observations made in the field and the subsequent total salt analysis of the soil samples taken from the areas on which they were growing. Within the three groups, the plants are listed approximately according to their tolerance.

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* Plant identification through the courtesy of the Botany Dept., University of Manitoba.

Salt Tolerant Native Plants in Manitoba:

Highly Tolerant

Salicornia spp.	-	
Suaeda erecta	-	sea blite
Distichlis spicata	-	salt grass

Moderately Tolerant

Grindelia perennis	-	perennial gumweed
Hordeum jubatum	-	wild barley
Aster ericoides	-	many flowered aster
Aster laevis	-	smooth blue aster

Slightly Tolerant

Brachyactis angusta	-	rayless aster
Cirsium arvense	-	sow thistle
Bechmannia Syzigachne	-	slough grass
Atriplex spp.	-	
Agropyron repens	-	western couch grass
Chenopodium leptophyllum	-	narrow-leaved goosefoot
Carex Bebbii	-	Bebbs sedge
Achillea spp.	-	yarrow
Artemesia glauca	-	smooth-leaved wormwood
Artemesia biennis	-	biennial wormwood
Poa spp.	-	blue grass
Salsola pestifer	-	Russian thistle
Polygonum neglectum	-	narrow-leaved knotweed

Bouteloua gracilis	-	blue grama
Solidago spp.	-	golden rod
Stipa comata	-	common spear grass
Bidens frondosa	-	common beggar ticks
Agalinis tenuifolia	-	slender agalinus
Symphoricarpos spp.	-	snow berry
Monarda fistulosa	-	common bergamot
Elaeagnus argentea	-	silver berry
Sporobolus heterolepsis	-	prairie dropseed
Phacelia Franklinii	-	Franklin's Phacelia
Agrostis alba	-	red top

The plants listed as highly tolerant were found only on strongly salinized soils. Those shown as being moderately tolerant were often observed on the land surrounding these areas of strongly salinized soil and in other areas where the total salt content of the composite profile samples was less than nine to ten thousand parts per million. The slightly tolerant species listed above usually occurred on the outer edges of the saline areas or in areas where the total salt content was less than two to three thousand parts per million.

No regionality was noted with respect to the occurrence of different species of plants throughout the province and the total salt content of the soil seems to be the main factor determining the vegetation that will grow on the saline soils. The restricted growth of Salicornia spp., sea blite, salt grass and gumweed to soils that are high in soluble salts makes them useful as indicators of saline soils in field investigations, but more detailed work is required before the presence or absence of these plants can be used for estimations of salt concentration.

V. SUMMARY:

This investigation was undertaken to gather information on the nature of the salinized soils in Manitoba and to try to ascertain the origin of the salts and the reason for their accumulation in toxic amounts in certain areas. Field trips covering most of the agricultural area of the province were made for the purpose of making observations on the known saline areas and collecting representative samples for laboratory studies. Information on soil conditions, topographical relationships and native saline vegetation was obtained in the field. In the laboratory, 1:1 extracts of thirty-six composite profile samples were analysed for: calcium, magnesium, sulphates, chlorides, bicarbonates, carbonates, nitrates, total solids and reaction. The alkali cations were estimated by difference and expressed as "sodium". A number of other samples were tested for reaction and qualitatively for sulphates and chlorides. Their total salt content was estimated from measurements of the electrical conductivity of their saturation extracts by means of a graph set up on the basis of conductivity tests on the 1:1 extracts for which the total salt content was determined by chemical analysis.

To facilitate the presentation and discussion of the results of these field and laboratory investigations, the province was divided into four main physiographic areas, which were further subdivided on the basis of differences in soil parent material and soil forming processes. The location of these areas and sub areas is shown on a map which accompanies this thesis. A cross section through Manitoba showing the

underlying geological formations, with a map showing the surface contacts of these formations, was made up from information obtained from the Manitoba Department of Mines and Natural Resources and included for reference purposes as these formations are referred to in the discussion of the possible origin of the salts.

The results of this investigation indicate that the principal salts responsible for the salinization of soils in Manitoba are sulphates and chlorides of magnesium, calcium and the alkali cations. The analysis of the samples from the different areas suggest that a regionality exists in the proportions of sulphates and chlorides present in the saline soils. In both the boulder till and the lacustrine clay soils of the Western Upland area, sulphates of magnesium and sodium are the dominant soluble salts and chlorides are usually present in relatively small amounts. A few small areas of black alkali soils have been observed in the field, but none of the samples analysed in this investigation contained measurable amounts of sodium carbonate. The salts in the salinized soils developed on the lacustrine deposits and the river and lake terraces of the Souris Basin and Assiniboine Delta area also seemed to be chiefly sulphates of calcium, magnesium and the alkali cations. In one of the samples from the eroded river channels, where the soils are developed on shale clay, a high concentration of chlorides was present. In the West Lake and Interlake regions of the Agassiz Basin and Lowland area, the composition of the salts was found to vary somewhat with the source. In the northern portions of these regions most of the salinized soils are formed because of salt water springs and these soils are very high in sodium chloride; while in the southern portion the salinized soils contain both chlorides and sulphates in varying proportions. The samples taken from the various soil areas in the Red River Plain indicated that high concentrations of chlorides, as well as sulphates, are present in the salinized soils in the clay-boulder till transitional area north of the Assiniboine River and in the lacustrine and deltaic deposits adjacent to the United States border; while sulphates are the dominant salts in the central clay basin.

No soils containing appreciable amounts of soluble carbonates were encountered during this investigation, and nitrates were found in only trace amounts in a few of the samples analysed. Bicarbonates were present in relatively small concentrations in all of the samples tested. The pH of the salinized soils ranged from slightly over 7.0 to 8.65, indicating a lack of alkaline salts such as sodium carbonate.

No direct relationship was established between the gypsum deposits and saline water horizons in the underlying rock formations and the soluble salt accumulations in the salinized soils, except in the case of the soils surrounding salt water springs in the northern portion of the West Lake area. The field and laboratory investigations indicated that in most areas the salinization of soils has occurred in the low-lying portions where the percolation of water through the soil was not sufficient to leach out the soluble salts which had been released by the weathering of soil minerals in the higher land and carried in by the drainage waters. However a knowledge of the presence of gypsum strata and saline water horizons in the rock formations is important to this investigation because these rocks are the source of the materials on which the soils have been developed and from which the soluble salts have been derived through the decomposition of the minerals by weathering processes.

Conductivity measurements were conducted on extracts from the soil samples and a graph showing the relationship between conductivity and salt concentration from the samples which had been analysed chemically was made up and used for the estimation of total salt content of the other samples. This graph illustrates the variability of the electrical conductivity of solutions containing sulphates and chloride salts and points to the need for a graph based on representative samples from the area being investigated if accurate estimations of total salt content are to be obtained from conductivity measurements.

The native plant species found growing on saline soils throughout the province were listed in order of their apparent tolerance to salts. From observations made in the field and subsequent total salt analysis of soil samples it was found that Salicornia spp., sea blite, salt grass and gumweed are good indicators of highly saline soils and therefore useful for recognition of saline soil in field investigations.

Although this investigation did not include any saline soil improvement or reclamation studies, the information obtained on the kind of salts present in the soils and the reasons for their accumulation in certain areas is fundamental for this purpose and should be of value for such studies in the future. The main problem in reclamation of saline soils in Manitoba is that the salinized soils generally occur in small undrained depressional areas where improvement in drainage is not usually feasible. An exception to this is the lacustrine deposits of the Red River Plain where desalinization of large areas has been brought about through the installation of an extensive system of artificial drains. This method of improvement might be useful in other parts of the province, such as the saline area at the south end of Lake Dauphin and in the Big Grass Marsh area north of Gladstone, where the topography is relatively flat and a system of open ditches would improve the surface drainage and lower the ground water table. In the small depressional areas, where improvement in surface drainage is not feasible, internal drainage may be improved in some places by the use of deep wells bored down to a porous substrata, such as a lens of gravel between the boulder till and the underlying rock or a shale strata containing numerous cracks and fissures.

VI. CONCLUSIONS:

(1) Small scattered areas of salinized soils occur over most of the non-forested region of Manitoba, and occasionally in the forested region where special conditions such as saline springs or surface gypsum deposits exist.

(2) The principal soluble salts in these soils are sulphates and chlorides of magnesium, calcium and the alkali cations.

(3) The proportion of sulphates to chlorides in the salinized soils varies with different areas.

(4) Most of the saline soils in the province are high in sulphates, while high concentrations of chlorides seem to be restricted to:

(a) The saline spring areas in the northern part of the West Lake region.

(b) The shale clay soils in the glacial Lake Souris outlet.

(c) The transitional area between the heavy clay soils of the Red River Plain and the calcareous boulder till soils of the Interlake and West Lake regions.

(d) The delta and lacustrine deposits in the southern portion of the Red River Plain.

(5) "Black alkali" soils, or soils containing appreciable amounts of sodium carbonate, are not commonly found in Manitoba.

(6) The general source of the salts, which accumulate in the upper horizons of the soils where the internal drainage is impeded by an impervious subsoil or a high water table, is the weathering of the soil minerals in the surface deposits

of the surrounding area or the areas from which drainage waters originate.

(7) Except where halomorphism is clearly due to the occurrence of saline springs or surface gypsum deposits, no direct relationships were established between the gypsum strata and saline water horizons in the underlying rock formations and the saline soils of Manitoba.

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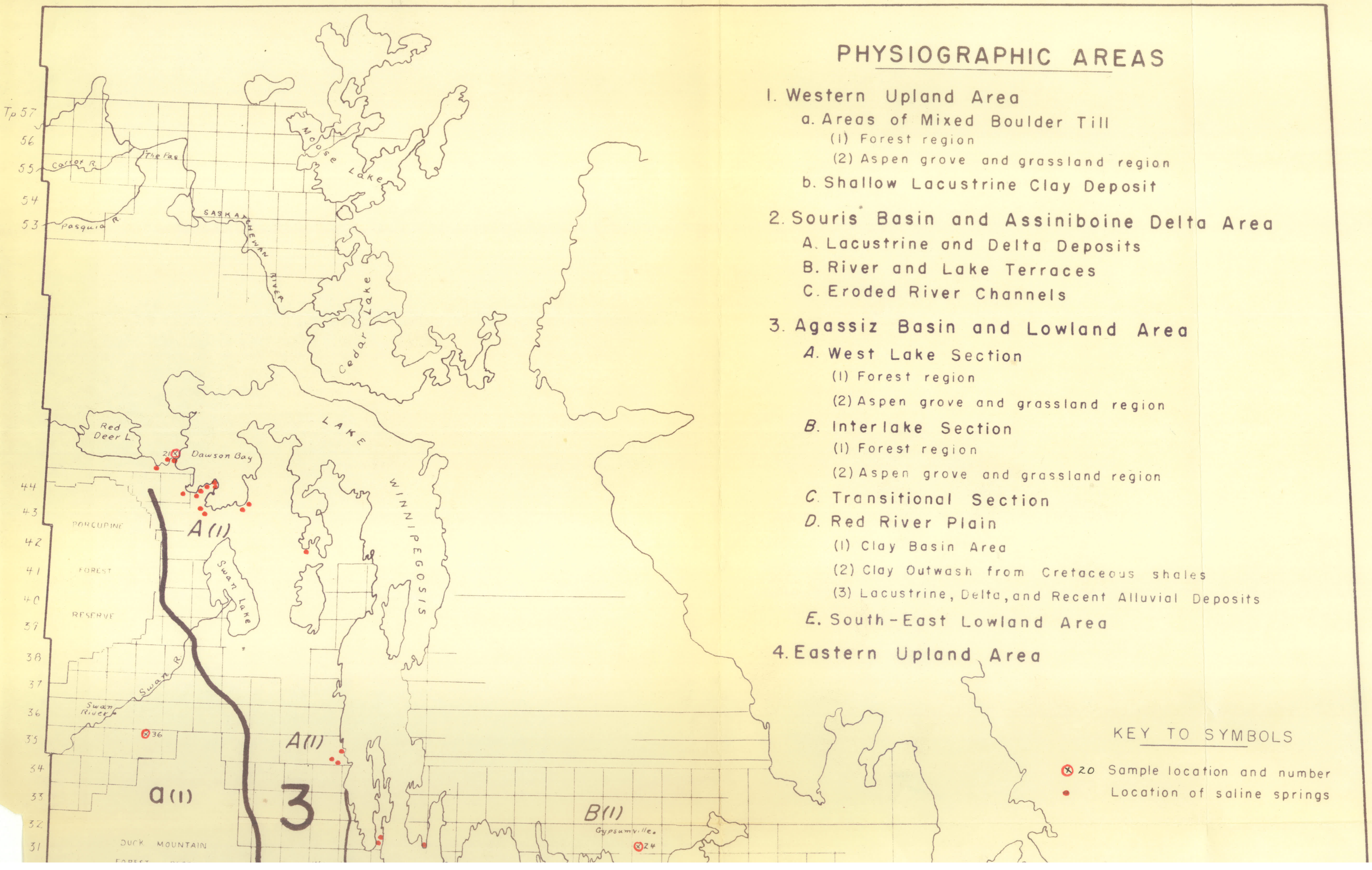
MAP OF SOUTHERN MANITOBA

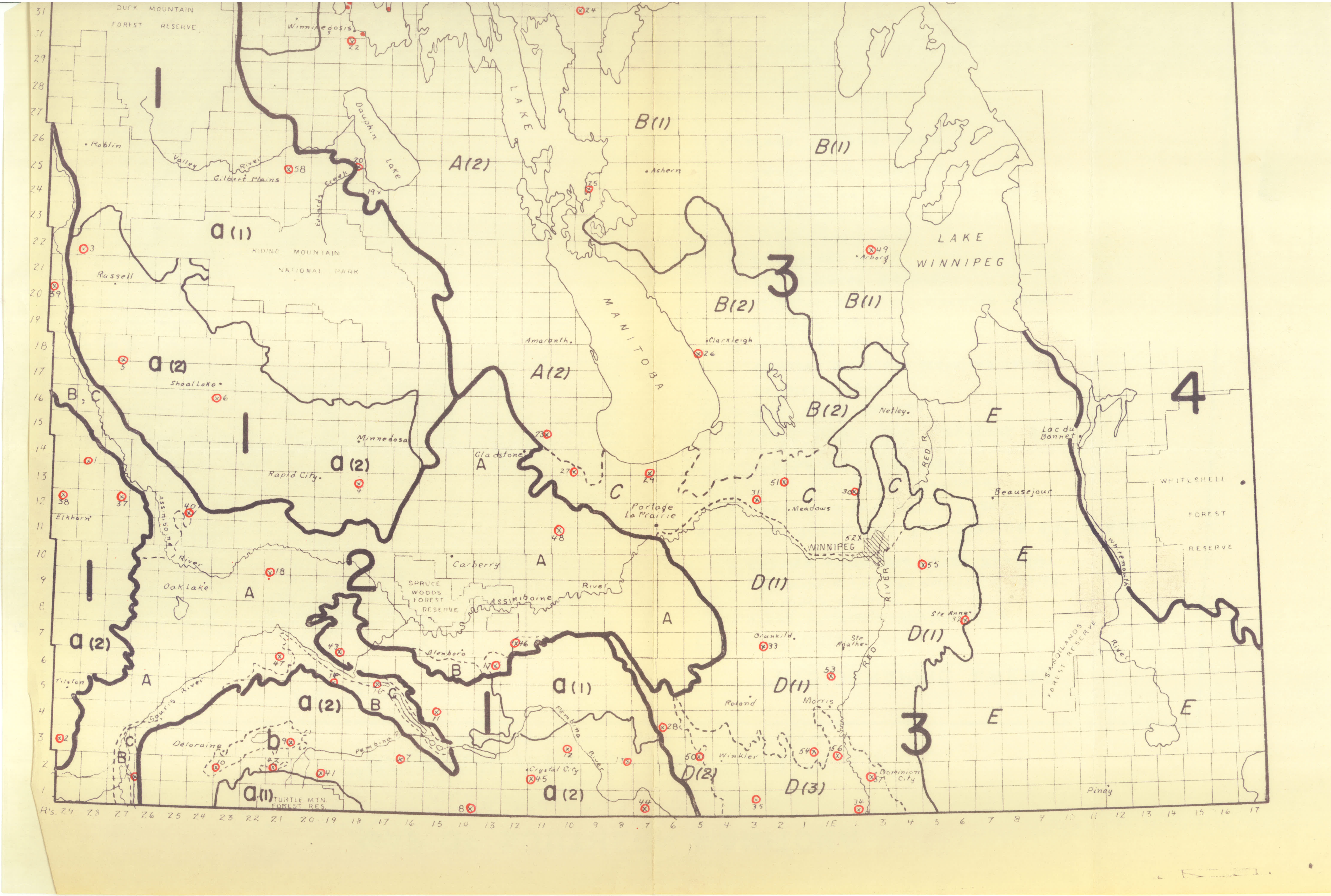
Figure No. 7

TO ACCOMPANY THE THESIS

"HALOMORPHISM IN MANITOBA SOILS"

Scale 20 miles to 1 inch or 1:1,267,200

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Roblin
Valley River
Gilbert Plains
Dauphin Lake
Edwards Creek
RIDING MOUNTAIN NATIONAL PARK
Russell
Shoal Lake
Minnedosa
Rapid City
Elkhorn
Assiniboine River
Oak Lake
Carberry
SPRUCE WOODS FOREST RESERVE
Assiniboine River
Glenboro
Souris River
Tilston
Deloraine
Pembina
TURTLE MTN FOREST RES.
Crystal City
Pembina River
LAKE
Ashern
LAKE MANITOBA
Amaranth
Gladstone
Portage La Prairie
Clarkleigh
Arborg
LAKE WINNIPEG
Netley
Meadows
WINNIPEG
RED R.
RED RIVER
Beausejour
Lac du Bonnet
WHITESHELL FOREST RESERVE
Whitemouth River
Ste Anne
Grunthal
Ste Agathe
Morris
Roland
Winkler
Dominion City
SANDILANDS FOREST RESERVE
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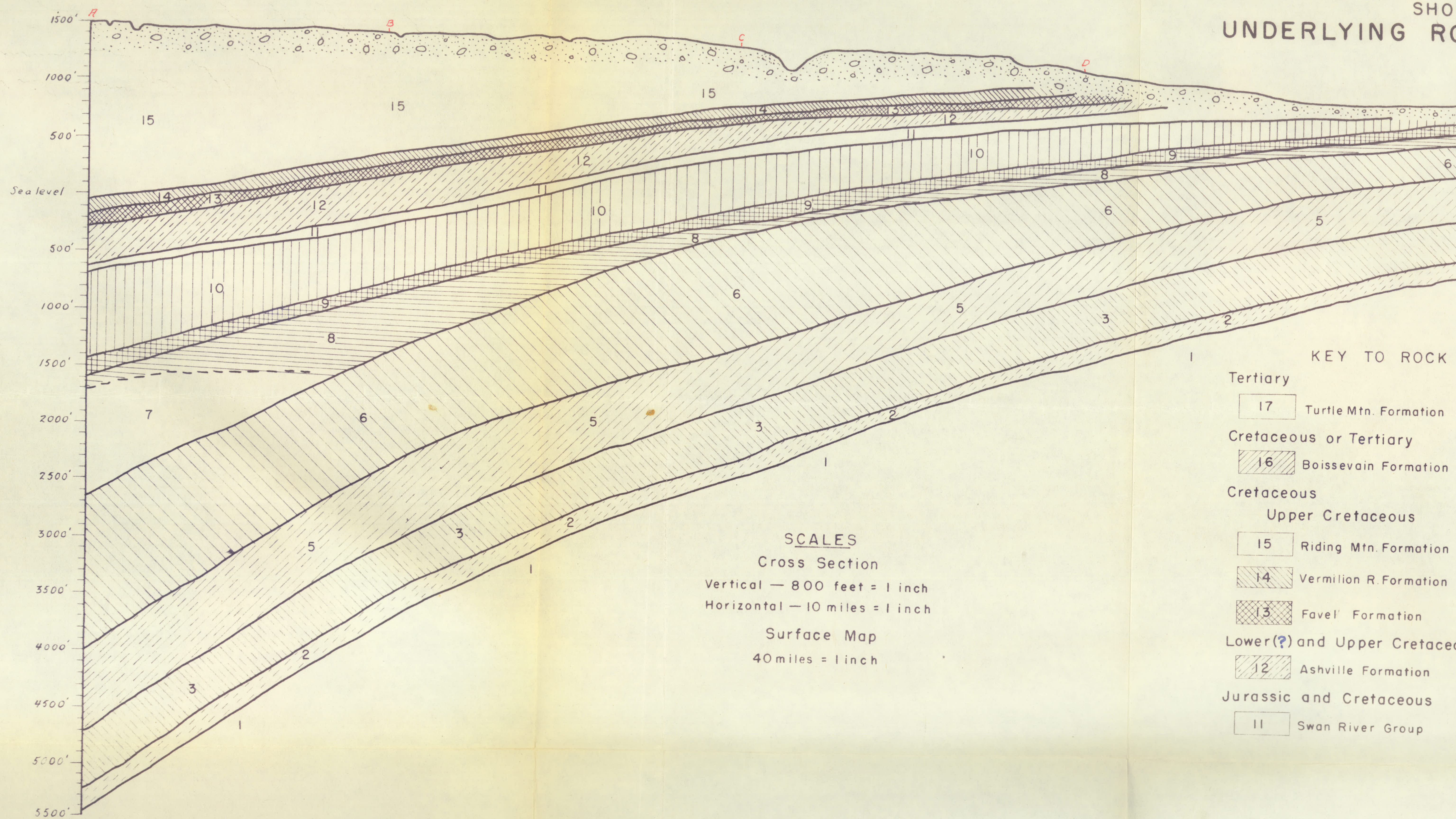

Information
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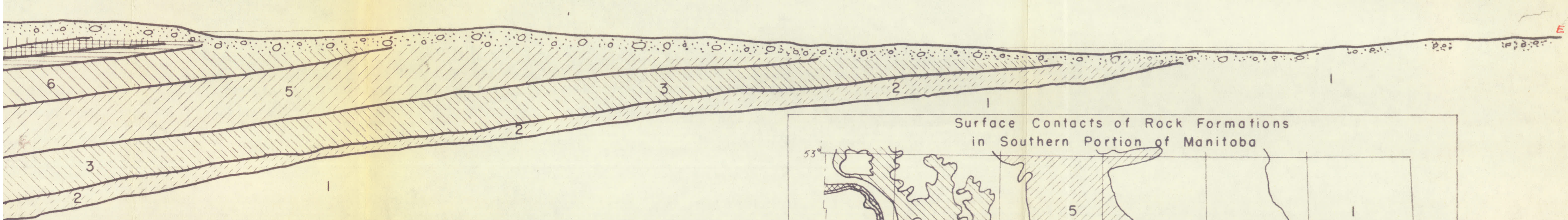
Manitoba Dept

TION OF MANITOBA
SHOWING
ROCK FORMATIONS



ROCK FORMATIONS

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Cretaceous
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Jurassic and Earlier

- 10 Sundance Formation
- 9 Gypsum Springs Formation
- 8 Spearfish Formation

Mississippian

- 7 Mississippian

Devonian

- 6 Unnamed Devonian

Silurian

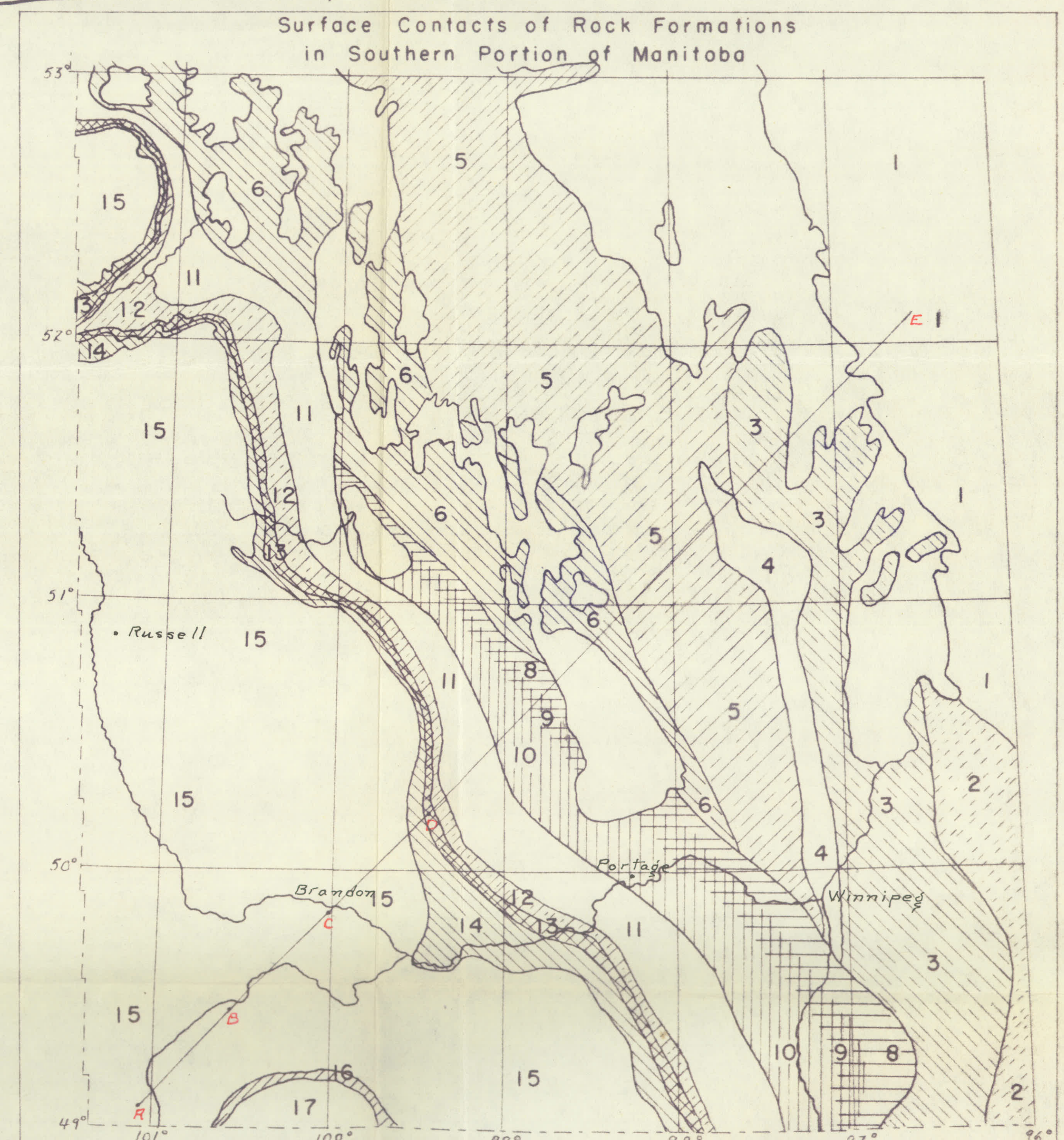
- 5 Interlake group

Ordovician

- 4 Stony Mtn. Formation
- 3 Red River Formation
- 2 Winnipeg Formation

Precambrian

- 1



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