The University of Minnesota

MINNESOTA GEOLOGICAL SURVEY

WILLIAM H. EMMONS, DIRECTOR

IN COÖPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

BULLETIN NO. 12

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS OF NORTHWESTERN MINNESOTA

BY

FRANK LEVERETT

WITH A CHAPTER ON

CLIMATIC CONDITIONS OF MINNESOTA

BY

U. G. PURSSELL

Minneapolis
The University of Minnesota
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INTRODUCTION

By W. H. Emmons

The natural economic assets of an area, such as its soils, clays, building stones, iron ores, etc., all bear a direct relation to the geological features of that area, and a rational discussion of such assets must give due importance to the geological history and environment of the area which contains them. The last, and, therefore, from the standpoint of the soils and surface features of the country the most important, great geological event that has affected this area is the invasion of sheets of ice that moved southward from the Canadian highlands carrying with them rocky material which they had gathered in the north. When the ice melted it left large quantities of rock and soil and in the area here described this material nearly everywhere now forms the surface.

The last great ice sheet that covered this area melted very slowly and the southern part was melted long before the northern part. The ice that still remained in the north formed a great dam which held back the drainage of the Red River Basin and formed a large lake which is called the glacial Lake Agassiz. This lake overflowed southward through the Minnesota River and into the Mississippi. These conditions endured through a long period and this lake was partly filled with material that washed into it and its bottom was washed and smoothed over by waves and shore currents. Later, when at the north the ice dam melted, the lake was drained to the north, and its bottom now forms one of the largest and richest agricultural regions of the world. This lake was drained very gradually, however, its level remaining stationary through considerable periods so that gravel beaches were formed here and there along its shores. These gravel beaches supply material for roads and they furnish also attractive building sites for farmhouses and barns.

After the ice had melted, large swamps and marshes occupied poorly drained portions of the region and many of them remain to the present day. The drainage and reclamation of these lands is one of the most important problems of this region.

The great productivity of Minnesota soils is due, not only to their recent origin by reason of which nearly all of them still contain the soluble mineral foods for plants, but also to a very favorable climate. The low temperatures which frequently prevail during certain periods in winter make for healthful conditions for animal life and they also benefit plant life. The rainfall, though not excessively great, is sufficient and, since most of it occurs during the growing period, drouths are rare and crop failures almost unknown except in the more sandy soils, which

are, however, adapted to quick-growing crops like potatoes. As shown herein, the length of the crop-growing season, that is, the time between late spring frosts and early autumn frosts, is between 100 and 170 days for all except the extreme northeast corner of the State, and in the southern half is nearly everywhere above 130 days, a period that is ample for growing the highly productive crops of Indian corn. The long days, high proportion of sunshine, and the moderate humidity are all favorable to plant growth.

This bulletin is a preliminary paper which treats the soils of only the northwest quarter of Minnesota. It will be followed by a report on the entire State, the field work for which will soon be completed. The work has been done in accordance with the agreement for coöperation between the United States Geological Survey and the Minnesota Geological Survey, entered into March, 1912. By this agreement the services of Professor Frank Leverett were secured for surveying the surface formations and soils. Mr. Leverett has been engaged for some twenty years in studying the surface geology of the Great Lakes region and because of his large experience in the greater area he is particularly well prepared to undertake the studies in Minnesota. He has spent, moreover, considerable time in the State studying its physiography in connection with the preparation of a monograph for the United States Geological Survey. Since the reorganization of the State Survey, the salary of Mr. Leverett has been met by the United States Geological Survey, while the greater part of his expenses have been paid by the State Survey. The State Survey has provided also for this work the services and expenses of Professor F. W. Sardeson, who has assisted in this work for the past three seasons. For brief periods, also, the State has supplied the services of Arthur H. Elftman, P. R. McMiller, and G. R. McDole. We wish to acknowledge the generous assistance of the Division of Soils of the Department of Agriculture of the University of Minnesota and of the United States Bureau of Soils, both of which have contributed unpublished data. The valuable contributions to the knowledge of the surface formations of Minnesota by the Minnesota Geological and Natural History Survey, under the direction of Professor N. H. Winchell, particularly those of Mr. Warren Upham of that Survey, have aided greatly in the preparation of this report. The section on climatic conditions in Minnesota has been generously contributed without any cost to the Survey by Mr. U. G. Purssell, Director of the Minnesota Section of the United States Weather Bureau. In the preparation of the maps and other data showing dates of killing frosts, lengths of growing season, rainfall, etc., Professor C. J. Posey has rendered efficient service.

The cost of preparation of this report has been met by the Minnesota Geological Survey and the United States Geological Survey. This

bulletin is printed by the Minnesota Geological Survey. Arrangements will be made so that land and colonization companies can secure these reports at actual cost of printing, and it is expected that this arrangement will secure a wide distribution. The maps are not intended to be used as a basis for the purchase of land; they do not give an accurate description of each forty-acre tract or each section, but they show the general classification of the land, its climate, and its surroundings.

SURFACE FORMATIONS AND AGRICULTURAL CONDITIONS IN NORTHWESTERN MINNESOTA

By Frank Leverett

FIELD WORK AND ACKNOWLEDGMENTS

This report treats particularly the northwest quarter of Minnesota, but a brief general description of the surface features and deposits of the entire State is given because the larger area makes a more natural unit for purposes of description. For this reason, also, Mr. Purssell has discussed the climate of the entire State. In this report no attempt is made to measure the crop-growing capacity of any class of soil, or the adaptation of certain soils to particular crops. These matters fall naturally to the Department of Farm Management. It seems pertinent, however, to note that soils which are classed as light may under intelligent management be made to yield returns which compare favorably with the yield from heavier soils. The sandy areas shown on the map which accompanies this report thus afford an inviting field for experimentation. The drainage and utilization of the great swamps constitute another large field for intelligent operation.

The productiveness of a soil usually has some relation to its origin and to underground conditions. It therefore means more to say that a given soil is a glacial lake clay or a lake sand than merely to call it a clayey soil or a sandy soil. If formed of the very productive wind-deposited material called loess, there is an advantage in making this appear in the name rather than merely to term it a silt loam. So also the pebbly clay loams and pebbly sandy loam of the glacial deposits may have one degree of productiveness in a level till plain and quite another in a hilly moraine. It is for this reason that pains have been taken in the legend of the map to set forth the geologic as well as the soil names. Another reason for this mapping and description is that the method of the work is genetic rather than analytic. It deals with the origin of the formations in larger divisions rather than with the physical conditions section by section and area by area. It is not sufficiently detailed to justify the purchase or sale of the land from an examination of the map alone. It gives, however, an accurate general classification of the land and its surroundings.

The field work of this report on Minnesota was begun in 1906. The writer has devoted to this work a considerable part of each field season to 1914, except 1908. Field assistance has been rendered four seasons

by Frederick W. Sardeson as geologist, and one season each by Rollin T. Chamberlin and Earl R. Preston as field assistants. Arthur H. Elftman furnished valuable information and accompanied the writer for a brief period in 1913 into the wild portion of the State with which he was especially familiar from work on an earlier State Survey. Field conferences have been held also with members of the United States Bureau of Soils and of the State Department of Agriculture. The map and report on Pennington County and part of Polk County here presented is based largely upon the work of the Bureau of Soils. In the preparation of this report much aid has been derived from the monograph on the glacial Lake Agassiz by Warren Upham and from the reports of counties in the Final Reports of the Geological and Natural History Survey of Minnesota. Free use has been made also of the reports and maps of the State Drainage Commission.

CHAPTER I

TOPOGRAPHY OF MINNESOTA

GENERAL FEATURES OF THE DRIFT

Minnesota presents more variety in surface features than most of the North Central states, though a great part of it has a level or gently undulating surface. The flattest portion falls largely in the northwest quarter of the State and was once the bed of a great lake known as glacial Lake Agassiz, held in on the north by a sheet of ice or great glacier. The roughest portion is in the northeast quarter which is traversed by volcanic formations and adjacent iron-bearing ranges. In the southeast part along the borders of the Mississippi River there are tributary valleys from 300 to 600 feet deep cut in horizontal beds of sandstone and limestone of that district. There is an elevated area in the southwest part rising in places to over 1,900 feet above sea level, but it has a relatively smooth surface because the inequalities of the rock surface are concealed under a great deposit of drift. The interior of the State has features due entirely to the ice, or great glacier, and its melting waters. It comprises a complex system of undulating to hilly moraines, sandy outwash plains, and clayey till plains, whose extent and distribution bear definite relation to the melting of glaciers that overspread the region.

At and beneath the border of the ice, systems of interlocking ridges and knolls with inclosed basins and lakes, were formed at certain definite lines where the edge of the ice held its position for a relatively long time. These systems are the moraines. The ice border, after long holding its position at one of these moraines, would recede somewhat rapidly to another position and there halt long enough to build up another moraine and so on step by step until the ice had disappeared from the State. On the outer border of a moraine there is often a plain of sandy gravel spread out as an outwash by waters escaping from the ice. On the inner border there is usually a clayey plain known as till plain which was ice-covered during the development of the moraine.

Large areas were covered by lakes as the ice was melting away, and thus much of the drift has been lake-washed and rendered somewhat smoother than the unmodified glacial deposits. Many of these lakes have disappeared because their shallow basins have been filled up.

ALTITUDE

In Minnesota altitudes range from 602 feet, the level of Lake Superior, up to 2,230 feet on high knolls in western Cook County. The

altitude is only 620 feet where the Mississippi River leaves the southeast corner of the State, and is 750 feet along Red River in the northwest corner. The headwaters of the Mississippi and the Leaf Hills farther south reach 1,750 feet. The average altitude of the State is not far from 1,200 feet and a large part of it stands between 1,000 and 1,500 feet. A narrow area below 1,000 feet covers the Red River Valley and extends from it into the Minnesota Valley and expands to considerable width in the eastern part of the State. There is another narrow strip below 1,000 feet on the border of Lake Superior. The chief areas above 1,500 feet are found in the rocky ranges of the northeast part, in the high tract from the head of the Mississippi to the Leaf Hills in the western part, and in the plateau southwestward from Coteau des Prairies in the southwest part. Only a few square miles in the northeast part rise above 2,000 feet.

RELIEF

The most conspicuous relief is found in the "Sawtooth Range" and other prominent ridges that closely border Lake Superior and which rise abruptly from 500 to 900 feet above the lake. The rock ranges lying back from the shore, though more elevated than those fronting on the lake, seldom rise more than from 200 to 300 feet above the swamps and lakes among them. In fact several of the lakes of Cook County are above 1,900 feet or within 300 feet of the level of the highest points in the State. The most prominent part of the Mesabi Iron Range in St. Louis County rises from 400 to 450 feet above bordering plains. The Coteau des Prairies rises about 700 feet above the plain northeast of its border, but in Minnesota the rise is usually spread over a space of from 12 to 15 miles or more in width, so that the elevation can scarcely be appreciated by one crossing over it. There is a rather rapid rise of from 300 to 500 feet to the sharp range of hills in Ottertail and Becker counties from the Red River Valley. This rise is of especial interest since it seems to have some influence on the rainfall, the precipitation being greater in these hills where air currents are forced upward and cooled than in the bordering lower lands to the north, west, and south.

DRAINAGE

The drainage of Minnesota is widely divergent, part of it leading to the Gulf of Mexico, part to the Gulf of St. Lawrence, and part to Hudson Bay. The Gulf of Mexico receives about 57 per cent, the St. Lawrence less than 9 per cent, and Hudson Bay fully 34 per cent of the drainage. There was a time, however, after the glacial ice had melted from Minnesota but was still occupying the northeast part of the

Superior Basin and neighboring parts of Ontario and Manitoba, when all the drainage was southward to the Gulf of Mexico. The western Superior Basin then overflowed into the St. Croix River, while the Red River Drainage Basin, largely covered by Lake Agassiz, drained southward through Lakes Traverse and Bigstone into the Minnesota Valley.

The drainage to the south, or Gulf of Mexico, has generally a gentle descent, and waterfalls are rather rare, though the Mississippi has notable falls at Minneapolis and there are one or more falls or rapids on several of the tributaries. The drainage to Lake Superior is generally rapid and nearly every stream has several cascades. There is, however, a wide area of the upper St. Louis Basin in which that stream and its tributaries have relatively gentle descent for many miles. The Hudson Bay Drainage has a few rapids and waterfalls in the headwater part of Rainy River and its tributaries, but Red River and its main Minnesota affluent Red Lake River have no falls since no outcrops of solid rock occur along them. There is, however, very rapid descent for a few miles along Red Lake River and its tributary Clearwater River in Red Lake County. Red River is subject to great freshets because its lower course often remains frozen after the southern or headwater part has broken up. Thus ice jams are formed which divert the waters from the channel over the bordering plain.

LAKES

Throughout much of Minnesota, except the northwest, southwest, and southeast corners, small lakes are a common feature. They usually occupy basins among the moraine ridges and knolls and on the outwash plains, but occur to some extent also on the till plains and among rock knobs. The combined area of the lakes within the State is estimated to be about 5,650 square miles, or nearly 7 per cent of the entire area. The largest lake is Red Lake, a very shallow body of water with an area of 440 square miles. Other large lakes are Mille Lacs, also very shallow, Leech, Winnibigoshish, and Minnetonka. Minnetonka and the southern part of Leech Lake extend into a network of deep depressions among morainic ridges, but the other lakes are largely in plains that are slightly below the neighboring districts, partly morainic and partly plain.

CHAPTER II

CLIMATIC CONDITIONS OF MINNESOTA

By U. G. Purssell

Director of the Minnesota Section of the United States Weather Bureau

INTRODUCTION

The agriculture of any region is controlled by its climate. In some parts of the world temperature is the main factor in determining the limits of growth of certain kinds of crops; in others it is rainfall, and in still others it is the amount of sunshine. All of these factors are important in influencing the crop yield even in districts where the general climatic conditions are satisfactory for the growth of plants. In Minnesota these elements are so favorable that a majority of the crops common to the temperate zone may be successfully grown, and a failure of all the important crops is very rare even over a small portion of the State.

Rainfall is an important factor for most crops in the State, because the proper amount of water in the soil at the critical period of development of the plant is necessary to produce a large crop. The length of the growing season also is important and probably no other factor in the study of climate from the standpoint of the agriculturist should be given more consideration. This is the key to an actual knowledge as to the possibilities of success or failure in the production of crops since in parts of the State crops are menaced by frost at some period of their growth, whereas sunshine and moisture seldom vary in Minnesota beyond safe limits.

The State extends from the northern boundary of Iowa, latitude 43° 30′, some 400 miles northward to the farthest point north in the United States, which is 22.85 miles beyond the 49th parallel in the projection to the northwest point of the Lake of the Woods. The greatest width east and west is 367 miles.

The factors which determine the climate of any area are the relative distribution of land and water, the topography of the land surface, and the situation of the area in question with relation to the general movement of the cyclones and anti-cyclones.

The position of Minnesota at the center of North America gives it a climate that is largely continental. In continental climates the temperature extremes are greater and the humidity and rainfall generally less than at places near large bodies of water, such as border on the Atlantic, Pacific, and Gulf coasts of the United States. The effect of

A. PLOWING FOR SEEDING ON A CLAY PLAIN IN BED OF LAKE AGASSIZ

B. HARVESTING CROP ON A CLAY PLAIN IN BED OF LAKE AGASSIZ

winds from great bodies of water is to equalize temperatures of lands near by and to lengthen materially the crop-growing season. This is particularly true of the country in the vicinity of Lake Superior, where the influence of that great inland sea in modifying the cold anti-cyclones gives to that section a more equable climate than would otherwise obtain in that portion of the State. The summer temperatures are likewise modified and people from long distances inland in steadily increasing numbers are establishing summer homes about the lake, to which they are attracted during the hot summer months. There are more than 7,000 small lakes scattered throughout the State and these have a material local influence in modifying the heat of summer and give comfort to thousands of residents on their shores.

Monthly and annual reports of temperature, rainfall, snowfall, etc., have been published for a large number of regular and coöperative stations in Minnesota since 1895. Recently three special section reports have been issued by the United States Weather Bureau giving monthly and annual precipitation totals for all points in the State with a record of ten years or over, together with average temperatures and other data. In these reports the more important facts from all portions of the State are tabulated and the comparative climatic conditions of the different sections graphically shown.

GENERAL CLIMATIC CONDITIONS

Minnesota is in the path of a large proportion of the low-pressure areas which move across the United States from west to east. These areas move at an average speed of 600 miles in twenty-four hours and are preceded by southerly winds and higher temperature and followed by northerly winds and lower temperature. They are usually accompanied by cloudy weather and precipitation; each storm causing an average of from one to two rainy days as it crosses the State.

As there is an average of almost two of these storms each week with fair weather periods between, it follows that the changes in weather conditions are rather rapid. One or two days of stormy weather preceded by fair weather and followed by clearing and lower temperatures to be repeated in turn, make up the usual routine for the week. However, Minnesota is so far from the coast that damaging ocean storms lose much of their severity before reaching its borders.

The northwestern cold waves pass across the State and send their health-giving winds into all parts, and yet they are frequently not so severe as they are in some of the plains states in the same latitude or even farther south.

Temperature.—The average annual temperature of Minnesota for the

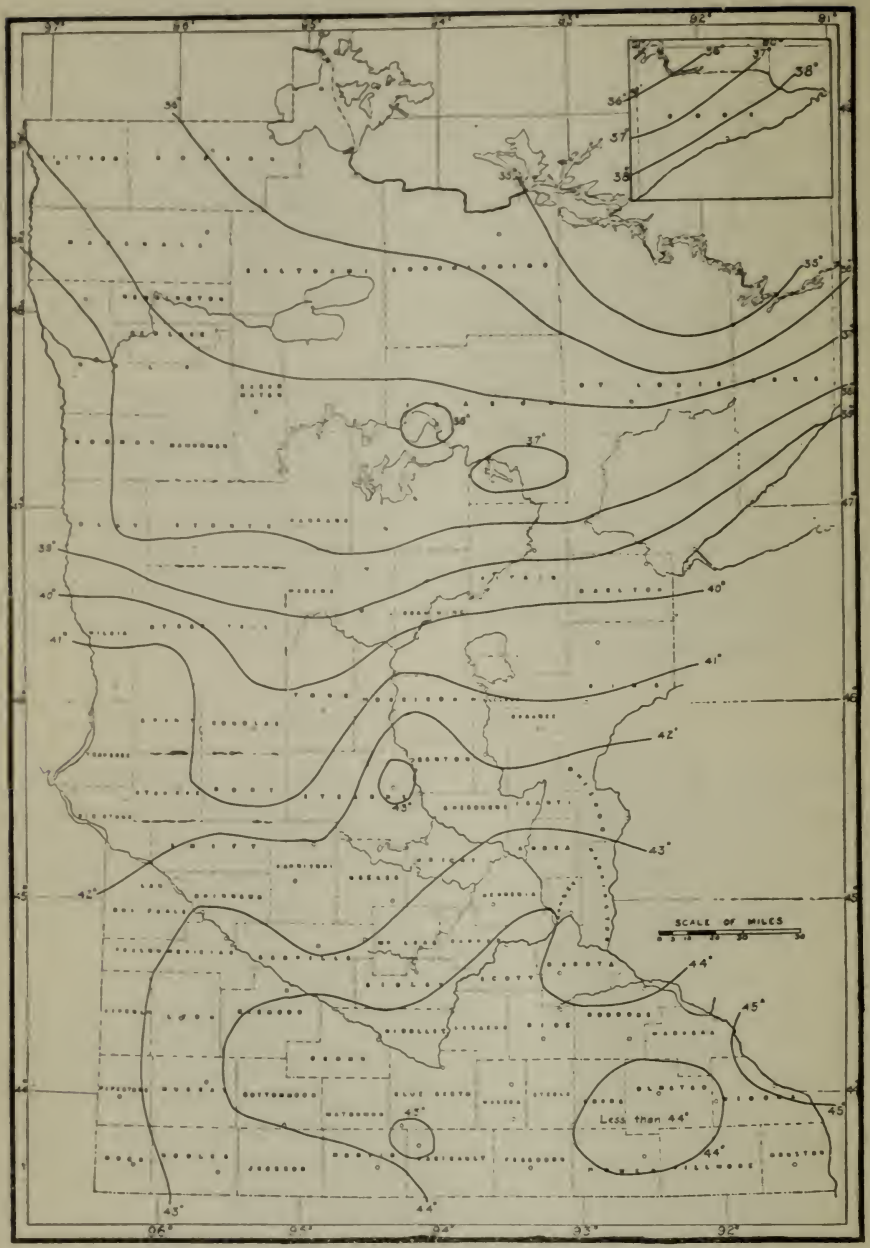


FIGURE 1. MAP SHOWING MEAN ANNUAL TEMPERATURES OF MINNESOTA (DEGREES FAHRENHEIT)

period 1895 to 1913 inclusive, is 41.7°, as shown in Table I and graphically by Figure 1. The highest annual mean temperature, 43.9°, occurred in 1900, and the lowest, 39.9°, in 1912. The departure of the average temperature of any year from the normal may readily be determined by comparing the yearly average with the mean at the foot of the column.

Table I. Monthly and Annual Mean Temperature for Minnesota (Degrees Fahrenheit)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1895	.....	.....	.....	49.9	56.9	64.6	67.8	67.4	61.5	41.4	27.8	18.3	.....
1896	12.3	17.9	21.4	44.5	60.9	66.5	69.9	67.9	54.3	42.4	18.0	20.3	41.6
1897	7.2	15.3	20.7	43.7	55.2	62.5	71.6	64.2	65.3	50.0	26.6	12.3	41.2
1898	18.3	16.4	30.3	43.5	55.6	67.0	69.8	66.9	60.6	42.9	26.6	11.9	42.2
1899	9.9	4.5	14.7	44.0	55.1	65.4	70.2	69.1	56.4	49.0	39.6	17.9	41.2
1900	18.4	5.2	23.4	49.5	59.9	66.8	68.8	74.3	58.2	55.1	25.4	18.6	43.9
1901	13.2	10.0	27.3	46.7	58.2	65.5	74.7	69.8	57.3	49.2	28.8	13.0	42.8
1902	15.9	15.5	34.0	42.6	57.0	61.3	69.7	65.2	55.2	47.1	33.3	12.6	42.6
1903	11.3	10.6	29.6	43.3	55.7	62.3	67.2	63.6	55.5	46.1	27.3	9.8	40.3
1904	4.5	2.3	24.8	38.8	55.4	63.2	66.0	64.9	57.4	47.4	36.7	16.7	40.1
1905	5.6	8.9	33.7	42.0	52.6	63.0	67.3	68.9	61.9	43.5	33.1	20.6	41.5
1906	17.0	13.8	20.6	47.9	53.7	63.7	68.3	68.7	63.3	45.7	30.7	15.9	42.0
1907	3.8	14.8	28.7	34.7	45.5	63.3	68.2	66.1	55.9	45.4	31.7	21.3	40.1
1908	16.4	17.9	26.4	45.2	53.9	62.5	69.4	65.5	64.2	47.0	33.8	17.5	43.4
1909	10.5	13.7	26.1	35.8	53.2	65.0	69.2	70.9	58.7	44.7	33.8	10.0	41.0
1910	11.8	7.5	41.7	48.0	51.6	67.8	70.6	65.8	58.4	50.8	25.3	14.7	42.8
1911	5.4	16.6	32.7	42.7	59.8	69.7	68.2	64.0	56.7	43.4	20.2	19.4	41.6
1912	—6.7	10.6	19.8	45.5	55.9	62.5	68.5	63.9	57.2	47.5	33.9	20.0	39.9
1913	7.2	8.6	20.4	46.4	52.7	67.4	67.3	69.2	58.6	42.7	36.9	26.1	42.0
1914	16.9	2.8	26.6	41.2	57.6	64.6	72.4	66.1	60.0	52.6	33.0	.....	.....
Mean	10.5	11.2	26.5	43.8	55.3	64.7	69.3	67.1	58.8	46.5	30.1	16.7	41.7

The coldest month is January, which has a mean temperature of 10.5°, although the average for February is only 0.7° higher. In a great many instances February has averaged colder than the preceding January. This condition occurred in the seven successive years from 1898 to 1904 inclusive. Average January temperatures are plotted on Figure 2.

July is the warmest month, with an average temperature of 69.1°, although in a few years the mean temperature for June or for August is higher than for July of the same year. Average July temperatures are plotted on Figure 3.

The highest summer mean, 70.0°, occurred in 1900 and 1901. The coldest summer was that of 1903, with an average of 64.4°.

The warmest crop-growing season (April to September inclusive) of the eighteen years under discussion was in 1900, when the average was 62.9°, and the coldest was in 1907, with an average of 55.6°.

The warmest winter (December to February inclusive) was in 1907-8, when the mean temperature was 18.5°. The coldest was in 1903-4, with a mean temperature of 5.5°. Table II shows also the warmest and coldest spring and autumn.

In Figures 4 and 5 are shown the highest and lowest temperatures ever recorded in the various counties where records have been kept.

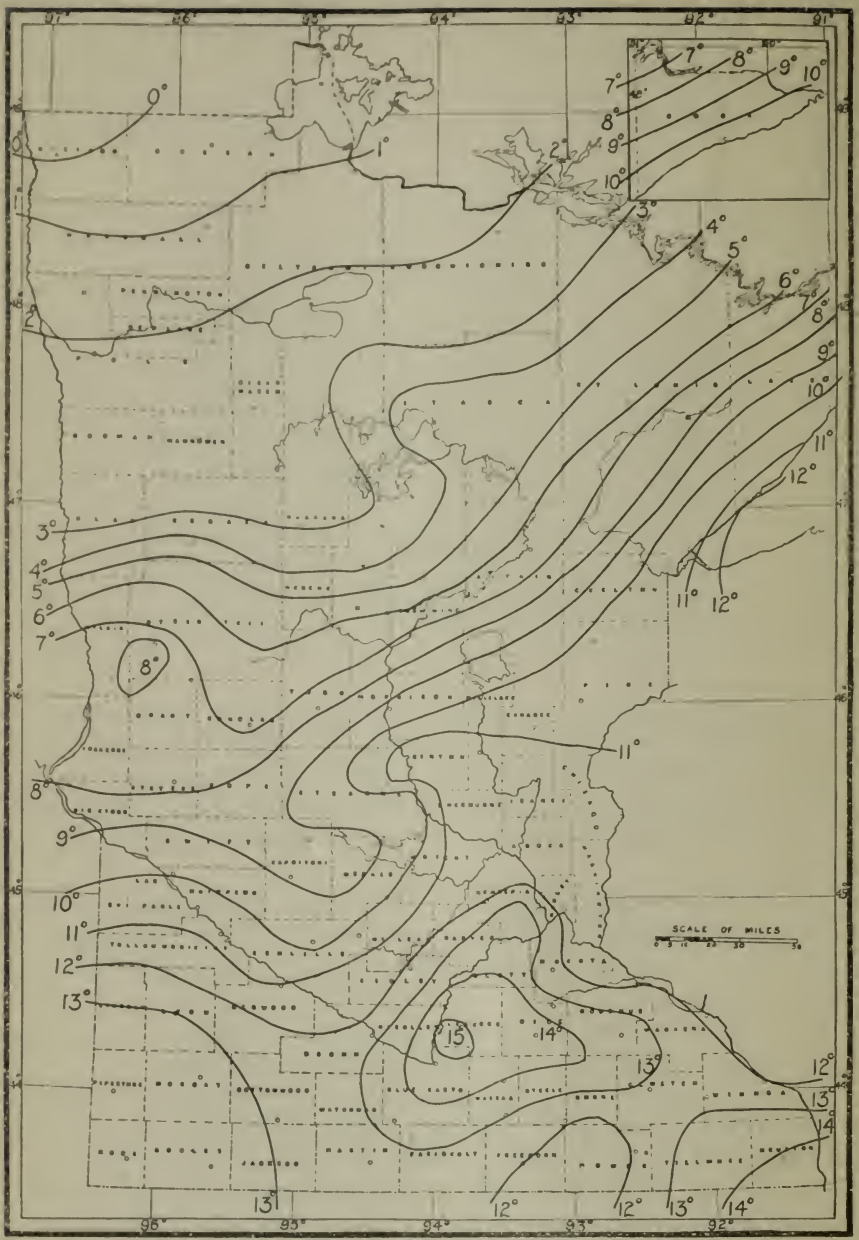


FIGURE 2. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JANUARY (DEGREES FAHRENHEIT)

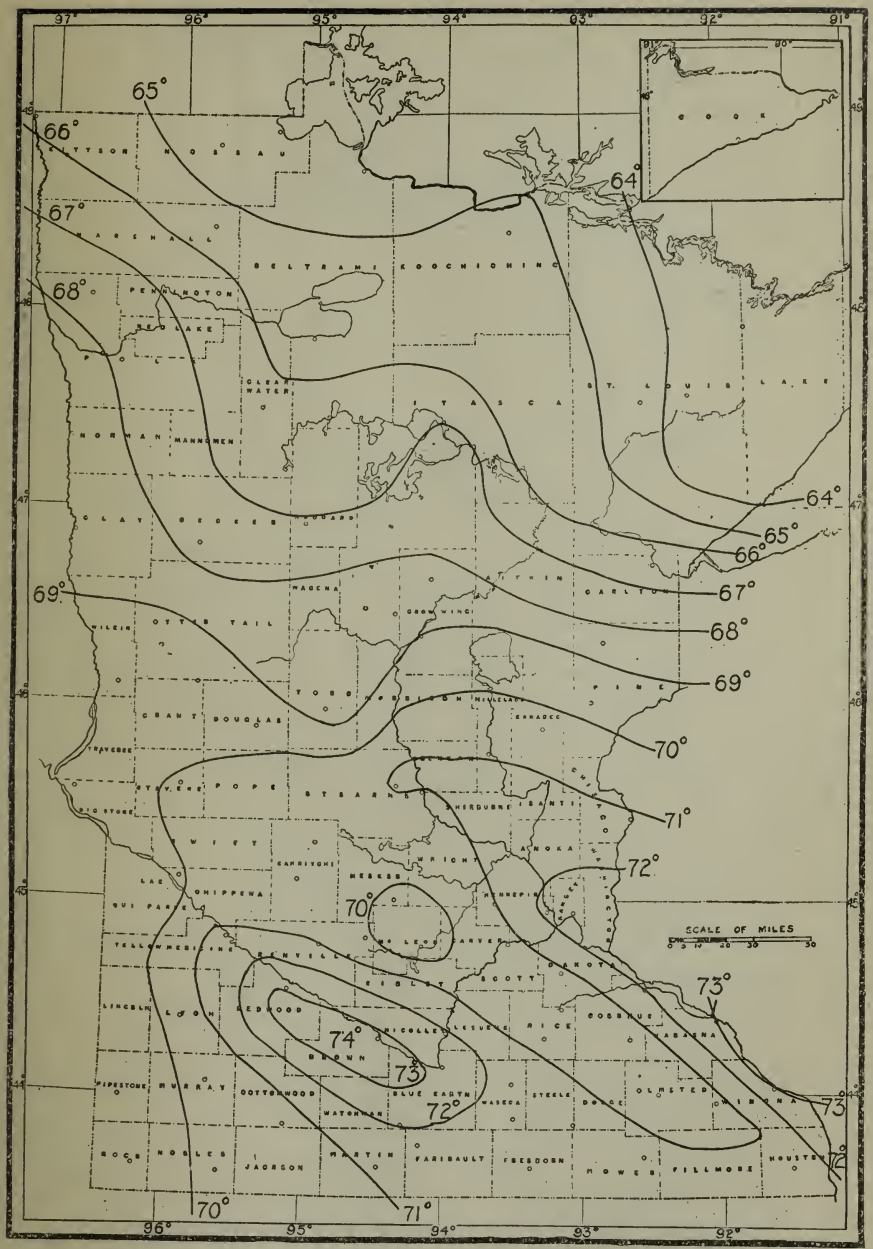


FIGURE 3. MAP SHOWING MEAN TEMPERATURES OF MINNESOTA FOR JULY (DEGREES FAHRENHEIT)

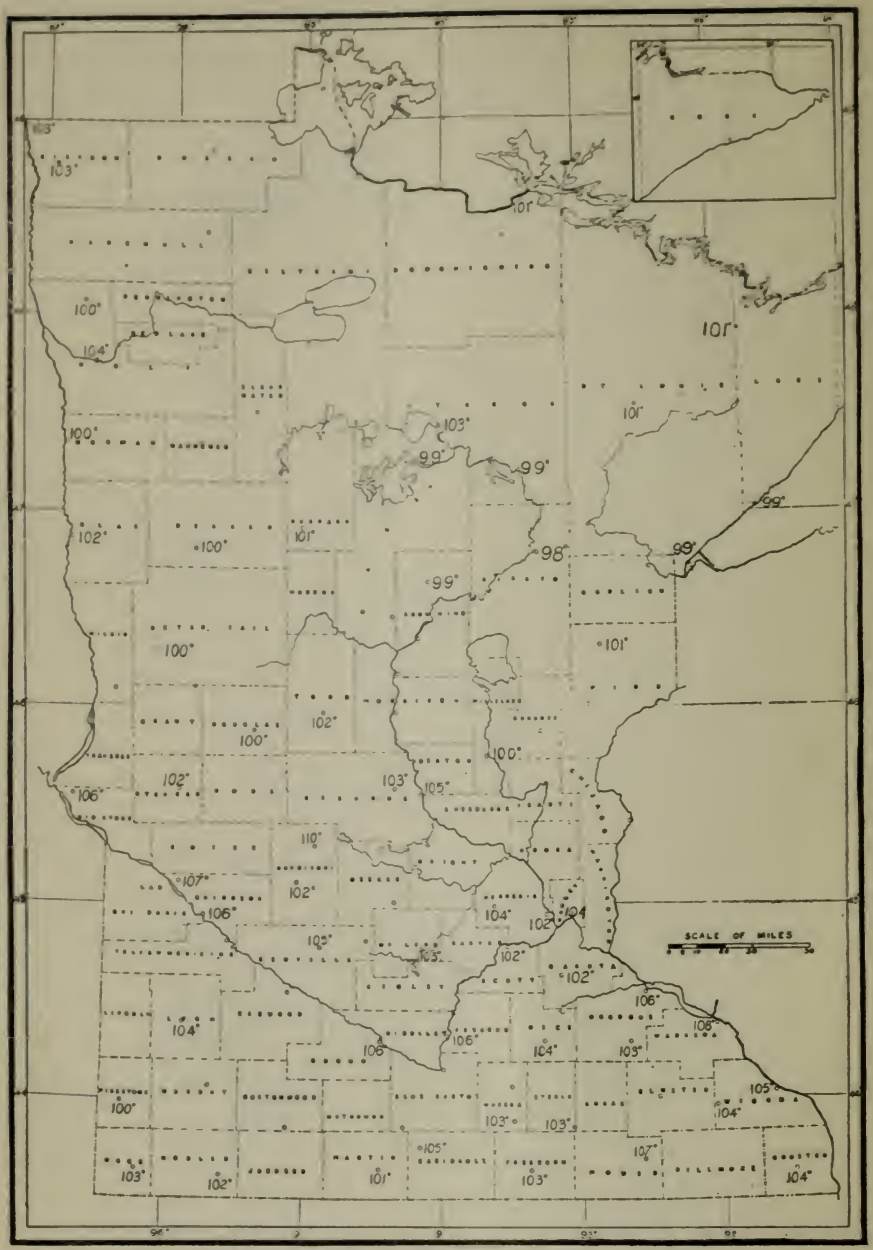


FIGURE 4. MAP SHOWING HIGHEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

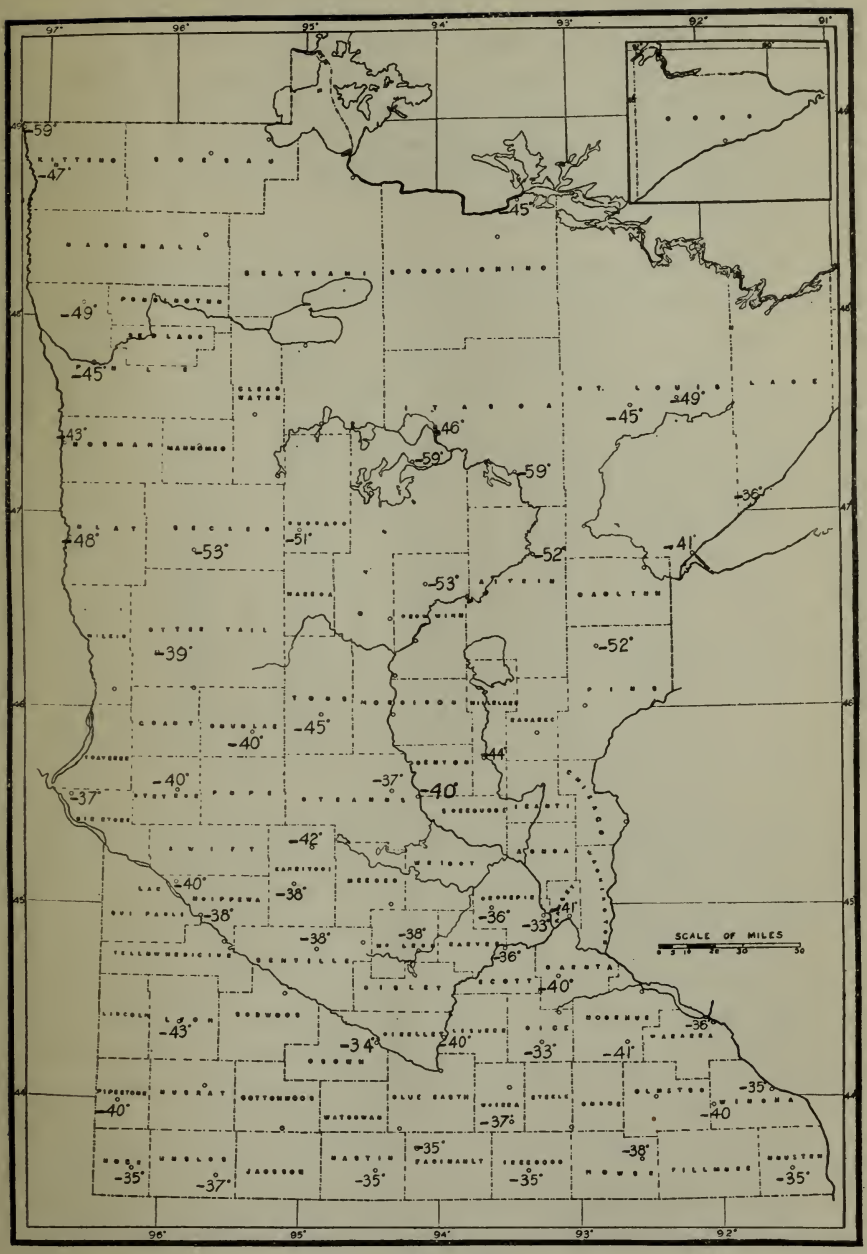


FIGURE 5. MAP SHOWING LOWEST KNOWN TEMPERATURES IN MINNESOTA (DEGREES FAHRENHEIT)

From these figures it can readily be seen that the extreme range of temperature is from 107° at Grand Meadow and Milan, to — 59° at Leech Lake Dam and Pokegama Falls. Temperatures above 100° have been recorded in all counties except those about the headwaters of the Mississippi River, and in the country immediately bordering on Lake Superior. Temperatures of — 40° have occurred in nearly all northern and central counties and in a few southern counties, but these great extremes do not occur frequently.

Table II. Seasonal Temperatures for Minnesota (Degrees Fahrenheit)

Year	Winter mean	Spring mean	Summer mean	Fall mean	April to Sept. inclusive (crop-growing season)
1895	.....	.....	.....	.....	61.4
1896	16.2	42.3	68.1	38.2	60.7
1897	14.3	39.9	66.1	47.3	60.4
1898	15.7	43.1	67.9	43.4	60.6
1899	8.8	37.9	68.2	48.3	60.0
1900	13.8	44.3	70.0	46.2	62.9
1901	13.9	44.1	70.0	45.1	62.0
1902	14.8	44.5	65.4	45.2	58.5
1903	11.5	42.9	64.4	43.0	57.9
1904	5.5	40.0	64.7	47.2	57.6
1905	10.4	42.8	66.4	46.2	59.3
1906	17.1	40.7	66.9	46.6	60.9
1907	11.5	36.3	65.9	44.3	55.6
1908	18.5	41.8	65.8	48.3	60.1
1909	13.9	38.4	68.4	45.7	58.8
1910	9.8	47.1	68.1	44.8	60.4
1911	12.2	45.1	67.3	40.1	60.2
1912	7.8	40.4	65.0	46.2	58.9
1913	11.9	39.8	68.0	46.1	60.3
1914	15.3	41.8	67.7	48.5	60.3
Mean	12.8	41.7	67.0	45.3	59.8

Frosts.—Although frosts have occurred in some portions of the State every month of the year, damaging temperatures are not to be expected during June, July, and August, and they are comparatively rare in the last half of May and the first half of September. Records of ten or more years are available from a large number of places in the State, of which charts have been constructed showing the average date of the last killing frost in spring and the first one in autumn. Using these dates as boundaries, we can mark the average beginning and ending of crop growth and determine the average length of the growing season. All of this information is graphically shown in Figures 6, 7, and 8. By reference to Figure 8 the influence of Lake Superior in lengthening the crop-growing season in its vicinity may be seen; while in the same latitude in the highlands of Hubbard, Becker, eastern Mahnomen, and Clearwater counties the season is twenty to thirty days shorter. The longest season, 160 days, obtains along the Mississippi River from Hennepin County to the southeastern corner of the State, and the shortest, 100 days or less, is in the region of the Mesabi and Vermilion Iron Ranges.

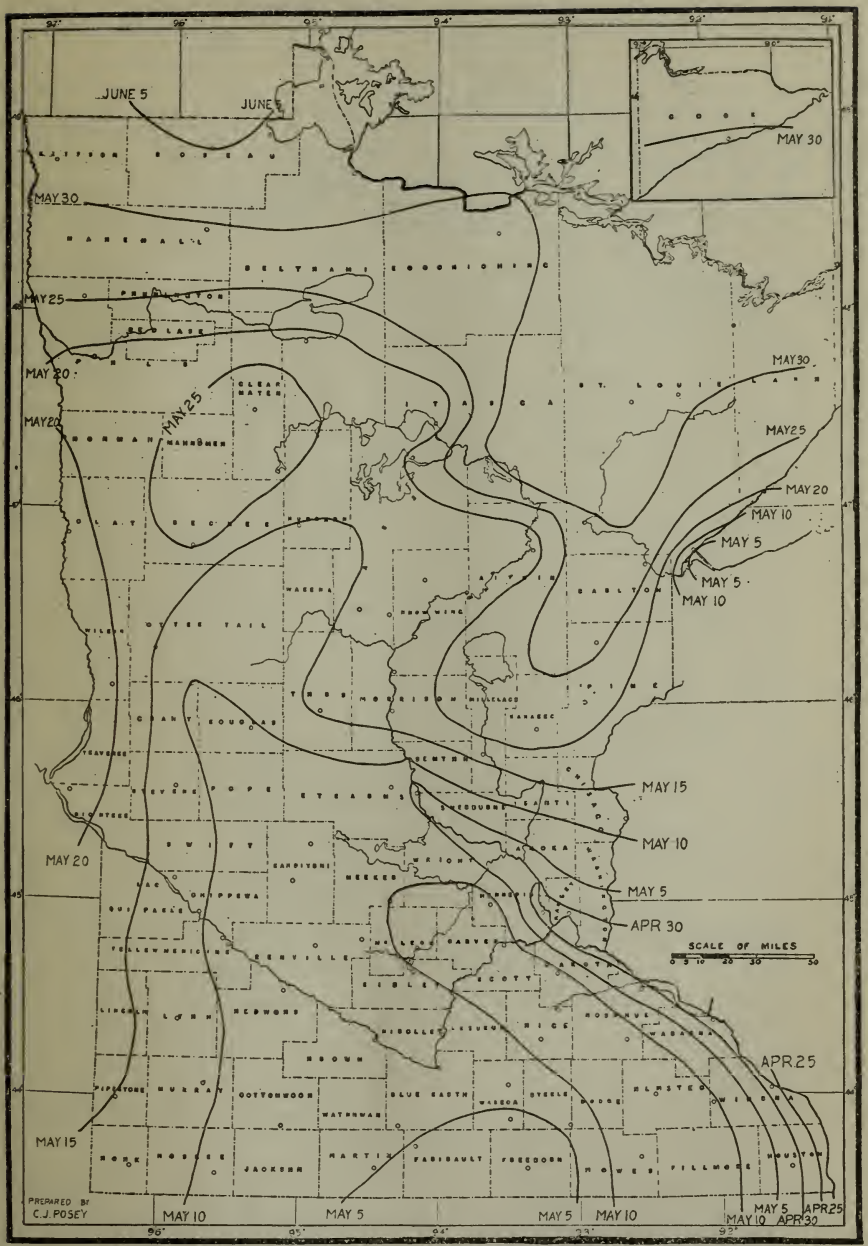


FIGURE 6. MAP SHOWING AVERAGE DATE OF THE LAST KILLING FROST IN SPRING IN MINNESOTA

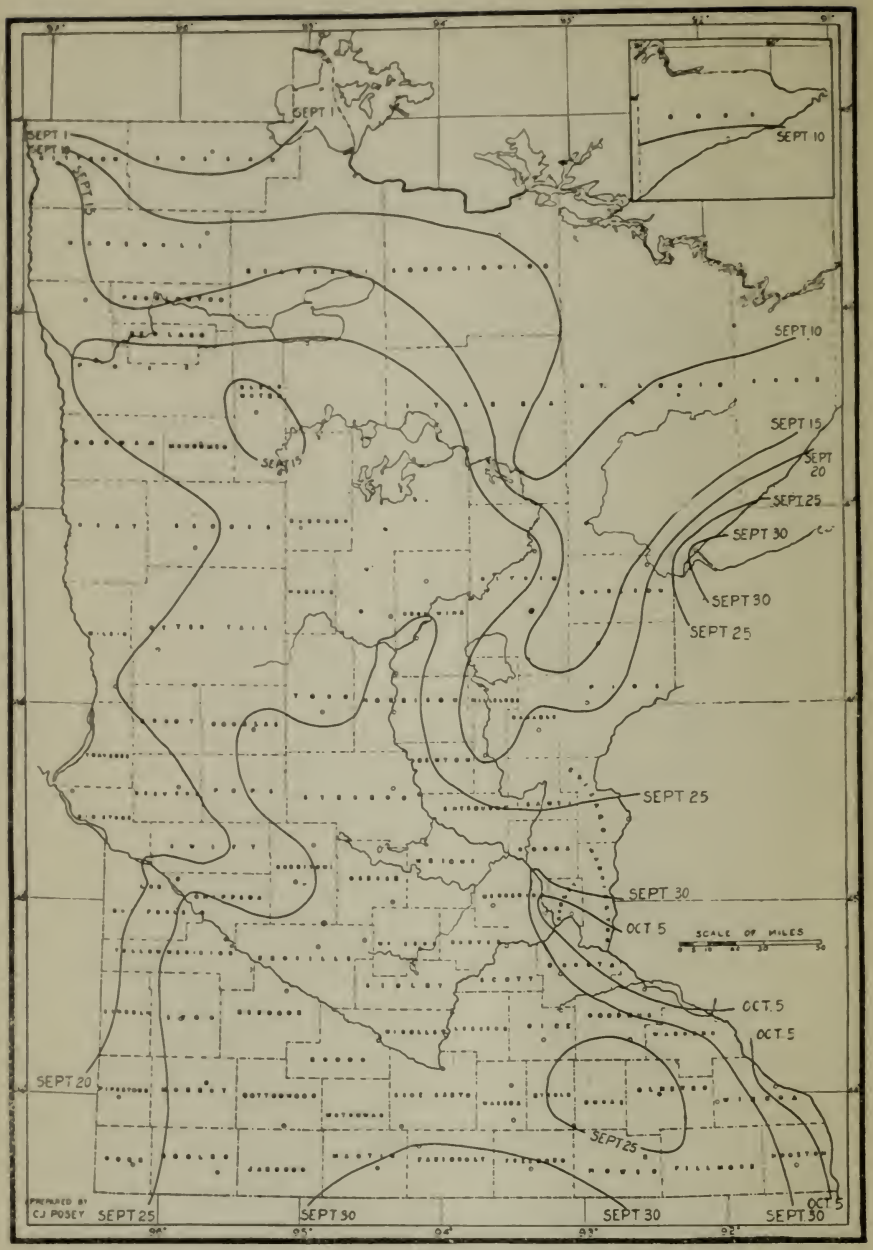


FIGURE 7. MAP SHOWING AVERAGE DATE OF FIRST KILLING FROST IN AUTUMN IN MINNESOTA

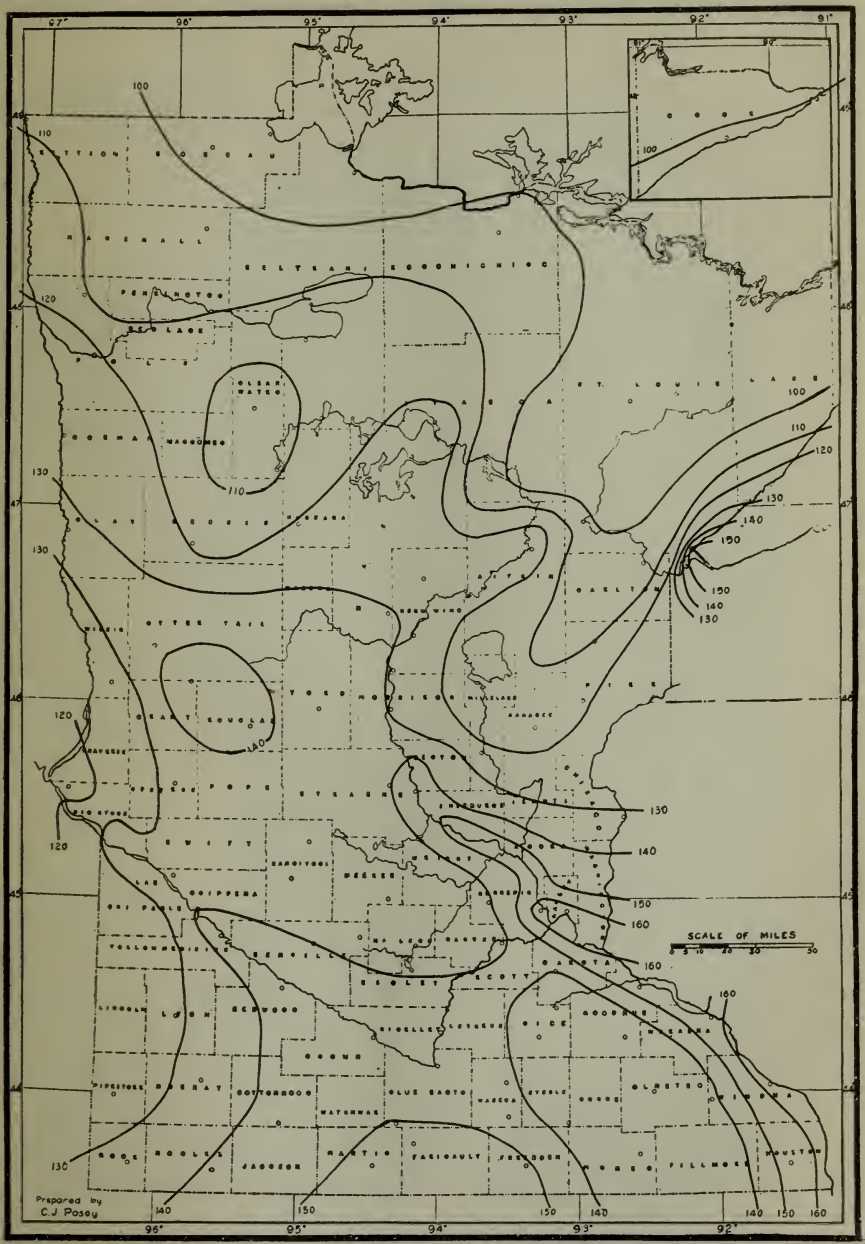


FIGURE 8. MAP SHOWING NUMBER OF DAYS OF THE AVERAGE CROP-GROWING SEASON IN MINNESOTA

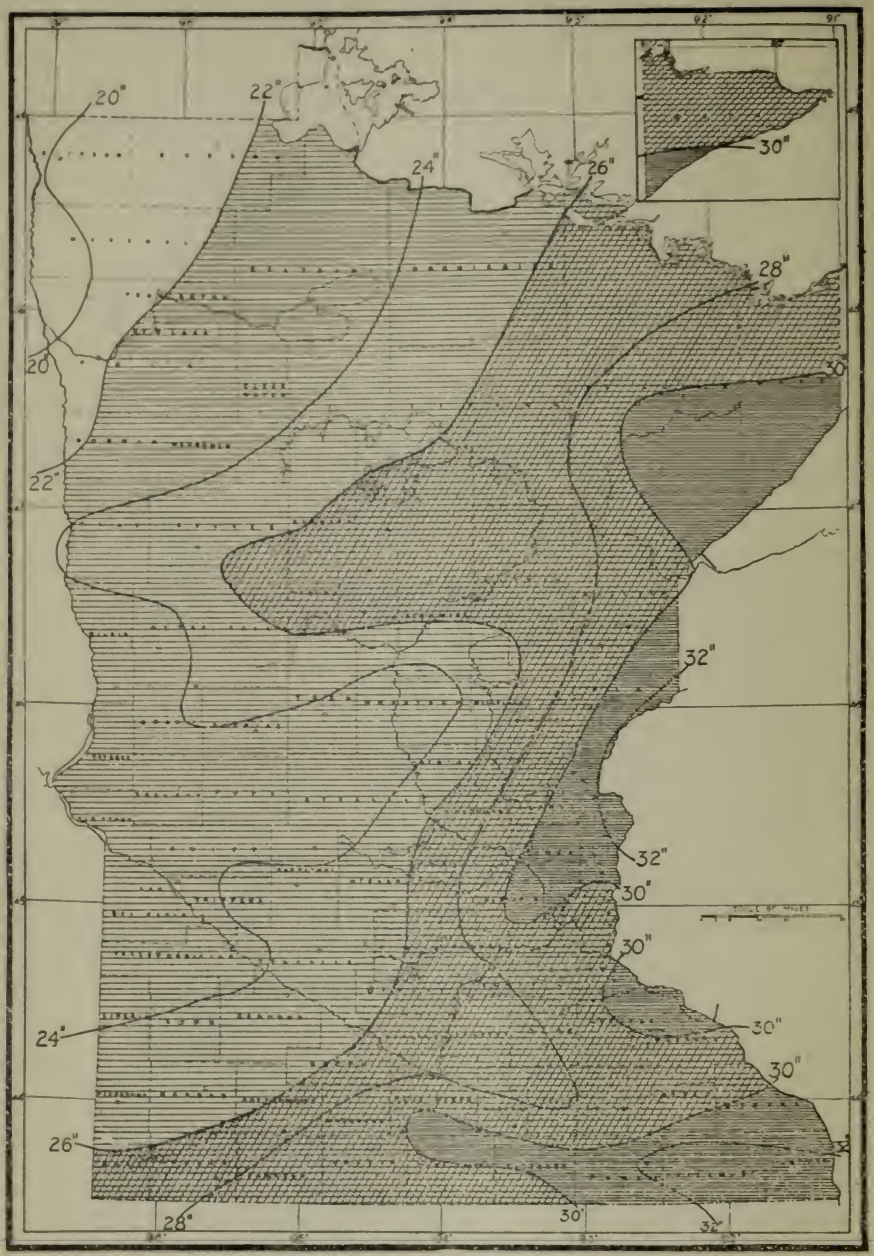


FIGURE 9. MAP SHOWING THE AVERAGE ANNUAL PRECIPITATION FOR MINNESOTA

Table III. Average Monthly and Annual Precipitation for Minnesota (in Inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Total April to Sept. incl.
1895....	.....	.....	.....	1.68	3.30	4.37	3.25	2.27	3.93	0.25	1.22	0.28	.....	18.80
1896....	0.76	0.39	1.97	5.91	5.02	4.07	1.88	2.28	2.49	2.95	2.69	0.61	32.04	21.65
1897....	1.77	1.21	2.07	1.55	1.38	5.40	6.62	2.54	1.89	1.55	0.53	0.38	27.23	19.38
1898....	0.16	1.02	1.21	1.64	3.26	3.93	2.94	3.22	1.52	3.83	1.02	0.18	24.21	16.51
1899....	0.60	0.78	1.58	1.49	4.46	6.36	2.84	5.35	1.47	3.22	0.63	0.95	30.14	21.97
1900....	0.48	0.56	1.30	1.47	0.90	1.71	5.48	6.44	6.55	3.85	0.62	0.51	29.79	22.55
1901....	0.38	0.40	1.68	1.73	1.41	5.81	3.33	2.21	4.34	1.86	0.78	0.57	24.26	18.83
1902....	0.44	0.67	0.92	1.67	5.10	3.32	4.76	4.35	2.23	1.93	1.57	1.79	29.46	21.43
1903....	0.45	0.59	1.75	2.82	5.37	1.96	5.11	4.65	5.63	3.13	0.35	0.84	32.85	25.54
1904....	0.39	0.62	1.51	1.72	2.43	4.26	3.96	2.77	3.14	3.50	0.14	0.82	29.65	18.28
1905....	0.65	0.55	1.21	1.46	5.54	6.41	4.12	4.36	3.45	2.53	2.64	0.15	33.10	25.34
1906....	1.15	0.27	1.20	1.72	5.58	4.55	2.93	4.66	3.73	2.28	1.82	0.91	31.66	23.17
1907....	1.17	0.58	0.94	1.01	2.14	4.31	3.57	4.11	3.48	1.31	0.57	0.57	24.03	18.62
1908....	0.31	1.11	1.47	2.55	6.31	6.35	3.21	2.07	2.41	1.91	1.18	0.79	29.49	22.90
1909....	1.32	1.31	0.54	1.89	3.36	3.53	3.84	4.54	3.16	1.56	2.68	1.54	29.27	20.32
1910....	0.83	0.45	0.27	1.54	1.58	1.39	1.94	2.35	2.45	0.97	0.52	0.44	14.73	11.25
1911....	0.81	0.88	0.63	1.88	3.48	3.79	3.61	4.27	3.35	3.93	1.12	1.35	29.10	20.38
1912....	0.40	0.21	0.45	2.04	4.13	1.66	4.30	3.97	3.03	0.97	0.36	0.93	22.45	19.13
1913....	0.33	0.44	1.27	1.87	3.53	3.08	5.56	2.79	3.33	2.58	0.66	0.05	25.49	20.16
1914....	0.81	0.44	1.12	2.41	2.89	8.34	2.48	3.97	3.08	2.00	0.38	.....	.....	23.77
Mean..	0.70	0.66	1.22	2.00	3.56	4.18	3.79	3.66	3.23	2.31	1.07	0.71	27.72	20.33

Precipitation.—The annual average precipitation of the State as a whole for a period of eighteen years, 1896 to 1913 inclusive, is 27.72 inches, and for the crop season, April to September inclusive, for nineteen years, 1895 to 1913, is 20.16 inches. The monthly, seasonal, and annual averages for this period are shown in Table III. The year with the greatest annual rainfall was 1905, when the total was 33.10 inches. The driest year was 1910 with 14.73 inches. In that year the rainfall during the crop-growing season was 11.25 inches.

Table IV. Average Monthly and Annual Precipitation by Drainage Districts

Watersheds	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake Superior...	0.88	0.88	1.41	2.05	3.50	4.19	4.21	3.73	4.18	2.80	1.45	1.13	30.40
Rainy River.....	0.94	0.94	1.42	1.96	3.10	4.04	3.76	3.32	2.98	2.08	1.46	0.98	26.98
Red River.....	0.55	0.56	0.98	1.84	2.85	3.83	3.34	3.12	2.32	1.55	0.72	0.56	22.22
Mississippi (above St. Croix).....	0.73	0.70	1.23	2.16	3.42	4.13	3.61	3.57	3.00	2.29	1.05	0.73	26.63
St. Croix and Mississippi (below St. Croix).....	0.92	0.95	1.49	2.37	4.01	4.46	3.72	3.69	3.72	2.73	1.36	1.13	30.57
Minnesota River.	0.79	0.73	1.19	2.30	3.52	4.18	3.34	3.44	2.63	2.11	1.02	0.79	26.04
Big Sioux and Des Moines Rivers.	0.50	0.54	1.13	2.09	4.00	4.39	3.49	3.58	2.79	2.07	0.94	0.63	26.15
State.....	0.76	0.75	1.25	2.18	3.53	4.19	3.55	3.50	3.02	2.24	1.09	0.84	26.90

June is the wettest month with an average rainfall of 4.18 inches, and July is next with 3.79 inches. The lowest monthly rainfall is that of February with an average of 0.66 inch. The greatest rainfall in one month for the State as a whole was 8.34 inches in June, 1914. The lowest rainfall for any month was .05 inch in December, 1913.

The geographic distribution of annual and monthly precipitation is

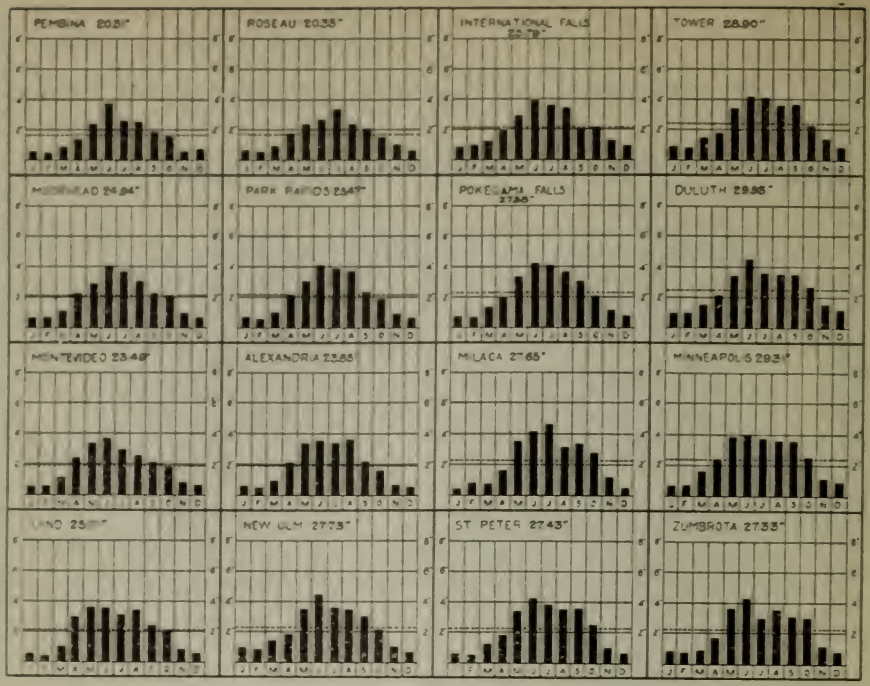


FIGURE 10. DIAGRAM SHOWING COMPARATIVE MONTHLY DISTRIBUTION OF PRECIPITATION IN MINNESOTA. LETTERS INDICATE MONTHS, BLACK COLUMNS INDICATE INCHES OF RAINFALL IN EACH MONTH AT STATION NAMED

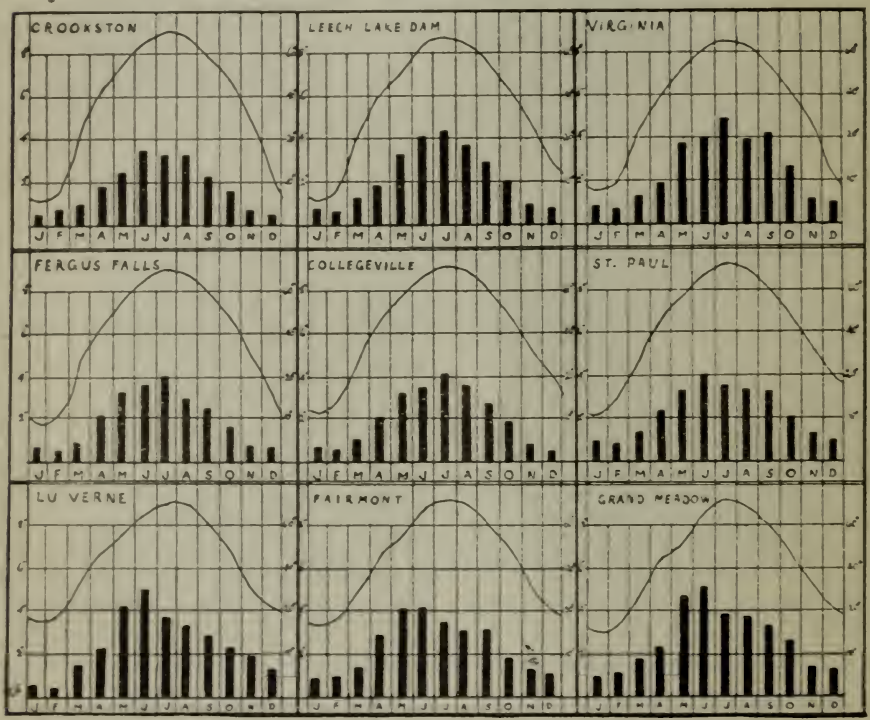
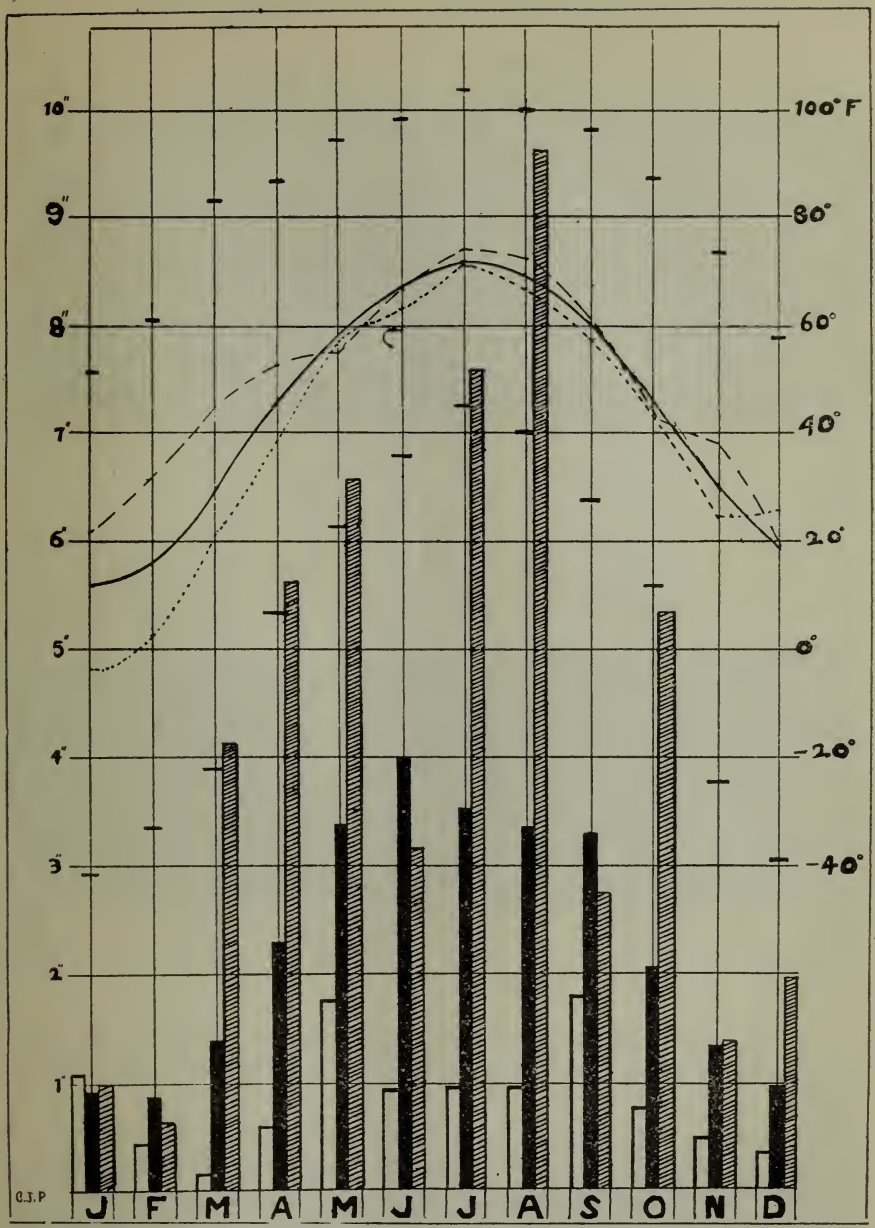


FIGURE 11. MEAN MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURE AT SEVERAL STATIONS IN MINNESOTA. MONTHS ARE INDICATED BY THEIR FIRST LETTERS. THE GREATEST RAINFALL IS IN THE GROWING SEASON



▮ =mean monthly rainfall, 1837-1913.
▨ =monthly rainfall of year of greatest rainfall recorded, 1849.
□ =monthly rainfall of year of least rainfall recorded, 1910.
Solid curve=mean monthly temperature, 1871-1913.
Dotted curve=mean monthly temperature for year of lowest annual temperature recorded, 1875.
Dashed curve=mean monthly temperature for year of highest annual temperature recorded, 1878.
Horizontal dashes show absolute maximum and minimum temperatures recorded.

FIGURE 12. DIAGRAM SHOWING RAINFALL AND TEMPERATURES (DEGREES FAHRENHEIT) AT ST. PAUL, MINNESOTA FROM 1837-1913. MONTHS ARE INDICATED BY THEIR FIRST LETTERS

graphically shown in Figures 9 to 11, and for the stations having ten or more years of record in Table V. Table IV shows the monthly and annual distribution in the various watersheds. From these illustrations it may be seen that the precipitation is about one-fourth to one-third greater along the eastern boundary of the State than along the western boundary.

Table V. Average Annual Precipitation in Minnesota by Stations

Station	County	Length of record	Average annual precip.	Station	County	Length of record	Average annual precip.
		Yrs.	Inches			Yrs.	Inches
Albert Lea	Freeborn	21	29.90	Montevideo	Chippewa	22	23.50
Alexandria	Douglas	25	23.74	Moorhead	Clay	31	24.92
Angus	Polk	10	19.00	Morris	Stevens	27	23.23
Ashby	Grant	14	24.47	New London	Kandiyohi	18	23.62
Beardsley	Bigstone	16	23.79	New Richland	Waseca	10	29.91
Bird Island	Renville	22	24.23	New Ulm	Brown	32	27.74
Blooming Prairie	Steele	13	27.45	Northfield	Rice	12	29.92
Caledonia	Houston	19	33.70	Osceola, Wis	Polk	21	32.13
Collegeville	Stearns	19	22.76	Park Rapids	Hubbard	22	25.71
Crookston	Polk	22	22.41	Pembina, N. D.	Pembina	14	19.79
Detroit	Becker	16	25.96	Pine River Dam	Crow Wing	25	27.52
Duluth	St. Louis	41	29.93	Pipestone	Pipestone	12	24.18
Fairmont (near)	Martin	25	28.20	Pokegama Falls	Itasca	25	27.62
Faribault	Rice	14	28.00	Red Wing	Goodhue	16	31.71
Farmington	Dakota	24	29.29	Redwood Falls	Redwood	13	24.65
Fergus Falls	Ottertail	24	23.24	Reeds Landing	Wabasha	16	29.31
Flandreau, S. D.	Moody	22	24.57	St. Charles	Winona	21	30.68
Fort Ripley	Crow Wing	43	25.25	St. Cloud	Sherburne	19	27.68
Glencoe	McLeod	15	26.64	St. Paul	Ramsey	41	28.68
Grand Meadow	Mower	24	32.59	St. Peter	Nicollet	18	27.89
Grantsburg, Wis	Burnett	21	33.06	Sandy Lake Dam	Aitkin	19	26.47
Hallock	Kittson	13	21.37	Shakopee	Scott	15	28.85
Halstad (Ada)	Norman	16	21.27	Tonka	Hennepin	13	30.54
International Falls	Koochiching	10	25.75	Tower (Ely)	St. Louis	10	28.17
La Crosse, Wis	La Crosse	40	31.17	Two Harbors	Lake	18	30.56
Leech Lake Dam	Cass	24	27.00	University, N. D.	Grand Forks	20	20.47
Long Prairie	Todd	20	25.17	Virginia (Mt. Iron)	St. Louis	18	30.74
Luverne	Rock	15	27.60	Wabasha	Wabasha	17	30.54
Lynd	Lyon	19	25.43	Wahpeton, N. D.	Richland	20	23.67
Mankato	Blue Earth	14	27.50	Willmar	Kandiyohi	10	25.54
Mapleplain	Hennepin	17	31.11	Willow River	Pine	10	29.98
Milaca	Mille Lacs	13	27.27	Winnebago	Faribault	14	30.58
Milan	Chippewa	18	24.49	Winnibigoshish	Itasca	25	25.66
Milbank, S. D.	Grant	21	22.69	Winona	Winona	16	29.63
Minneapolis	Hennepin	21	29.31	Worthington	Nobles	17	28.24

Figure 11 makes an interesting comparison of monthly and annual values of both temperature and rainfall at certain selected representative stations.

Snowfall.—The snowfall averages from 24 to 54 inches. It is lightest in the southwest portion of the State and heaviest on the Mesabi Iron Range. The monthly and annual averages are shown in Table VI, arranged according to sections and drainage districts.

Winds.—The prevailing winds are from the northwest over most of the State. The monthly and annual prevailing directions are shown for a large group of stations in Table VII. The average hourly wind velocity is shown for six regular Weather Bureau stations and three special stations in Table VIII.

Relative humidity.—The average annual humidity for the State is

A. FLAX FIELD ON RED RIVER CLAY PLAIN

B. POTATO FIELD ON RED RIVER CLAY PLAIN

C. CORN FIELD ON RED RIVER CLAY PLAIN

Table VI. Average Snowfall

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Yrs.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
Lake of the Woods Group—														
Tower	9	9.0	8.6	10.9	4.2	0.6	0	0	0	0.2	0.4	8.4	8.2	50.5
Red River Valley Group—														
St. Vincent-Pembina	14	8.4	5.1	6.9	5.2	0.7	0	0	0	0.1	0.7	5.7	6.4	39.2
Crookston	14	6.3	6.7	8.8	3.2	0.2	0	0	0	T.	0.4	4.5	5.7	35.8
Moorhead	17	7.6	6.7	8.9	4.9	0.3	0	0	0	0.1	1.0	6.9	6.8	43.7
Upper Mississippi River Valley Group—														
Park Rapids	14	9.0	6.5	9.1	5.4	0.9	0	0	0	0.2	1.4	7.4	6.3	46.2
Lake Winnibigoshish	14	8.6	6.5	9.9	3.3	0.8	0	0	0	T.	1.0	7.8	7.8	45.7
Sandy Lake Dam	14	9.0	9.5	10.6	3.6	0.7	0	0	0	0.2	1.1	7.4	7.4	49.4
Lake Superior Group—														
Mt. Iron	13	9.9	7.8	11.2	3.9	1.1	0	0	0	0.1	0.8	8.1	11.6	54.4
Duluth	25	10.3	9.1	11.1	4.0	1.0	0	0	0	0.1	0.3	8.2	8.7	52.8
Lower Mississippi River Valley Group—														
La Crosse, Wis	15	8.4	8.7	6.6	1.4	T.	0	0	0	T.	0.1	3.9	8.9	37.1
Grand Meadow	14	8.0	9.8	9.9	3.1	0.4	0	0	0	T.	0.3	5.3	9.3	46.1
St. Charles	9	7.7	9.4	9.5	2.4	0.2	0	0	0	0	0.1	4.3	9.3	42.9
Red Wing	8	8.0	5.6	4.4	1.8	0.2	0	0	0	T.	0.3	1.5	7.1	28.9
St. Paul	24	7.7	6.2	8.8	3.6	0.2	0	0	0	T.	0.2	4.7	5.7	37.1
Lower Minnesota River Valley Group—														
Shakopee	14	7.7	8.1	7.8	1.9	T.	0	0	0	T.	0.4	3.0	4.6	33.5
St. Peter	13	5.5	6.1	7.1	0.7	T.	0	0	0	0	0.4	1.4	4.0	25.2
Winnebago	10	6.5	7.5	6.3	1.0	T.	0	0	0	T.	0.3	2.3	6.5	30.4
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8.3	8.6	9.5	4.0	0.2	0	0	0	T.	0.3	4.5	6.4	42.4
Collegeville	14	6.7	5.6	8.5	1.8	0.4	0	0	0	T.	0.3	3.5	5.0	31.8
Pine River Dam	14	9.1	8.4	9.5	2.8	0.8	0	0	0	0.1	0.6	5.9	6.8	44.0
Osceola, Wis	11	9.1	8.4	11.7	2.8	T.	0	0	0	T.	0.1	5.5	6.8	44.4
Grantsburg, Wis	11	9.2	9.0	12.2	4.2	0.1	0	0	0	0	0.1	8.5	8.9	52.2
Upper Minnesota River Valley Group—														
New Ulm	14	8.9	7.5	9.5	1.7	0.2	0	0	0	T.	0.3	3.5	4.4	36.0
Bird Island	14	4.7	5.8	6.0	1.5	0.4	0	0	0	T.	0.5	3.5	3.4	25.8
Milan	14	7.5	8.1	11.2	1.6	0.5	0	0	0	T.	0.6	4.1	6.1	39.7
Minnesota River Watershed Group—														
New London	14	4.6	4.2	7.0	1.7	0.1	0	0	0	0	0.3	2.7	3.4	24.0
Long Prairie	14	5.7	5.5	7.4	2.4	0.4	0	0	0	T.	0.2	3.3	4.4	29.3
Morris	14	5.2	5.4	7.8	2.1	0.5	0	0	0	0	0.6	3.2	4.4	29.2
Fergus Falls	13	6.2	5.7	7.6	2.8	0.4	0	0	0	T.	1.0	5.7	5.8	35.2
Southwestern Group—														
Fairmont	13	5.0	10.0	8.8	1.9	0.1	0	0	0	T.	0.2	3.9	5.3	35.2
Worthington	13	4.1	7.2	7.6	1.2	T.	0	0	0	0	0.3	2.7	3.6	26.7
Lynd	14	6.3	5.1	7.4	2.8	0.5	0	0	0	T.	1.2	2.8	5.3	31.4
Gary, S. D	11	4.4	6.6	12.4	4.5	0.2	0	0	0	T.	1.2	4.2	4.1	37.6

83 per cent at 7 a. m. and 72 per cent at 7 p. m. Table IX gives the monthly and annual data.

Number of rainy days.—In Table X the number of rainy days during each month and the year is given for thirty-three stations well distributed over the State. The smallest number is 64 at Lynd, Lyon County, and the largest 132 days at Duluth.

Sunshine.—The sunshine is abundant, averaging from 43 to 53 per cent of the highest amount possible. The daylight hours are materially longer during the crop-growing season in the northern portion of the State than in the southern. The greatest percentage of sunshine is in the southwestern portion and the least in the northeastern part.

Table VII. Prevailing Wind Direction

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Year
Lake of the Woods Group—														
Tower	9	nw.	w.	nw.	w.	w.	w.	w.	w.	w.	w.	w.	nw.	w.
Red River Valley Group —														
St. Vincent-Pembina	23	nw.	nw.	nw.	nw.	nw.	se.	s.	se.	nw.	nw.	nw.	nw.	nw.
Crookston	14	s.	nw.	s.	n.	nw.	s.	sw.	se.	nw.	s.	s.	nw.	s.
Moorhead	28	nw.	nw.	nw.	n.	n.	se.	s.	se.	se.	se.	nw.	nw.	n.
Upper Mississippi River Valley Group—														
Park Rapids	16	nw.	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lake Winnibigoshish	16	nw.	nw.	w.	nw.	nw.	w.	w.	w.	w.	nw.	nw.	nw.	nw.
Sandy Lake Dam	14	nw.	nw.	nw.	se.	e.	e.	nw.	nw.	s.	nw.	nw.	nw.	nw.
Lake Superior Group—														
Mt. Iron	14	nw.	n.	n.	n.	n.	s.	s.	n.	s.	s.	nw.	nw.	n.
Duluth	38	sw.	nw.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	ne.	sw.	sw.	ne.
Lower Mississippi River Valley Group—														
La Crosse, Wis	36	s.	s.	n.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
Grand Meadow	15	nw.	nw.	nw.	nw.	nw.	se.	s.	s.	s.	sw.	nw.	nw.	nw.
St. Charles	13	nw.	nw.	se.	se.	nw.	se.	se.	nw.	s.	se.	nw.	nw.	nw.
Red Wing	12	nw.	nw.	nw.	se.	e.	se.	sw.	w.	e.	w.	nw.	nw.	nw.
St. Paul	38	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Lower Minnesota River Valley Group—														
Shakopee	14	nw.	nw.	nw.	se.	se.	nw.	nw.	nw.	se.	nw.	nw.	nw.	nw.
St. Peter	13	nw.	nw.	nw.	nw.	nw.	nw.	se.	nw.	s.	nw.	nw.	nw.	nw.
Winnebago	9	nw.	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	nw.	nw.	nw.
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	nw.	nw.	nw.	nw.	ne.	s.	s.	s.	s.	s.	nw.	nw.	nw.
Collegeville	14	nw.	nw.	nw.	s.	nw.	sw.	s.	nw.	s.	nw.	nw.	nw.	nw.
Pine River Dam	16	nw.	nw.	nw.	nw.	nw.	w.	w.	nw.	nw.	nw.	nw.	nw.	nw.
Osceola, Wis	11	s.	s.	n.	n.	s.	s.	s.	s.	s.	n.	n.	s.	s.
Grantsburg, Wis	11	nw.	nw.	sw.	se.	ne.	sw.	sw.	sw.	sw.	nw.	nw.	nw.	nw.
Upper Minnesota River Valley Group—														
New Ulm	14	nw.	nw.	s.	s.	s.	s.	s.	s.	nw.	nw.	nw.	nw.	nw.
Bird Island	16	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Milan	14	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Minnesota River Watershed Group—														
New London	14	nw.	nw.	nw.	se.	se.	se.	se.	se.	se.	se.	nw.	nw.	se.
Long Prairie	14	nw.	nw.	nw.	se.	se.	nw.	nw.	se.	se.	nw.	nw.	nw.	nw.
Morris	17	nw.	nw.	s.	s.	s.	s.	s.	s.	s.	s.	n.	s.	s.
Fergus Falls	13	nw.	nw.	nw.	se.	se.	se.	nw.	se.	nw.	nw.	nw.	nw.	nw.
Southwestern Group—														
Pairmont	15	nw.	nw.	nw.	nw.	nw.	s.	s.	nw.	s.	nw.	nw.	nw.	nw.
Worthington	13	nw.	nw.	nw.	s.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.	nw.
Lynd	14	nw.	nw.	nw.	nw.	se.	nw.	sw.	nw.	nw.	sw.	nw.	nw.	nw.
Gary, S. D	11	nw.	nw.	nw.	sw.	se.	se.	se.	s.	ne.	sw.	nw.	nw.	nw.

Table VIII. Average Hourly Wind Velocity in Miles

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth	5	14.3	14.2	15.0	15.1	15.2	11.6	11.3	12.0	12.7	13.9	14.1	14.2	13.6
Moorhead	19	10.3	10.5	11.3	12.0	10.7	10.0	8.3	8.4	10.4	10.4	10.1	10.0	10.2
St. Vincent-Pembina	15	7.7	9.4	10.0	10.7	10.0	8.7	7.5	7.5	9.1	9.3	9.5	8.9	9.2
Two Harbors	6	9.0	8 2	9.7	9.4	7.6	7.4	7.3	7.2	8.0	8.3	8.7	8.9	8.3
La Crosse, Wis	36	7.1	7.5	8.0	8.5	7.5	6.7	6.0	5.8	6.9	7.5	7.5	7.2	7.2
St. Paul	36	7.8	8.3	8.8	9.3	8.7	7.7	7.1	7.1	8.0	8.5	8.1	7.8	8.1
Minneapolis	18	11.5	11.6	12.3	12.8	12.1	10.3	9.9	9.9	11.6	11.7	11.0	11.2	11.3
Faribault	7	9.4	9.1	9.4	11.0	9.0	7.3	5.9	6.4	7.8	8.8	9.0	9.1	8.5
Collegeville	11	9.5	9.6	11.0	12.2	11.1	10.0	9.4	9.4	10.9	9.5	9.9	9.9	10.2

Table IX. Mean Relative Humidity in Degrees

Stations		Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Duluth	8 a.m.	21	83	83	81	76	76	79	79	81	82	81	83	84	81
	8 p.m.	21	77	75	71	65	64	69	65	69	71	72	76	78	71
Moorhead	8 a.m.	21	89	88	88	84	79	84	86	87	87	84	89	89	86
	8 p.m.	21	86	86	82	65	56	62	64	61	63	69	81	85	72
St. Vincent	8 a.m.	4	80	80	88	88	79	84	88	90	87	89	89	87	86
	8 p.m.	4	83	86	88	77	58	66	71	70	71	78	89	89	77
La Crosse, Wis.	8 a.m.	21	83	82	79	74	75	79	81	85	85	81	81	83	81
St. Paul	8 a.m.	21	84	84	81	75	75	79	79	83	83	81	81	83	81
	8 p.m.	21	76	75	68	55	54	58	55	56	60	63	69	76	64
Minneapolis	8 p.m.	7	83	79	76	66	66	67	65	68	72	73	79	83	74

Table X. Number of Days with 0.01 Inch or More of Precipitation

Stations	Length of record, yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Lake of the Woods Group—														
Tower	9	5	4	6	5	8	9	10	8	10	7	5	5	82
Red River Valley Group—														
St. Vincent-Pembina	25	7	6	7	7	8	11	10	9	8	7	7	7	94
Crookston	14	4	4	5	6	8	10	8	8	6	5	3	4	71
Moorhead	28	8	9	8	9	11	12	10	9	8	8	7	8	107
Upper Mississippi River Valley Group—														
Park Rapids	14	8	7	10	9	11	13	11	10	9	9	7	8	112
Lake Winnibigoshish	15	6	4	7	6	10	10	9	8	7	5	5	6	83
Sandy Lake Dam	14	6	6	8	6	10	10	10	10	9	8	6	6	95
Lake Superior Group—														
Mt. Iron	14	5	4	5	5	9	11	10	9	9	7	5	6	85
Duluth	38	10	9	10	9	12	14	12	12	12	10	11	11	132
Lower Mississippi River Valley Group—														
La Crosse, Wis	36	10	8	10	10	12	12	10	9	10	9	8	10	120
Grand Meadow	15	6	5	7	7	12	9	9	8	8	7	6	6	90
St. Charles	12	5	4	6	6	9	11	7	6	8	7	5	4	78
Red Wing	10	5	5	6	7	11	10	7	7	8	6	5	5	82
St. Paul	38	9	8	10	10	12	12	10	10	9	9	8	9	114
Lower Minnesota River Valley Group—														
Shakopee	14	5	5	7	8	11	10	9	9	9	8	6	5	92
St. Peter	12	3	3	5	6	10	9	7	7	6	5	3	2	66
Winnebago	10	4	4	6	6	12	11	9	9	7	7	3	4	82
Middle Mississippi River and St. Croix Valleys Group—														
Minneapolis	18	8	7	9	9	12	12	9	9	8	9	7	8	107
Collegeville	14	6	5	8	7	10	12	10	10	9	8	6	5	96
Pine River Dam	15	4	4	6	6	9	10	8	8	7	6	4	4	76
Osceola, Wis	11	7	5	6	6	8	9	8	7	6	7	5	5	79
Grantsburg, Wis	11	5	4	5	6	8	7	7	6	5	4	5	6	68
Upper Minnesota River Valley Group—														
New Ulm	14	5	5	7	7	11	11	8	8	8	7	5	4	86
Bird Island	14	4	3	6	7	10	10	8	8	8	6	5	3	78
Milan	14	6	5	7	7	9	11	8	8	7	6	5	5	84
Minnesota River Watershed Group—														
New London	14	3	3	5	5	9	9	7	6	6	5	4	3	65
Long Prairie	14	4	4	6	8	10	11	8	8	8	7	5	3	82
Morris	16	4	4	6	7	11	12	9	9	7	6	4	4	83
Fergus Falls	13	11	8	11	9	12	15	11	11	10	8	7	10	123
Southwestern Group—														
Fairmont	15	4	4	5	6	10	8	7	7	7	5	3	3	69
Worthington	13	4	4	4	6	11	10	14	8	6	5	4	4	80
Lynd	14	3	3	5	5	8	9	7	8	6	4	3	3	64
Gary, S. D	11	3	2	3	5	6	5	6	5	4	4	3	1	47

CHAPTER III

SURFACE GEOLOGY

ROCK AREAS

The areas in which rock is so exposed as to render the land untillable are largely in the northeast quarter of the State, or along valleys in the southeast quarter. The northwest quarter is estimated to have less than 10 square miles of bare rock outcrop, and the southwest scarcely 100 square miles. It is doubtful if there is an area of 1,000 square miles in the entire State in which the plow would generally strike into rock ledges. The rock areas thus form a much smaller percentage of the State than the lake areas. The rock areas of the northeast part are chiefly rock bosses standing above the surrounding land, but the beds of the streams that lead directly down to Lake Superior are also usually on rock ledges. Among the rock knobs are some depressions covered only with moss and peaty material, glacial material being wanting, but ordinarily some glacial material is present and nearly all the land has soil enough over the bedrock to support a rich forest growth. Many of the knobs preserve the smooth surface left by the scouring effect of the ice sheet and are nearly destitute of vegetation. But certain others have become disintegrated to a depth of several inches or even to several feet from the surface and are supporting growths of vegetation of considerable density.

The rock areas of the southwest part of the State are largely of Sioux quartzite which in places comes to the surface over areas of several square miles. The rocks have scarcely enough soil over them to support the scanty vegetation. There are a few small areas of granite knobs along the Minnesota Valley from Bigstone Lake down to New Ulm. In the driftless area and part of the drift-covered area in southeastern Minnesota rock ledges of limestone and sandstone outcrop along the steep slopes of the valleys, often forming walls of considerable height. Rock is rarely exposed along the stream beds and valley bottoms. The uplands and the higher parts of the slopes of the valleys even in the driftless area usually have several feet of residuary clay and also a coating of loess or wind-deposited silt loam covering the rock formations and rendering the land tillable.

THE EARTHY MANTLE

GENERAL STATEMENT

The variety of earthy, sandy, and gravelly unconsolidated deposits which cover the rocky floor of Minnesota were formed or deposited by

different agencies and at different times. They may be grouped as follows:

First. Residuary material.
Second. Wind deposits.
Third. Glacial deposits.
Fourth. Stream deposits.
Fifth. Lake deposits.

RESIDUARY MATERIAL

The residuary material, as its name implies, has been left as a residue during the breaking down or decay of the surface rocks through weathering and solution. On limestones it is usually a dark, reddish brown, gummy clay, but on sandstones and crystalline rocks it is usually granular and loose-textured. There is but a small part of Minnesota, chiefly in the southeastern counties, where residuary material is within reach of the plow. It occurs there on the upper part of the slopes of the valleys and on the narrow upland strips between valleys, but is usually covered by loess.

WIND DEPOSITS

Loess.—The wind-deposited material known as loess is largely a fine silt loam, which forms the surface in an area in the southeast part of the State embracing much of Goodhue, Olmsted, Wabasha, Winona, Fillmore, and Houston counties and parts of Mower, Dodge, Rice, and Dakota counties. It covers a small tract in the southwest part of the State in Rock, southern Pipestone, and western Nobles counties. In the southeastern counties it rests in part on glacial drift deposits and in part on the residuary clay and rock formations of the driftless area. In the southwestern part it covers glacial deposits. In the southeast district its border is very irregular, there being long strips of loess-covered land projecting westward or northwestward into the region free from loess, and also long strips free from loess extending eastward into the loess-covered tracts. The condition there is such as might result from the presence or absence of vegetation giving different degrees of protective power from the wind; areas with dense vegetation being able to hold dust that settled from the atmosphere while bare ones allowed it to be gathered up and carried on.

Wind-blown sand.—Wind-blown sand is also an important deposit. It embraces a district east of the Mississippi from Minneapolis up to Brainerd. It is narrow above St. Cloud, but below that city extends eastward to the St. Croix River. The sand does not, however, cover the entire surface in this area. Where present it rests upon glacial deposits. It has low ridges seldom 20 feet and usually 10 feet or less in height.

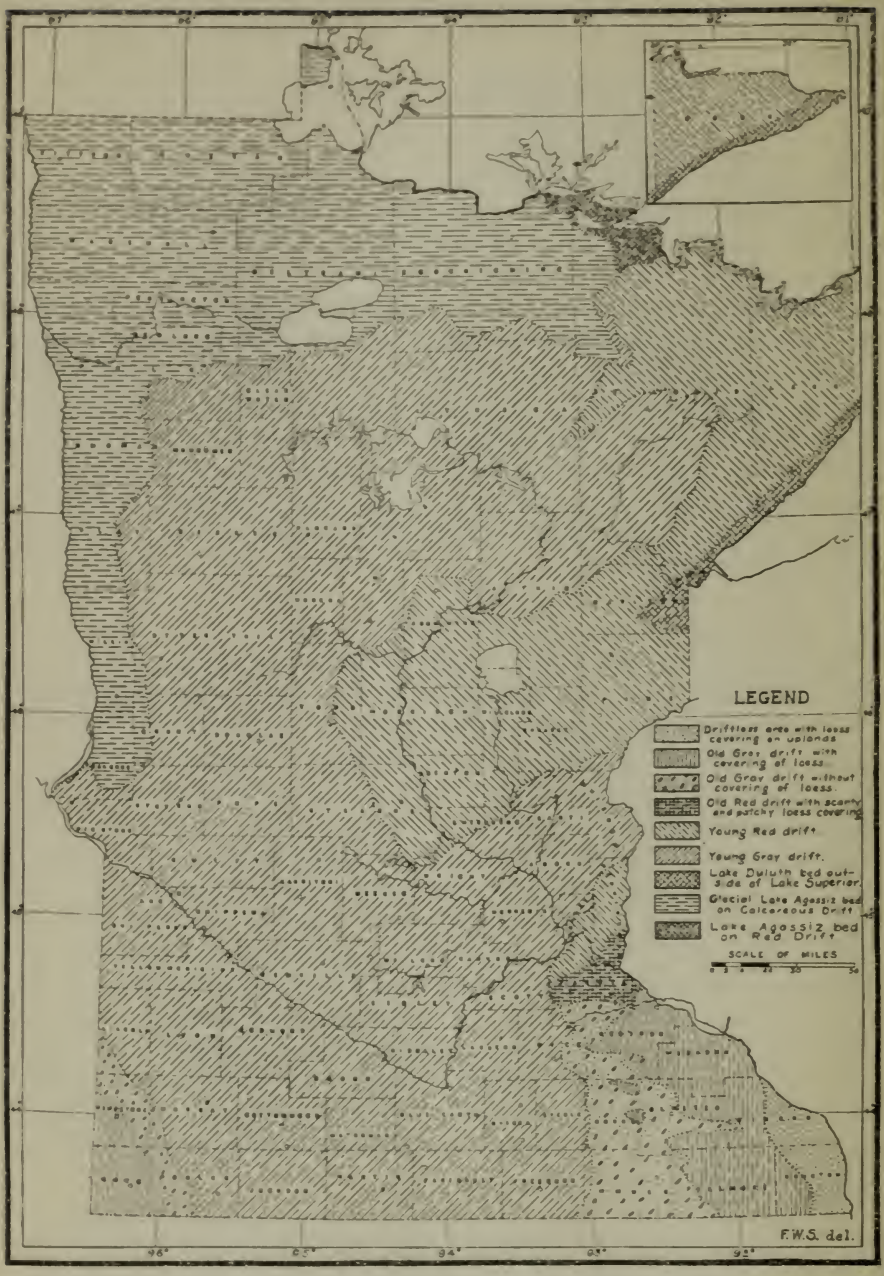


FIGURE 13. MAP SHOWING DISTRIBUTION OF GLACIAL DRIFT LOESS AND GLACIAL LAKES IN MINNESOTA BY FRANK LEVERETT

There is more or less wind-drifted sand in the sandy parts of the St. Louis River Drainage Basin, but it is sparingly developed compared to that in the district between the Mississippi and St. Croix rivers. Wind-blown sand occurs also in Aitkin County in the vicinity of McGregor and also in the northeastern part of the county in island-like tracts that are surrounded by marshes. There are numerous small areas of such sand scattered over the State, some of them being along the shores of the glacial Lake Agassiz.

GLACIAL DEPOSITS

The glacial deposits extend over the entire State except eastern Winona County and the greater part of Houston County, which are in the driftless area of the upper Mississippi. They underlie the wind-deposited sands and much of the loess area. They also underlie stream deposits and lake sediments. The glacial deposits are separable into till or bowlder clay in which stones, clay, and sand are closely commingled, and into sand or gravel beds which show some assorting and bedding by water action. The percentage of stony material varies greatly and the matrix also shows variations from compact clay to loose sand. These variations are to be expected in a deposit that had been formed from the dirt and stones included in an ice sheet. Every observing farmer has probably noted and perhaps speculated upon the cause for these variations in the drift deposits which form the basis for so large a part of the Minnesota soil. The assorted sand and gravel beds are largely due to waters escaping from the melting ice and many of them may be traced up to a moraine which marked the position of the ice border at the time they were laid down. They show a decrease in coarseness in passing away from the edge of the moraine, the coarse material having been dropped close to the edge of the ice and only the fine carried to a great distance outside.

The glacial deposits also show some variations that relate to the kind of rock formations over which the ice passed. Thus, the northeastern portion of the State has a rather stony drift from the volcanic and hard crystalline rocks of that region. This stony material was carried as far south as Dakota County and forms the red drift of eastern and northeastern Minnesota. The western and southern parts of the State have a large amount of clayey drift material with limestone pebbles imbedded. This material was gathered by this ice as it passed across in its southward course from the shales and limestone of southern Manitoba, that greatly dominate there over the granite and other crystalline rocks. These clayey and limy deposits form what is known as the gray drift of Minnesota.

STREAM DEPOSITS

The stream deposits, being restricted to the valleys, are of limited area, though in such valleys as the Minnesota and Mississippi they are locally several miles in width and form important agricultural belts. On the Minnesota and the part of the Mississippi below the confluence with the Minnesota the deposits made by the rivers are sand or silt. On the Mississippi above the mouth of the Minnesota the deposits range from sand to coarse cobble and bowlders in correspondence with the swiftness of the stream. On nearly all the tributaries of the Mississippi and Minnesota the streams are able to carry coarse as well as fine material. Along the Red River a considerable amount of fine clay and clay loam has been deposited in seasons of flood on the plains outside the immediate river channel. Because of the flatness of the surface many of the small tributaries of Red River have been unable to maintain courses clear through to the river, and so have dropped their deposits where the gradient became too low for the stream to carry them farther. The deposits made by glacial streams or those which had their sources at the edge of the ice and were receiving much of their water from the melting ice, now appear usually as terraces along the valleys above the limits of floods. From the fact that the glacial rivers were of greater volume these deposits are generally composed of sandy and gravelly material somewhat coarser than that carried by the present rivers.

LAKE DEPOSITS

The lake deposits consist of fine sediments washed into the deep parts of the lakes and sandy and pebbly deposits washed up and formed into beaches along the shores. In parts of the lakes where the glacial deposits which they covered were pebbly and the water was shallow enough for wave action, there was a concentration of stony material by the washing-out of the finer material. By this process considerable areas of the bed of Lake Agassiz were covered by very pebbly beds several inches in depth. They are classed on the map of northwestern Minnesota as "lake-washed till." In the narrow strip along the shore of Lake Superior that was covered by the waters of a glacial lake known as Lake Duluth, gravelly and cobbly beaches were formed at several successive levels, while fine material was washed down into the deeper parts of the basin covered by the present lake.

In the Red River Basin and to a slight extent at the west end of the Superior Basin there are fine sediments of considerable depth which had a close relation to the melting ice and yet are not in all places clearly separable from the lake sediments of later date. While including masses of till or bowlder clay and nests of bowlders, they are largely of fine silt which was laid down at the ice margin in the lake where the ice

A. RIVER SCENE AT ROSEAU, MINNESOTA

B. WHEAT FIELD ON CLAY PLAIN ON BED OF LAKE AGASSIZ

C. HOMESTEAD ON CLAY PLAIN ON BED OF LAKE AGASSIZ

sheet terminated. The supply of material in such cases was from the ice instead of from the washing-in of material from the land outside. The great brickyards at Wrenshall in Carlton County obtain their material from silt deposits of this sort.

THE GLACIAL FEATURES

It has been found through a study of the deposits in Minnesota and neighboring states that the glacial deposits which form so extensive a mantle in Minnesota are the result of more than one invasion of the ice from the Canadian highlands. At each invasion the ice left a deposit of drift gathered partly from Canada and partly from the deposits over which it passed in Minnesota. The advances were so widely separated in time that the drift deposits of one invasion had large valleys cut in them by the action of streams before the next invasion occurred. The later advances failed to cover some parts of the earlier deposits, so they are still exposed to view, and the degree of erosion of the surface of the older can be compared with that on the surface of the younger deposits. It is found that the older drift deposits have been so greatly eroded and are so ramified by drainage lines that no lakes or undrained basins remain on them, while the younger drift deposits have numerous lakes and undrained basins and also large, poorly drained areas which the streams have not yet reached. It is because they are not covered by the latest drift that Rock and Pipestone counties in southwestern Minnesota, and Goodhue, Dodge, Wabasha, Olmsted, Winona, Fillmore, and Mower counties in southeastern Minnesota have no lakes and basins such as characterize neighboring counties that were covered by that drift.

The invasions of the ice into Minnesota not only took somewhat different paths but have come from more than one direction. In the earlier invasions the greater part of the State was covered by ice coming from Manitoba as shown by limestones derived from rock formations of that country which are imbedded in the lower part of the drift over all of the State except its northeast part, and also in the drift of western Wisconsin. The movements in the closing stage of the glacial epoch were more largely from the northeast, there being an extension of ice southwestward from the Superior Basin nearly to Mille Lacs Lake, and an extensive southward movement from the highlands northwest of Lake Superior to points a little beyond St. Paul. But even in this closing stage the ice from Manitoba covered much more than half of the State and on the melting-away of the ice that came from the northern highlands extended over some of the ground that ice had vacated. This is known from the presence of a thin deposit of clayey and limy drift containing rock

material brought from Manitoba over parts of the drift that was deposited by ice coming from the highlands northwest of Lake Superior. The drift from these highlands together with that from the Lake Superior Basin forms the stony red drift of eastern Minnesota, while that from Manitoba forms the clayey and limy gray drift which covers almost all of the remainder of the State.

That the ice mass moved in different directions at different times in certain parts of the State is further shown by striations or ice markings on the surface of the rock ledges. In the district east and south of the Lake of the Woods a set of glacial grooves or ice markings bears west of south, while a newer set crosses them in an eastward or southeastward direction. The older set was formed by ice moving into Minnesota from the highlands that lie between Lake Superior and Lake Winnipeg, while the younger set was formed by ice moving into the State from Manitoba. In North Minneapolis there are rock ledges on which the glacial grooves have three courses; first, a southeastward course at the time when the old gray drift which came from the northwest was brought in; second, a southward course at a time when the red drift which came from the north was deposited; third, an eastward course at the time when the ice from the northwest advanced over land that had been vacated by the ice which deposited the red drift.

GLACIAL LAKE FEATURES

Minnesota contains parts of the beds of two large glacial lakes: Lake Duluth, which occupied the western part of the Superior Basin, and Lake Agassiz which occupied the Red River Basin. Lake Duluth covered a narrow strip along the shore of Lake Superior and extended a few miles beyond the west end of Lake Superior into eastern Carlton County, Minnesota. Its highest stages were about 500 feet above the present surface of Lake Superior. Lake Agassiz extended as far south as Lake Traverse, where it discharged past Brown Valley to the Minnesota. Its border is only from 20 to 30 miles east from the North Dakota-Minnesota line from Lake Traverse northward to Polk County. About 20 miles east-southeast of Crookston it makes an abrupt eastward turn and continues eastward past the south side of Red Lake and on across Koochiching County into St. Louis County as far as the valley of Little Fork River. It then turns northward and enters Canada from northeastern St. Louis County. There were several islands in it in northern St. Louis County.

The western or prairie portion of this lake area was studied by Warren Upham[1] some thirty years ago, and his monograph on the glacial

[1] Monograph XXV, U. S. Geological Survey.

Lake Agassiz contains a large body of important data on this region. In this monograph an island, called Beltrami Island, is represented to cover a large area north of Red Lake. This, however, is now known to have been covered by Lake Agassiz, its highest points being bars of gravel and sand in the lake.

There were also small glacial lakes in other parts of Minnesota where waters were temporarily ponded in front of the ice. These will be mentioned in the description of the counties. None of them, however, fall within the limits of the northwest quarter of the State.

The most prominent features of the two great glacial lakes, Lake Agassiz and Lake Duluth, are the beaches or ridges of sand and gravel washed up along their shores. The shores of Lake Agassiz stand high and dry above the flat parts of the lake bed between or below them and form excellent lines for highways. For this reason much of the pioneer settlement and travel was along these ridges. They generally stand from 5 to 10 feet above the bordering plains and occasionally from 15 to 20 feet. On the inner or lakeward side they are generally more prominent than on the outer or landward side. This is due in part to the original slope toward the center of the lake, but there is also a tendency for a lake to eat back into the bordering land and throw its coarser material up on the edge of the plain outside; at the same time the fine material is carried in suspension from the shore into the deeper water.

The levels of these glacial lakes were lowered from time to time, partly by the cutting-down of the outlets and partly by an uplift of this region which caused the water to fall away where the land rose. There was also a change of outlet in Lake Agassiz from the southern end to the northern and in Lake Duluth from the southward outlet into the St. Croix River to an eastward outlet into the Lake Huron Basin. As a result shore lines were formed at various levels on the slopes of the old lake beds. As a result of the gradual lowering of the water level the greater part of the beds of these glacial lakes has at some time been subjected to wave action. This has produced a widespread pebbly coating which is a concentrate from the washing of the surface of the bowlder clay and the carrying-away of its finer material. Where the bowlder clay was sandy, the sand as well as stones remain, but where it was clayey there is often a clear bed of pebbles a few inches in depth covering the clayey till subsoil. The deep part of Lake Agassiz along the borders of Red River received nearly all the fine sediment which was washed out from the till at higher levels. This forms the bulk of the rich black clay and clay loam of the Red River Basin. At its eastern border 15 to 25 miles from Red River there is a transition to sand. This is succeeded within 2 to 5 miles east by stony sandy deposits which seem to be a glacial material worked over by the lake.

CHAPTER IV

GENERAL SOIL CONDITIONS

Soil is composed of materials derived from the subsoil and mixed with organic matter. Subsoil is the weathered and disintegrated top of the subjacent geological formation. For its qualities and composition the soil of a given region therefore depends quite closely upon the nature of the geological formations there exposed. In Minnesota the land mantle of glacial and lake deposits affords a well-mixed and rich supply of materials suited for soil-making. This is particularly true where it consists of till or bowlder clay in which all classes of material are loosely but thoroughly mixed. This contrasts with soils in which there is too much uniformity and which, when of water-washed sand or gravel, are often deficient in fine material. On the other hand, the loess and the lake silts, though of somewhat uniform texture, make rich soils because of the variety of finely divided minerals which they contain.

The soil and its productiveness depend largely upon the drainage conditions. A soil of clay or clay loam over gravel or loose sand suffers in time of deficient rainfall, while a soil resting upon heavy clay may be drowned out unless surface drainage is perfectly adjusted. For this reason the geologic formation underlying a soil is of great importance. Soil underlaid by limestone, by loess, or by a till consisting of a light clay, or a heavy loam will stand great variation in rainfall and still be highly productive. In some parts of the State the surface drainage is naturally well developed, while in other parts it needs to be greatly supplemented by tile draining or surface ditching.

In the Driftless Area the drainage is everywhere complete, for nearly every acre slopes toward some drainage line. In the old drift also there are few undrained areas and tiling or surface ditching is seldom necessary. In the young drift there are many basins, and undrained depressions and drainage lines are not well distributed over the surface. Except, therefore, where the material is loose enough for the rainfall to be absorbed completely the young drift areas need considerable ditching and tiling. In the bed of Lake Agassiz, although basins and depressions are rare, there are wide areas in which the surface is very flat and extensive and systematic ditching is required to keep the land from being flooded.

VEGETATION

The condition of the soil depends to some degree upon the character of the vegetation which has covered it. In prairie districts there is a more uniform exposure to weathering agencies than in forested districts

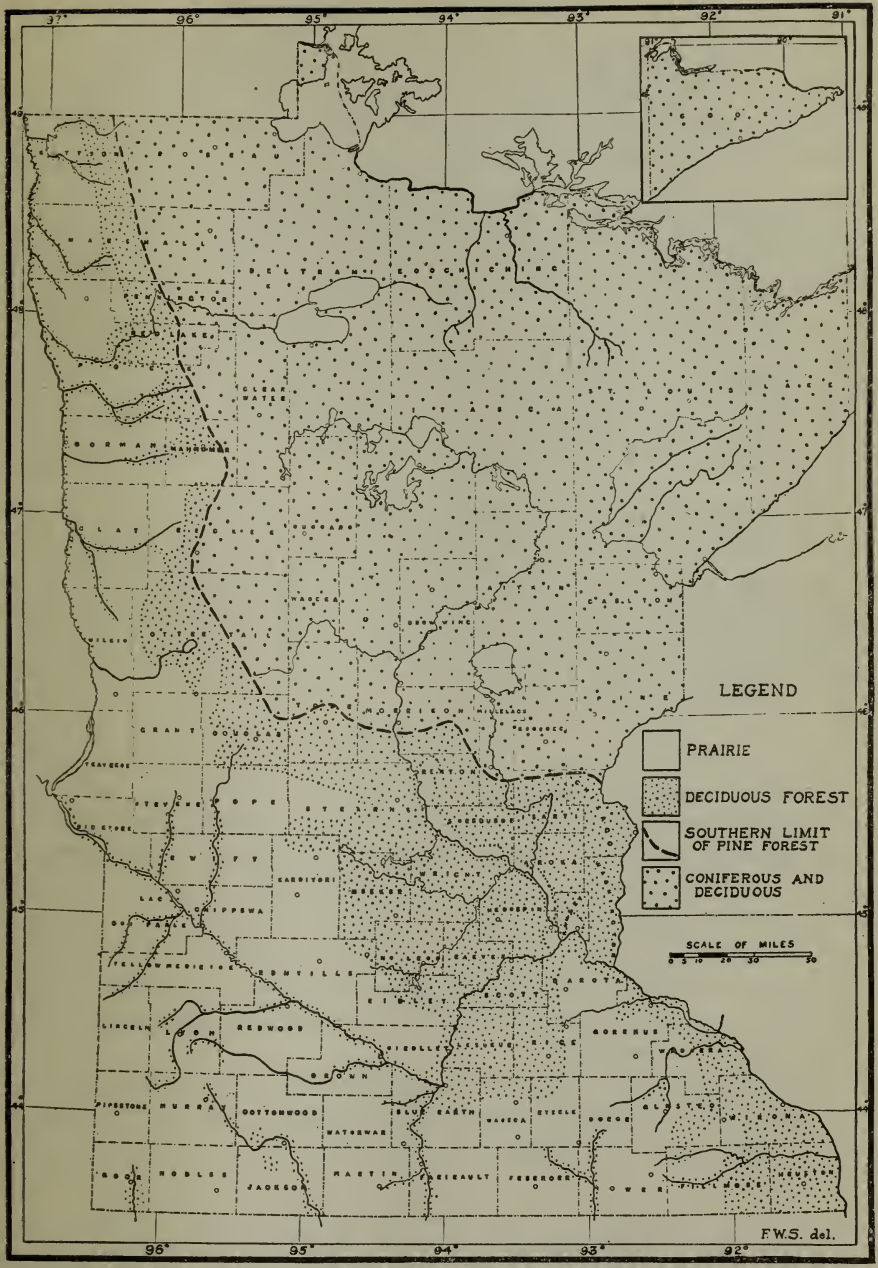


FIGURE 14. MAP OF MINNESOTA SHOWING DISTRIBUTION OF FOREST AND PRAIRIE. (AFTER MAP BY WARREN UPHAM AND BY FREDERIC K. BUTTERS)

and consequently a more uniform soil is developed on a given deposit. On the whole, leaching of lime seems to be less rapid on prairies than in forests so that in the newer drift limestones are often present at the surface in prairies, but in the forested areas limestones are usually dissolved out to a depth of some inches and often to some feet from the surface. On the older drift the limestone is generally removed to a depth of several feet both in prairie and forest, but the leaching is perceptibly deeper in the forested areas. The rate of erosion and removal of soil is more uniform in prairie than in forested tracts. It takes more force to dislodge the trees than the grassy vegetation on hillside slopes, and erosion in the forests is likely to become concentrated in occasional gullies, whereas on prairies there are many small channels developed on every hillside which serve to break it down rapidly. On the whole, therefore, erosion is greater but leaching is less in prairie than in forested areas.

The forests occur only on protected slopes in much of southern Minnesota and are absent from such slopes in much of the western part of the State (Fig. 14). In the central and northeastern parts they cover plains or uplands as well as valley slopes. The muskegs, which have a scanty forest growth, are developed chiefly in the northern half of the State and chiefly within the forested area.

WEATHERING

There are parts of the newer drift in which fresh material is close to the surface so that they can scarcely be said to have a subsoil different from the drift sheet as a whole. There are also places on valley slopes in the older drift where unweathered material is close to the surface, because erosion keeps pace with the weathering of the drift. At most places, however, the older drift has a mantle of weathered material several feet in thickness, while that of the younger drift is only one or two feet thick. In this the feldspar and other minerals are disintegrated and made ready for plant food.

Weathering in the loess-covered areas is moderately deep, as it is in the older drift. The entire deposit of loess, however, is of fine texture and is found to be very fertile from top to bottom.

LIME

While most of the soils of the northwestern part of the State seem abundantly supplied with lime, it is probable that some of the more sandy ones would give a sufficiently greater yield of certain crops to make it profitable to purchase some form of lime if this could be obtained at a low price. Usually when a soil needs lime, it is advisable to apply one

ton or more of ground limestone or marl per acre. If this has to be shipped any considerable distance, the freight charges may greatly exceed the cost of the material on board of the cars at the point of shipment. For this reason it is important to locate a supply as near as possible to the place where it is to be used.

Lime occurs abundantly in two forms in Minnesota: as bog-lime or marl, and as limestone. The marl is unconsolidated and easily pulverized. It needs no crushing or grinding. Limestone is consolidated and must be crushed or ground for use on fields.

Marl is found in Minnesota in many lakes and under some bogs that have been lakes. It is of most frequent occurrence in the central and north central part of the State. It lies always in low wet ground and can be found, as a rule, only by boring or ditching. It is a soft, white or gray, chalky material. Since it needs no crushing or grinding, the cost of the marl is in the finding, ditching and draining, or drying of it. Deposits from 1 to 10 feet in thickness and covering from 1 to 100 acres are known to be of common occurrence.

Limestone formations outcrop in the bluffs along the Mississippi and its tributaries in southeastern Minnesota. The formations lie horizontally and are of wide extent, or practically continuous for many miles. Limestone formations 100 feet or more thick extend along the valleys from the southeastern corner of the State to Stillwater, Minneapolis, Mankato, Austin, and intermediate points. An inexhaustible supply of limestone is easily found in outcrops that are high, so that quarrying, crushing, and loading can all be done in a down-hill direction, the cost of production being thereby lessened.

CHAPTER V

AGRICULTURAL CONDITIONS AND LAND CLASSIFICATION IN THE NORTHWEST QUARTER OF MINNESOTA

GENERAL STATEMENT

The area embraced in this report covers northwestern Minnesota as far eastward as the 94th meridian and southward to the median line of the State which is near latitude 46° 25′. It embraces about 24,000 square miles outside of Lake of the Woods. The greater part is tributary to Hudson Bay, only 5,600 square miles being tributary to the Mississippi River. Nearly all of this Hudson Bay drainage lies in the bed of the glacial Lake Agassiz. The altitude has a range of about 1,000 feet, or from 750 to 1,750 feet, the highest points being around the head of the Mississippi River. The western part is prairie and the eastern forested land, the line between forest and prairie being from 20 to 40 miles east of Red River. The rainfall ranges from 21 to 28 inches, being lowest on the western border and increasing toward the southeastern.

Settlement began earlier on the prairie portion. Indeed, much of the forested portion still remains unoccupied. Likewise large swamp areas, chiefly in the eastern part of the bed of Lake Agassiz, await artificial drainage before they can be occupied. Four of the great railway systems, the Northern Pacific, Great Northern, Soo Line, and Canadian Northern, have lines traversing northwestern Minnesota and render the greater part of it readily accessible.

In general the supply and quality of well waters throughout the region is good. This region also embraces very extensive flowing well areas in parts of the Red River lowland and in other low areas farther east.

Valuable data on the extent of swamp areas, the direction in which swamps may be most easily drained, and other matters pertaining to drainage conditions, may be obtained from the reports of the State Drainage Commission, from topographic sheets of parts of Ottertail and Becker counties by the United States Geological Survey, and from a report and map of a drainage survey of lands in the region south of Lake of the Woods, published as House Document 27, Sixty-first Congress, First Session. These reports and maps have been of much service in preparing the estimates presented below.

DESCRIPTIONS OF COUNTIES

In the descriptions of counties the first county taken is in the northwest corner of Minnesota, and following this, counties to the east, thence south to the southeast corner of the area embraced in this report, and

A. TILL PLAIN IN MAHNOMEN COUNTY

B. WHEAT FIELD ON TILL PLAIN IN MAHNOMEN COUNTY

thence westward to the southwest corner. General observations concerning settlement and utilization of the land and a few data from the census of 1910, as well as the results of the land classification on a geologic basis, are presented.

KITTSON COUNTY

Kittson County is the northwest corner county of Minnesota and lies entirely within the limits of the glacial Lake Agassiz. As a consequence the classes of land are restricted to lake deposits and lake-washed glacial deposits, though the swamps are covered to considerable extent by peat. The following percentages of each class of land have been computed from field maps. Their distribution in the county may be seen by reference to the general map (Plate I) accompanying this report.

Percentages of Classes of Land in Kittson County

	Sq. miles	Per cent of county
Black clay and clay loam, lacustrine	463	41.7
Sandy deposits of old lake shores	175	15.7
Stony or pebbly sandy loam, lake-washed drift	270	24.3
Stony or pebbly clay loam, lake-washed drift	130	11.7
Swamp land	73	6.6
Totals	1,111	100.0

The black clay and clay loam of the Red River Valley, being a highly productive soil with no forests to remove, has naturally been the first to be taken up for farms. The part of the stony clay loam which borders the black clay loam on the east has also been largely settled and brought into cultivation. Its texture being looser than that of the black clay loam, it is more easily cultivated. The only drawback to cultivation is the presence of surface bowlders which in parts of the area are numerous. They are especially abundant north of Orleans and in the northeast part of the county between Hemmington and Caribou, and in the eastern part north of Pelan. They do not greatly encumber the land in the southeast part of the county or in the district southeast of Orleans.

The areas of stony sandy loam have a variable soil ranging from sandy to gravelly and embracing many patches of clayey drift. The large ditches which traverse the area show abrupt changes from bowlder clay to sand or gravel. In places bowlder clay underlies the sandy gravel at a depth of from only 3 to 5 feet. Such areas and those with a bowlder clay soil are as productive as either of the clay loams. But on the whole the spotted character renders this class of soil somewhat inferior to the areas of clay loam. The land is very thickly strewn with bowlders in

the district between Bronson and Pelan, and is still largely in a wild state. The areas in the northeast part of the county and northeast of Bronson have only a moderate number of bowlders. They embrace much wet land which is as yet only partially drained by artificial ditches.

The sandy land varies greatly as to agricultural conditions. The old shore lines are rather barren because of the relief which they have above the bordering plains and consequent depth of the water table. The sandy plains, for a few miles from the western edge, are generally underlaid by clay at very slight depth and thus have a water table sufficiently near the surface to supply moisture for the crops. In fact some of the sandy land on the immediate border of the black clay loam, as already noted in the general discussion of the region, is preferred as farm land because of its loose texture and easy cultivation. In the northern part of the county the sandy land is so interspersed with marshes that systematic ditching will be necessary to render it suitable for farming. There is an area of sandy land extending from Bronson southward past Halma to the county line with large numbers of surface bowlders, a rather rare feature on so sandy a soil. The presence of the bowlders indicates that the sand may be largely of glacial deposition. The productiveness of the deposit is also greater than in the ordinary lake sand. It is extensively cultivated for potatoes and other root and vegetable crops.

The swamp lands in the eastern part of the county generally have peat and black muck to a depth of from 3 to 6 feet or more, beneath which there is usually a clayey glacial deposit. The swamps in the northern part are more generally underlaid by sand.

Farm and Crop Data for Kittson County from the Census of 1910

Percentage of land area in farms	52.3
Percentage of farm land improved	77.2
Average acres per farm	307.5
Average improved acres per farm	237.5
Value of all farm property	$13,730,520.00
Percentage of gain since 1900	110.3
Average value of a farm	$11,348.00
Cereals produced in 1909	$2,043,887.00
Other grains and seeds	$91,269.00
Hay and forage	$179,805.00
Vegetables	$41,007.00
Fruits and nuts	$727.00
All other crops	$17,400.00
Total crop production in 1909	$2,374,095.00

It should be noted that the prices of farm lands have made a marked advance since 1910, so that the average value for the bare land in 1914 is likely to be nearly $40.00 per acre, and for land with improvements fully $50.00 per acre. The black clay loam of the western part of the county will probably now average nearly $75.00 per acre, if the land carries with it good buildings and improvements.

The most complete settlement is on the black clay loam and the neighboring tracts of sandy land and stony clay loam in the western part of the county, and in the southeast part of the county along the Soo Railroad. But farms are rapidly being developed over the remainder of the county and the large swamps are being drained preparatory to settlement.

ROSEAU COUNTY

Roseau County lies next to the Manitoba line and extends from Kittson County to Lake of the Woods. It is entirely within the limits of the glacial Lake Agassiz and consequently has soils formed from lake deposits or from lake-washed glacial deposits. There is, in its northwestern part, a considerable area of lake clay and clay loam with black soil similar to, and yet isolated from, the area of black clay loam of the Red River Valley. The greater part of the county has soils formed on lake-washed glacial material. Old shore lines and associated sands are, however, conspicuous in the southeastern part of the county, and such a shore line is followed by the Great Northern Railroad from Greenbush nearly to Roseau. There are very extensive swamps in the northern and the southeastern parts of the county on which considerable ditching has been started preparatory to settlement. A great body of first-class land extends from the southwest part of the county northeastward past Roseau to the south fork of Roseau River.

The following estimated percentages of each class of land were computed from field maps. The general map accompanying this report (see Plate I) sets forth their distribution.

Percentages of Classes of Land in Roseau County

	Sq. miles	Per cent of county
Black clay and clay loam, lacustrine	170	10.2
Sandy deposits of old lake shores	210	12.6
Stony or pebbly sandy loam, lake-washed drift	270	16.1
Stony or pebbly clay loam, lake-washed drift	470	28.1
Swamp, largely peat covered	550	33.0
Totals	1,670	100.0

Much of the area of black clay loam in the northern part of the county is under cultivation and it not only supports the three settlements around Pine Creek, Ross, and Duxby, but adds materially to the prosperity of Roseau, the county seat. The areas of stony and pebbly clay land are also very largely under cultivation both in the district southwest from Roseau and that south of Warroad and Swift, but are more slowly developing in the district southeast of Roseau between Falun and Wannaska. Bowlders seldom impede cultivation of the soil.

In the vicinity of America and Clear River there are good farms with sandy soil covering a clay subsoil. In places the sand is so thin that bowlders of the glacial material are only partly covered. In the southwestern part of the county, south from Greenbush, on each side of the Great Northern Railway, the land is very spotted, some farms being largely of pebbly clay loam and others chiefly sandy or gravelly loam. There are also areas of clear sand and gravel extending to the depth of the ditches, 3 to 5 feet or more.

The southeastern borders of the county embrace areas of productive land among the swamps, but much ditching and road-building is necessary there in order to make conditions suitable for successful farming. The areas of lake sand over water-laid moraine (marked on map *"LS over MW"*) have a base of glacial material of variable constitution thinly veneered with sandy lake material. In places the bowlders of the glacial formation are visible, though usually they are concealed by the sand.

The swamps of this county form an almost complete barrier to communication with Manitoba, so that customs officials are needed only at Pine Creek and Warroad. A large amount of systematic ditching will be necessary to prepare this swamp for settlement. The amount of peat over much of this area is so great that it presents a forbidding outlook. Yet swamps similar to this, when the water is removed, and intelligent farming methods are employed, often are made to yield profitable returns.

Farm and Crop Data for Roseau County from the Census of 1910

Percentage of land area in farms	29.5
Percentage of farm land improved	49.9
Average acres per farm	196.7
Average improved acres per farm	98.2
Value of all farm property	$6,135,882.00
Percentage of gain since 1900	176.3
Average value of a farm	$3,830.00
Cereals produced in 1909	$430,443.00

Other grains and seeds	$111,428.00
Hay and forage	$163,021.00
Vegetables	$64,523.00
Fruits and nuts	$270.00
All other crops	$49,271.00
Total crop value	$818,956.00

Farm land prices have made a material advance since 1910, much of the good land now being held at from $40.00 to $50.00 per acre.

MARSHALL COUNTY

Marshall County lies immediately south of Kittson and Roseau counties. It extends about 70 miles east from Red River and has a width from north to south of 25.5 miles. The area, as given in the census of 1910, is 1,788 square miles. It is wholly within the limits of the glacial Lake Agassiz and its classes of land are therefore restricted to lake deposits and lake-washed glacial deposits. Much of the stony clay loam land was poorly drained and was classed as swamp land before artificial drainage was established. But only a small part of it has a peaty cover and on that the peat is but a few inches in depth. This land, when properly ditched, can scarcely be distinguished from the areas that were originally classed as dry land. The swamp land with peat cover lies mainly along the northern edge of the county east from the Soo Railroad. There are smaller areas east and south of Mud Lake, and others among the sand ridges east of Viking. The peaty swamp land, however, is estimated to occupy only about 10 per cent of the area of this county.

The following percentages of each class of land have been computed from field maps, and their distribution is shown on the general map (Plate I).

Percentages of Classes of Land in Marshall County

	Sq. miles	Per cent of county
Black clay and clay loam, lacustrine	450	25.2
Sandy deposits, of old lake shores	315	17.6
Stony or pebbly sandy loam, lake-washed drift	175	9.8
Stony or pebbly clay loam, lake-washed drift	665	37.2
Swamp land	183	10.2
Totals	1,788	100.0

The large body of pebbly clay loam in this county, when given proper

drainage, will probably be as productive as the black clay and clay loam of the Red River Valley. In fact its texture is looser than that of the deposits of the Red River Valley, and it is being converted into farm land as fast as the drainage work is completed. Bowlders are numerous only in small strips and patches and nowhere do they greatly impede cultivation of the soil.

The large water-laid moraine which extends from the north side of Thief Lake southwestward along the west side of Thief River has a stony or pebbly clay loam soil very similar to that of the plain to the east, and has therefore been included in this class of land in the above estimate. Its chief difference, so far as agriculture goes, is one of natural drainage, there being a more rapid escape of water from it than from the plain. Its slopes, however, are so gradual as to be scarcely perceptible to the eye, and its surface is nearly as free from knolls as that of the bordering plains.

The sharp ridges of sandy gravel, marking shore lines of Lake Agassiz, are very conspicuous features in two main belts which run across the county west of Thief River. These ridges are excellent lines for highways, and will supply plenty of material for graveling railways and highways. But they have lower productiveness because of their relief above the bordering plain, which is often as much as from 10 to 15 feet. The sandy plains among and west of the western belt of ridges have generally a light soil easily affected by drouth. There is, however, a strip 1 or 2 miles wide along the border next to the black clay of Red River Valley in which the soil is more productive.

The areas of stony and pebbly sandy loam vary greatly in degree of fertility because of variability in constitution and in drainage conditions. They include small areas of good clay loam but are usually of loose texture. These areas are much less affected by drouth than the sandy areas and include a number of good farms.

Farm and Crop Data for Marshall County from the Census of 1910

Percentage of land area in farms	49.6
Percentage of farm land improved	67.0
Average acres per farm	267.7
Average improved acres per farm	179.5
Value of all farm property	$16,952,344.00
Per cent of gain since 1900	99.6
Cereals produced in 1909	$2,313,218.00
Other grains and seeds	$230,560.00
Hay and forage	$328,798.00
Vegetables	$72,664.00

Fruits and nuts	$1,372.00
All other crops	$40,171.00
Total crop value	$2,986,783.00

PENNINGTON COUNTY

Pennington County was organized from a part of Red Lake County in 1910 and has an area of 607 square miles. It lies immediately south of the eastern part of Marshall County and is entirely within the limits of the glacial Lake Agassiz. Consequently its soils are all from lake deposits and lake-washed glacial deposits. Its western end has considerable light sandy soil connected with some of the lower beaches of Lake Agassiz, but the central and eastern parts of the county have heavier soil and there are also strips of heavy soil between the sandy strips in the western third of the county.

A large water-laid moraine runs southward across the county on the west side of Red Lake River. But it has been so covered with the beach material that the glacial deposits of which it is composed are exposed only on the eastern or outer slopes of the moraine for a short distance west of Red Lake River and the lower course of Thief River. These glacial deposits are of pebbly clayey material like that underlying the plains farther east. Low swells from 3 to 5 feet high are present on the outer slopes, some of which are to be seen within the limits of the city of Thief River Falls. The slope on the outer face is barely perceptible to the eye, as it amounts to scarcely 20 feet in a distance of from 1 to 2 miles.

In the central and eastern part of the county no definite beaches or ridges of sandy gravel occur to break the monotony of the plain. The prevailing material is a lake-washed pebbly clay loam, but in nearly every township there are numerous small areas of sand and fine gravel and also small swamps filled with peat nearly to the level of the bordering dry land. Large ditches opened in this district show abrupt changes from pebbly clay to sandy, gravelly, and peaty deposits and the peat is found in some cases to be 5 feet or more in depth. There are a few low swells standing 5 feet or less above the bordering plain, and these as a rule are found to be composed of glacial material, usually a pebbly clay. Not infrequently a strip of gravel comes in between the clay and the peat as one passes from the dry ground into the swampy land.

Farm and Crop Data for Pennington County from the Census of 1910

Area of county in square miles	607
Percentage of land area in farms	66.3

Percentage of farm land improved	53.1
Average acres per farm	207
Average improved acres per farm	109.9
Value of all farm property	$6,326,149.00
Cereals produced in 1909	$548,253.00
Other grains and seeds	$100,726.00
Hay and forage	$208,626.00.
Vegetables	$41,791.00
Fruits and nuts	$817.00
All other crops	$22,923.00
Total crop value	$923,136.00

As in Marshall County the extensive ditching and heavy assessment for draining the wet areas have tended to keep down land prices. Yet the land is increased in value far beyond the expenditure in draining it.

This county is being covered by a detailed soil survey under the Bureau of Soils of the United States Department of Agriculture. The work is in charge of W. G. Smith. In this detailed study, there is of course a more refined analysis and classification of soils than has been attempted by the present writer in the survey of the glacial and lake deposits of this region. This will be brought out in a report by the Bureau of Soils. In the present report and accompanying map (Plate I) Mr. Smith has endeavored to group soils to correspond with the classes shown in the other counties. The percentages of the different classes of soil are based entirely upon the work of the Bureau of Soils and estimated by Mr. Smith.

Statement by W. G. Smith

The western third of the county has been open to settlement something over thirty years, while the remaining eastern portion was opened to settlement only ten years ago.

There is a somewhat uniform but rather sparse settlement all over the county, scarcely half of its area being in farms and less than one third under cultivation. Settlement and enlarging of cultivated acreage seem to be extending rapidly. The land would easily support a much larger population, for it is nearly all of good quality.

The sandy deposits of the old lake shores ("sand ridges") were settled first, as they were not subject to standing water that remained for a long time on the lower lying lands following wet seasons. Since the installation of large drainage ditches throughout the county most of the land is sufficiently protected against standing water to permit of use for farm purposes at all times. Some additional ditching would bring practi-

A. HOMESTEAD ON CLAY MORAINE IN OTTERTAIL COUNTY

B. OATS (AND CORN IN BACKGROUND) ON CLAY MORAINE IN OTTERTAIL COUNTY

cally the whole area of the county within the range of possible use for farm purposes.

Percentages of Classes of Land in Pennington County

	Sq. miles	Per cent of county
Sandy deposits of old lake shores	14	2.3
Stony or pebbly sandy loam, lake-washed drift	128	21.1
Stony or pebbly clay loam, lake-washed drift	368	60.6
Swamp (peat land)	97	16.0
Total	607	100.0

Nearly three fifths of the area of the county has stony or pebbly loam to clay loam surface soils with clay subsoils. Such lands have high agricultural value and under proper cultural methods they have the capacity of producing the staple crops under a wide range of moisture conditions.

About one fifth of the area of the county is covered by sandy loams and loams underlaid by sandy and gravelly subsoils of various depths. While in places the lands are somewhat subject to overdrainage and otherwise show less resistance to drouth than soils having clay subsoils, they should prove to be well suited to agricultural purposes under good cultural methods.

Treeless swamps and peat lands occupy a little less than one fifth of the area of the county. Adequate drainage is one of the first essentials to bring this character of land within the range of usefulness for field-crop purposes. The depth of peat varies considerably, from a few inches to 5 feet or more. The greater depths are found in the east and southeast portions of the county, where the larger areas of peat or swamp lands occur. Some of the townships there have nearly half of their areas covered with swamp or peat. While these areas are not extensively farmed, the staple crops seen growing on peat in some places give the impression that ultimately these peat lands will be subdued to a stage where they may be depended upon to produce profitable crops under a wide range of seasonal variations.

RED LAKE COUNTY

Red Lake County lies south of Pennington and is bordered on the west, south, and east by Polk County. It is traversed by Red Lake River from which its name was derived, as it does not touch upon Red Lake. Since Pennington County was cut off from it there remains an area of only 432 square miles. It is entirely within the limits of the glacial Lake Agassiz, and thus is restricted in soil classes to lake deposits and

lake-washed glacial material. There is a strip of light sandy land on its west border in connection with some of the lower shore lines of Lake Agassiz. The borders of Red Lake Valley, of Clearwater Valley and of its main tributaries, Lost, Hill, and Poplar rivers, have generally a sandy or sandy loam soil, but the greater part of the county has a pebbly clay loam soil, much of which is sufficiently well drained to be suitable for cultivation. There are few places where bowlders are so numerous as seriously to impede cultivation. Some of the sandy land along Clearwater and Red Lake rivers, in the vicinity of Red Lake Falls, is underlaid at slight depth by a lake clay and the sand itself is exceedingly fine-textured. Land of this class is as productive as any in the county. The swamp land is chiefly in the eastern end of the county, and has usually a thin growth of peat over glacial material of variable constitution, with abrupt changes from sand or gravel to pebbly clay.

The following percentages of each class of land have been computed from field maps, and their distribution may be seen on the accompanying general map.

Percentages of Classes of Land in Red Lake County

	Sq. miles	Per cent of county
Sandy and silty lake and stream deposits	110	25.4
Pebbly sandy loam, lake-washed drift	45	10.4
Pebbly clay loam, lake-washed drift	250	58.0
Swamp	27	6.2
Total	432	100.0

There is a somewhat uniform but rather sparse settlement all over this county, scarcely half of its area being in farms, and less than one-third under cultivation. The land would easily support double or treble its present population for it is nearly all of good quality.

Farm and Crop Data for Red Lake County from the Census of 1910

Percentage of land areas in farms	45.4
Percentage of farm land improved	61.5
Average acres per farm	238.0
Average improved acres per farm	189.8
Value of all farm property	$3,711,300.00
Cereals produced in 1909	$363,671.00
Other grains and seeds	$79,828.00
Hay and forage	$94,537.00
Vegetables	$24,028.00
Fruits and nuts	$119.00
All other crops	$12,180.00

POLK COUNTY

Polk County, of which Crookston is the county seat, lies south of Marshall and Red Lake counties, and extends from Red River eastward nearly 70 miles. Its area, as given by the census of 1910, is 1,980 square miles. Its greatest width is at the west in Red River Valley, and nearly half its area has the lacustrine black clay and clay loam. An area of about 500 square miles in the southeastern part lies outside the limits of the glacial Lake Agassiz.

A survey and map of the southwestern part of the county, around Crookston, has been made by the Bureau of Soils of the United States Department of Agriculture.[1] It is chiefly in the area of black clay and clay loam bordering Red River, but its eastern part extends up over some of the lower beaches and associated sandy strips of Lake Agassiz. The northeast part of the map includes a few square miles of stony sandy loam (Benoit fine sandy loam and Benoit loam), a glacial deposit modified more or less by lake action. In the eastern part there are very bowldery areas of lake-washed pebbly clay, classed in part as Benoit loam and in part as Sioux gravelly loam. They are very different from the lake beaches which are composed of sandy gravel and are classed as Sioux gravelly sandy loam. It has been found necessary, therefore, in the present map to depart somewhat from the soil map, in this eastern part of the Crookston area, and make a clear distinction between the lake beaches and the bowldery plain. A large part of the Fargo fine sandy loam of the Crookston area soil map is a deposit such as in other counties of the present report has been classed and represented on the map as lake sand. It has a light soil easily affected by drouth and requiring intelligent cultivation.

The classes of land represented in Polk County include two types of land-laid moraine, the sandy and the clayey, and plains of till or pebbly clay loam, which like the moraines stand above the limits of the glacial Lake Agassiz. The moraines are of a pronounced knob and basin type with numerous small lakes, ponds, and swampy depressions among the knolls and ridges. The till plains are also diversified by small lakes and ponds occupying shallow basins. A few of these are capable of drainage at moderate expense, but the majority have beds below the neighboring drainage lines. Some of the lakes have been partly and others almost completely filled by peaty growths. The extensive swamps are chiefly in the northeastern part of the county on the plain covered by Lake Agassiz, those outside the limits of the old lake being usually too small to admit of representation on the small scale here adopted.

[1] Mangum, A. W., and Schroeder, F. C., Soil survey of the Crookston area, Minnesota: Field operations of the Bureau of Soils 1906.

There is a large peaty swamp in the southwest part of the county across which Sand Hill River discharges by the aid of artificial ditches.

The percentages of the several classes of land here given are based upon field maps and the soil map of the Crookston area. Their distribution is shown on the general map.

Percentages of Classes of Land in Polk County

	Sq. miles	Per cent of county
Sandy moraine	86	4.3
Clayey moraine	73	3.7
Clayey till plain	265	13.4
Sandy soil in till plain	10	0.5
Lake-washed sandy till, pebbly sandy loam	60	3.0
Lake-washed clayey till, pebbly clayey loam	230	11.6
Sandy deposits of old lake shores	305	15.4
Lacustrine black clay and clay loam	835	42.2
Swamps and small lakes and ponds	116	5.9
Totals	1,980	100.0

The wild land in Polk County is found chiefly in the sandy areas and swamps and in the roughest or most hilly parts of the moraines, the first-class land being nearly all in farms. The land outside the limits of Lake Agassiz has about as productive a soil as the clay loams of the old lake area and more productive than the sand and light sandy loams of the lake area. This statement is made since there is a widespread impression that the fertility of northwestern Minnesota land is due to its having once been a lake bed, and it might be inferred that there is a markedly lower degree of fertility outside the lake area. The character of the soil is of course less uniform than in the part of the old lake bed immediately bordering Red River. It is necessary also in a district where ponds and lakes and small peaty basins occur to allow for a considerable percentage of waste land. But the tillable land of southeastern Polk County is a close rival in fertility to that of the Red River Valley. In this part of the county wheat was, for a time, the sole important crop, but now diversified farming is coming into vogue.

Farm and Crop Data for Polk County from the Census of 1910

Percentage of land area in farms	70.2
Percentage of farm land improved	72.4
Average acres per farm	252.2

Average improved acres per farm	182.7
Value of all farm property	$34,946,027.00
Percentage of increase since 1900	78.5
Average value of a farm	$9,914.00
Cereals produced in 1909	$4,216,361.00
Other grains and seeds	$331,471.00
Hay and forage	$670,551.00
Vegetables	$212,600.00
Fruits and nuts	$5,355.00
All other crops	$134,195.00
Total crop value	$5,570,593.00

There has been some advance in farm prices since 1910, so that the average value of an improved farm with good buildings may be not less than $50.00 per acre, while farms of this sort in the Red River Valley approach $75.00 per acre.

CLEARWATER COUNTY

Clearwater County was organized in 1903 from the southwest part of Beltrami County and has an area of 1,019 square miles. It is bordered on the west by Pennington, Polk, and Mahnomen counties and on the north and east by Beltrami County. Its northern part extends into the Red Lake Indian Reservation and its southwestern part into the White Earth Reservation. About one fourth of the county, at its northern end, is within the limits of the glacial Lake Agassiz. Its drainage is principally to Clearwater River, from which the county receives its name, but it also includes the headwaters of the Mississippi River and the State Reservation around Lake Itasca.

The portion of this county within the limits of Lake Agassiz is very largely undrained swamp land. Much of it is in the Red Lake Indian Reservation. Notes concerning the character of this swamp land have been furnished by Mr. A. P. Meade of the United States Geological Survey, who in 1913 made a survey for a topographic map of these wet lands. For a few miles along the extreme edge of the area covered by Lake Agassiz there is a sandy to gravelly loam with till of very variable constitution at slight depth and noted on the map *LST*. Farther out there is a general coating of peat over a clayey glacial deposit with local patches of sand and gravel, as in the part of Pennington County adjoining it on the west.

The part of the county outside the limits of Lake Agassiz is largely tillable land, its character being similar to that of the adjoining part of Polk County. It includes both the sandy and clayey moraines and ex-

tensive till plains of a prevailingly clayey constitution. There are numerous small lakes and swamps among the morainic knolls and ridges, and also scattered lakes and shallow swampy basins in the till plains. It is difficult to estimate the aggregate amount, but probably not less than 20 per cent of the area of the moraines and till plains of this county are water and waste land, which is not taken into account in the table below. There are extensive swamps in the southern part of the county extending out in all directions from Rice Lake, and others farther north in the vicinity of Bagley and Shevlin which are included in the swamp land in the table.

The percentages of the several classes of land here given are based upon field maps and to some extent on the notes by Mr. Meade. Their distribution is shown on the general map.

Percentages of Classes of Land in Clearwater County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil	173	17.0
Clayey moraine, with pebbly clay loam soil	180	17.6
Clayey till, with pebbly clay loam soil	208	20.4
Till plain with sandy patches	30	3.0
Outwash gravel, and glacial drainage deposits	71	7.0
Lake-washed till, largely loose-textured	97	9.5
Sandy gravel of lake shores	20	2.0
Swamps and small lakes and ponds	240	23.5
Totals	1,019	100.0

The lightest soils of the county are found in the outwash gravels and lines of glacial drainage and in the beaches of sandy gravel on the shore of Lake Agassiz. They are composed very largely of sand and fine gravel with only a slight amount of loam in the soil. The sandy moraines usually have a considerable admixture of loam with the sand and gravel which gives them a somewhat higher degree of fertility than the outwash plains and beaches. Portions of them, however, are greatly interrupted by small swamps and deep basins which render cultivation of the land rather difficult and in consequence only a small part of this land has been brought under cultivation. The wet lands of the northern portion of the county lie largely in the Red Lake Indian Reservation, but outside the reservation are very sparsely settled. They need considerable ditching to render them tillable. The areas of clayey moraine and clayey till which constitute about three eighths of the county have highly productive soils, but as yet only a small portion of the land is

improved. Settlement is more or less retarded from the fact that it is a forest-covered tract.

Farm and Crop Data for Clearwater County from the Census of 1910

Percentage of land area in farms	26.8
Percentage of farm land improved	23.2
Average acres per farm	165.5
Average improved acres per farm	38.4
Value of all farm property	$3,150,087.00
Cereals produced in 1909	$146,906.00
Other grains and seeds	$3,940.00
Hay and forage	$128,655.00
Vegetables	$39,659.00
Fruits and nuts	$461.00
All other crops	$65,326.00
Total crop value	$384,947.00

BELTRAMI COUNTY

Beltrami County extends from the Lake of the Woods southward past Red Lake to the line of Hubbard County. The south boundary is about 100 miles from the southernmost point on Lake of the Woods. There is also a small detached area known as the Northwest Angle lying west of Lake of the Woods whose northernmost point is about 135 miles from the Hubbard County line. In its widest part the county embraces nine ranges of townships or 54 miles. The census of 1910 gives the county an area of 3,822 square miles. This evidently does not include Red Lake and probably does not include the small lakes inside the county. The total area of Red Lake is 440 square miles, of which 408 square miles fall within the townships and ranges embraced in Beltrami County. The small lakes embrace about 100 square miles. The sum of the sections and parts of sections outside of Red Lake is 3,924 square miles. If 102 square miles are allowed for the small lakes, the land area is reduced to what is given by the census report, or 3,822 square miles. In the estimates of percentages given below it has been found necessary to include the small lakes as has been done in other counties, not only for the sake of uniformity, but also because it is not possible in some cases to draw the line between lake and swamp. The lakes and swamps are accordingly grouped together, and the percentages are estimated on the basis of an area of 3,924 square miles.

The greater part of Beltrami County lies within the limits of the glacial Lake Agassiz, whose southern shore passes along the south side

of Red Lake. As already noted, it was once supposed that a part of Beltrami County north of Red Lake stood above the level of Lake Agassiz and was called Beltrami Island. The highest points in that district, however, have bars of sandy gravel on them formed by Lake Agassiz. A considerable part of the bed of Lake Agassiz within the limits of Beltrami County is still a muskeg swamp which can be traversed only with great difficulty except when frozen. Through the heroic efforts of Mr. Meade and his party of surveyors it was traversed sufficiently to obtain data necessary to construct the topographic and drainage map which accompanies House Document 27 of the Sixty-first Congress, First Session. Mr. Meade has also kindly furnished such information as he had gained concerning the character of the soil of the small islands that rise here and there above the level of the muskeg. Information concerning the soil on some of the islands has been obtained from Mr. A. R. McDonnell, of Baudette, who had made timber estimates on them for lumber companies and who was the present writer's guide over parts of the district. The data are thus such as were noted incidentally in the course of other investigations and should be read with this understanding. As far out as settlements have reached, the present writer gave the soil personal examination.

Data concerning soils on the Northwest Angle were obtained from Mr. E. C. Barnard of the United States Coast and Geodetic Survey, who was in charge of the survey along the boundary between Minnesota and Manitoba in 1912 and 1913. Data on islands in Lake of the Woods were kindly supplied by Mr. W. A. Johnston of the Geological Survey of Canada who cruised among them and studied their geology in the summer of 1913. Mr. Johnston also supplied notes concerning the occurrence of lake clay over glacial deposits along the shore of Lake of the Woods and in the bluffs of Rainy River in this county.

The district south of Red Lake stands above the level of Lake Agassiz, and here roads are few and much of the land is still in forest. It was not possible, therefore, to obtain such full knowledge of the soil conditions as in the districts to the west where forests have been cleared and farms opened. Diligent inquiry was made, however, throughout this part of the county, of residents who had some personal knowledge of the character of the land.

Nearly all the rock outcrops of this northwest quarter of Minnesota are in the northern part of Beltrami County. They occur here and there for several miles south of Rainy River and Lake of the Woods, as well as on islands in Lake of the Woods, but their aggregate area is estimated to be only 8 square miles. Usually a rock knob on the mainland occupies only an acre or two, but there are a sufficient number to amount to a square mile or more of bare rock. On the islands in Lake

VIEWS ON GRAVEL OUTWASH PLAIN NEAR WADENA

of the Woods much of the surface is bare rock except Garden Island. This, Mr. Johnston reports, is thickly covered with a calcareous bowlder clay, and it derives its name from its having been cultivated to some extent.

Percentages of Classes of Land in Beltrami County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil	145	3.7
Clayey moraine, with pebbly clay loam soil	170	4.3
Outwash gravel, and sandy glacial drainage deposits	216	5.5
Till plains with prevailingly clay loam soil	393	10.6
Till plains with mixed soil, sandy to clayey	72	1.8
Stony or pebbly clay loam, lake-washed drift	292	7.4
Stony or pebbly sandy loam, lake-washed drift	266	6.7
Sandy and gravelly deposits of old lake shores	207	5.0
Lake clay	23	0.6
Rock outcrops	8	0.2
Small lakes	102	2.5
Swamp land	2,030	51.7
Totals	3,924	100.0

The settlements in the northern part of the county are chiefly within 10 miles of the Canadian Northern Railroad, and even here only a small percentage of the land is cleared and cultivated. There are a very few residences along Rapid River and Rainy River, and a few scattered over the high tract of gravel and sand from 12 to 15 miles south and southwest of Williams.

There are prosperous settlements in the district northwest of Red Lake, with post-offices at Malcolm, Thorhult, Jelle, Carmel, and Orheim. Grain and produce is marketed at Thief River Falls though this point is distant fully 50 miles from the eastern part of this farming district. Large ditches have been made and others are in course of construction which will give the region fair drainage. The soil is largely a pebbly clay loam, strewn thickly in places with bowlders, but generally supplied with only a sufficient number to provide foundations for buildings. The roads, which usually follow the lines of the ditches and utilize the embankments, are in good condition for hauling heavy loads to the distant market. This district had only a scattered and stunted forest cover so that it has been easier to bring it into cultivation than the heavily forested areas south of Red Lake.

In the part of the county south of Red Lake farming is chiefly carried on in the areas of pebbly clay loam and gravelly areas near Bemidji and south and west from that city. There is very little settlement as yet between Bemidji and Red Lake. There are small settlements along the eastern border near Kelliher, Funkley, Black Duck, and scattered settlers southward past Louis to the border of Cass Lake. The prevailing soil there is a pebbly clay loam, but it is interrupted by patches of sandy or gravelly soil. Much remains to be done in ditching the land and in road-building as well as in clearing of forests to bring this district into a condition of full cultivation, but the fertility of the soil is such as to encourage such development.

Farm and Crop Data for Beltrami County from the Census of 1910

Percentage of land area in farms	9.1
Percentage of farm land improved	14.9
Average acres per farm	141.9
Average improved acres per farm	21.1
Value of all farm property	$3,389,856.00
Cereals produced in 1909	$56,646.00
Other grains and seeds	$5,031.00
Hay and forage	$127,054.00
Vegetables	$126,585.00
Fruits and nuts	$1,221.00
All other crops	$286,922.00
Total crop value	$601,459.00

WESTERN KOOCHICHING COUNTY

Only the western three ranges of townships in Koochiching County, embracing an area of 1,027 square miles, will be considered in this report. It so happens that it includes the part of the county in which swamps are most extensive, and thus is not fairly representative of the county as a whole. About 80 per cent of this part of the county lies within the limits of the glacial Lake Agassiz, but about 200 square miles in the southern end stand above the highest shore line.

There are a few rocky knobs near Manitou Rapids and southwestward from there, and also near Clementson, but they aggregate scarcely a square mile in area.

The cultivable land in the portion within the limits of Lake Agassiz is mainly along the borders of the streams. In most places muskeg swamps set in within a mile back from these drainage lines. This is true even on the borders of Rainy River, in places where its valley is

from 30 to 40 feet deep. There are belts of sandy land, in part moraine and in part beach or shore deposit, which cross the interstream areas and break the continuity of the muskeg swamps. On one of the sandy strips near Wayland a few settlers have located. There are also a few in the vicinity of Norden, on the borders of Tamarack River, and on sand ridges to the south. Only small clearings have as yet been made by any of the settlers, and the narrowness of the cultivable strip will greatly restrict farming operations under present conditions of drainage. Several good county roads are projected across these swampy districts, and some are in process of construction.

In the portion of this county above the level of the highest shore of Lake Agassiz a large percentage of the land is tillable with but small expenditure for ditching, and this portion of the county is being developed rapidly. The soil is mainly a pebbly clay loam, but there are morainic strips in which gravelly and sandy knolls occur, and the soil is generally loose-textured, though quite productive.

Percentages of Classes of Land in Western Koochiching County

	Sq. miles	Per cent of area
Sandy moraine, with sandy to gravelly loam soil....	54	5.2
Till plain, with prevailingly clay loam soil.....	146	14.2
Stony or pebbly clay loam, lake-washed drift.....	114	11.1
Sandy and gravelly deposits of old lake shores.....	57	5.6
Rock knobs.....	1	0.1
Swamp land.....	655	63.8
Totals	1,027	100.0

NORTHWESTERN ITASCA COUNTY

An area of about 470 square miles in the western three ranges of townships in Itasca County will be discussed in this report. The south part is included in the Minnesota National Forest, and is uninhabited. The remainder is a very sparsely populated district, there being few farms except in the vicinity of the Minnesota and International Railroad, which crosses the northwest corner of the county. Much of this district is practically inaccessible unless one forces his way through brush and swamp, there being very few roads or trails across it. Considerable information has, however, been obtained in reference to it from residents who have had occasion to go into this district.

Aside from a morainic strip which runs southeastward from Orth past Island Lake to Popple, this district seems to be occupied entirely

by till plains and swamps. It is thought, however, that the wet land may be easily drained when the brush is removed and a moderate amount of ditching is done. The soil appears to be subject to abrupt changes from clay to sand or gravel, and the designation *TM* on the general map stands for mixed soil in a till plain. Of the 470 square miles fully 80 per cent is in the till plain. The sandy moraine occupies about 7 per cent. There thus remains about 10 to 12 per cent in lakes and swamps.

PARTS OF CASS AND CROW WING COUNTIES

The greater part of Cass and a few townships in the northwest part of Crow Wing County fall in the southeast part of the area embraced in this report. It is made to include the whole of the three townships southeast of the Mississippi River in Crow Wing County since they extend but a slight distance outside the limits of the map. But north of the Mississippi the estimates do not extend east of Range 27, as only a small part of Range 26 is within the limits of the map. In making the percentage estimates of the different classes of land Leech Lake and Winnibigoshish Lake are not included. Leech Lake has an area of 173 square miles at low-water stage and Winnibigoshish an area of 77 square miles. The smaller lakes of this district are estimated to have an aggregate area of about 177 square miles and the swamps 133 square miles. There is thus 560 square miles of lakes and wet land or about 25 per cent of the entire district. But counting out Leech and Winnibigoshish lakes and thus reducing the district 250 square miles, the lakes and swamps comprise 15.6 per cent, of which 8.9 per cent is lake and 6.7 per cent swamp. The area of the district as thus reduced is 1,990 square miles.

This district is separable into several distinct belts. At the north, along the south side of the Mississippi River and Winnibigoshish Lake, there is a plain of sandy gravel with forest of Norway pine which extends south about to the line of the Great Northern Railroad. South of this on the borders of Leech Lake is a great till plain with a pebbly clay loam soil to the northwest of the lake, and with a mixed or variable soil to the east and southeast. Extensive tracts of wet land are present on the plain east of Leech Lake. On the immediate south border of this lake there is a rolling country with stony or pebbly clay loam soil. This changes on the south into a more sandy and gravelly tract of moraine which covers several townships of this district and extends westward in a broad belt across Hubbard County to the headwaters of the Mississippi in Clearwater County. This moraine loses expression, however, toward the east side of the district under discussion and consists of scattered groups of knolls bordered by nearly plain tracts of mixed clay and

sand and gravel. From Whitefish Lake southward to Gull Lake and eastward to the Mississippi is a gravelly glacial outwash plain with numerous basins containing lakes. The strip of gravelly glacial outwash extends from Whitefish Lake northwestward past Backus along the south side of the great moraine just mentioned. The morainic tract has an offshoot to the south from near Hackensack which separates this gravelly outwash plain from a larger one in Hubbard and Wadena counties. In the southwest part of the district are several townships with gently undulating clayey moraines and bordering till plains. The till plains are in part clayey and in part have mixed soil with abrupt and frequent changes from pebbly clay to gravel or sand. In the extreme southeast part of this district on the east side of the Mississippi there is a rugged sandy moraine with small outwash gravel plains included among groups of morainic knolls.

Percentages of Classes of Land in Parts of Cass and Crow Wing Counties

	Sq. miles	Per cent of district
Sandy moraine, with sandy to gravelly loam soil	379	19.0
Clayey moraine, with pebbly clay loam soil	191	9.6
Outwash gravel plains	540	27.1
Clayey till plain, with pebbly clay loam soil	205	10.2
Till plain with mixed soil, clayey to sandy or gravelly	365	18.3
Swamps	133	6.7
Small lakes	177	8.9
Totals	1,990	99.8

This district has farming settlements in the western part along the line of the Minnesota and International Railroad and the Great Northern Railroad which extend over the till plains and clayey moraines of the southwest part. There is also a settlement at Longville, southeast of Leech Lake. The remainder of the district is very sparsely inhabited. The soil of much of this district is rich enough to justify large expenditures in road-building and in draining the land and in clearing it of brush. The heavy soil of the till plains and clayey moraines of Cass County is well adapted for stock-raising and dairying as well as general farming. The iron mines in the southeast corner of this district have brought in a large population which gives a good home market for garden produce and dairy products of that locality.

HUBBARD COUNTY

Hubbard County is a rectangular tract seven townships long and four townships wide lying west of Cass and south of Beltrami County. It contains 1,008 square miles, of which about 93 square miles are estimated to be covered by small lakes. The census of 1910 gives the land area as 958 square miles, some of the lakes apparently being included.

The southern end of the county is occupied by a large plain of sandy gravel in which there are a number of small lakes and marshes of considerable extent. North of this is a great moraine of sandy and gravelly constitution, in which a number of lakes are included, and from which the sandy outwash of the plain to the south was derived. On its north border the moraine becomes more clayey and graduates into a till plain which occupies much of the northern third of the county. There are small areas of sandy land along the north border, one being in the northeast corner near Farris, and another a few miles southwest of Bemidji, both of which extend into the great sandy plain of the southern part of Beltrami County. The till plain has a pebbly clay loam soil and constitutes the best farming land in the county, there being several prosperous farming settlements on it. A portion of the sandy plain in the southern part of the county had no forest on it at the time the country was settled, so that farms were easily cleared and brought into cultivation. The district around Park Rapids and Hubbard was therefore settled long before the neighboring forested areas.

Percentages of Classes of Land in Hubbard County

	Sq. miles	Per cent of county
Sandy moraine, with light sandy to gravelly loam soil	267	26.5
Clayey moraine, with pebbly clay loam soil	151	15.0
Outwash gravel plains	153	15.1
Till plain, with pebbly clay loam soil	224	22.2
Small lakes	93	9.3
Swamp land	120	11.9
Totals	1,008	100.0

Farm and Crop Data for Hubbard County from the Census of 1910

Percentage of land area in farms	24.8
Percentage of farm land improved	36.6
Average acres per farm	180.3

Average improved acres per farm	66.1
Value of all farm property	$3,175,028.00
Percentage of gain since 1900	212.1
Cereals produced in 1909	$171,961.00
Other grains and seeds	$9,417.00
Hay and forage	$116,760.00
Vegetables	$89,302.00
Fruits and nuts	$1,029.00
All other crops	$74,052.00

A considerable part of the gain in value of farm property in Hubbard County is due to development of new farms. The average value of land per acre in 1900, according to the National Census, was $7.10, or slightly more than half of that of 1910. The present value of land is somewhat higher than in 1910, and may average, with improvements included, about $30.00 per acre.

WADENA COUNTY

Wadena County embraces only fifteen townships or an area of 540 square miles. Its southern edge extends 3 or 4 miles beyond the southern limits of the map accompanying this report, but the discussion embraces the whole county. The greater part of this county is a sandy outwash plain, a southward continuation of that in Hubbard County. Along the west border, however, there is a till plain with pebbly clay loam soil embracing an estimated area of 117 square miles, or, including swamps, a little more than one fifth of the county. The southern end of the county, in the vicinity of the Northern Pacific Railroad, has been settled for many years. The western range of townships, along the line of the Great Northern Railroad, has more recently been converted into farms. But in the northeast part of the county there are still very few settlers. That part of the county has considerable wet land. The entire county has been estimated by George A. Ralph to contain 80,000 acres of swamp (*Drainage Engineer's Report,* 1906).

In the part of this county south of Leaf River there was a re-advance of ice over the gravelly outwash which greatly increased the fertility by introducing clayey calcareous drift a few feet thick and mixing it with the gravel. The farms are kept in a good state of fertility by the growing of clover which thrives on this soil.

Farm and Crop Data for Wadena County from the Census of 1910

Percentage of land area in farms	46.1
Percentage of farm land improved	43.9

Average acres per farm	158.0
Average improved acres per farm	69.4
Value of all farm property	$4,697,499.00
Percentage of gain since 1900	130.00
Cereals produced in 1909	$263,978.00
Other grains and seeds	$13,170.00
Hay and forage	$136,990.00
Fruits and nuts	$486.00
All other crops	$45,269.00
Total crop production in 1909	$512,294.00

NORTHERN OTTERTAIL COUNTY

The map accompanying this report includes twenty-six full townships and parts of nine other townships in the northern part of Ottertail County. The discussion and estimates here given will cover the entire thirty-five townships or 1,260 square miles.

In the northeastern part of the county there is an area of about 200 square miles of till plain with a pebbly clay loam soil, parts of which are thickly strewn with bowlders. It includes a few small lakes and swamps, and, until cleared of brush, parts of it are poorly drained. The surface, however, is undulating and but a moderate amount of ditching will be required to render much of the wet area suitable for cultivation.

In the northern and central parts of the county there is a very rugged moraine of sandy constitution with local developments of clayey drift. This includes a multitude of small lakes and undrained basins which in several townships comprise nearly half the surface. Estimates of the percentages of dry and wet land made from the topographic sheets of the United States Geological Survey, are presented below. In a large part of this area of morainic drift it would be difficult to find a square mile of land free from swamp or lake, and in some townships there is scarcely a 40-acre lot free from wet land. The slopes of the morainic knolls are also steep, as may be seen by an inspection of the topographic sheets. It is an interesting fact that this morainic area with its extremely rough surface stands almost in sight of the featureless plains of the Red River Valley, a few miles to the west. Here it would be difficult to carry a straight furrow for more than a fraction of a mile, while on the neighboring plains there is nothing to turn the plow aside. This rugged district, known as the Park Region of Minnesota, seems best adapted for grazing and dairying. The soil is of sufficient strength to give good pasturage, while there is no lack of water supply for the stock.

The western limits of this rugged moraine are at the east side of

A. DRAINING A MUSKEG SWAMP IN ROSEAU COUNTY

B. DRAINED SWAMP IN PENNINGTON COUNTY WITH FOREST ON LAKE-WASHED TILL IN BACKGROUND

Pelican River Valley. To the west of that valley is a moraine of clayey constitution and more gently undulating surface. This is in places thickly set with small lakes but the amount of lake and marsh is scarcely half as great as in the more rugged moraine to the east. Almost the entire area of this clayey moraine is under cultivation and the marshy ground is utilized to a considerable extent for pasturage. This tract stands at the border between forest and prairie, only a part of its surface being occupied by forests and groves.

There is an extensive outwash plain around Ottertail Lake and Rush Lake, and lines of glacial drainage come down to it from the north. One of these is along the line of Ottertail River and the other along Toad River. In this outwash plain and the lines of glacial drainage just mentioned, lakes and basins are very numerous, as in the rugged moraine to the west, but there is a much smaller amount of swamp land than in the moraine. The dry land also has a level surface and thus contrasts strikingly with the rugged surface of the moraine. This plain varies in fertility in proportion to the amount of loam in the soil and in proportion to the nearness of the water table to its surface. The soil is, however, on the whole lighter than that of the neighboring moraines.

There are two sharp gravel ridges, termed eskers, in the northeastern part of Ottertail County, one being east of Pine Lake, and the other on the upland south of Perham. These are more winding and sharper than the shore lines of the glacial Lake Agassiz, but like the shore lines are composed of sandy gravel. Ridges of this class often occur on till plains where gravel for roads is an important asset. The ridge east of Pine Lake may thus serve a useful purpose.

Percentages of Classes of Land in Northern Ottertail County

	Sq. miles	Per cent of district
Sandy moraine, with sandy to gravelly loam soil....	258	20.4
Clayey moraine, with pebbly clay loam soil.....	160	12.7
Outwash gravel and sandy glacial drainage deposits.	229	18.2
Till plain, with prevailingly clay loam soil.....	217	17.2
Lakes and swamps.....	396	31.5
Totals	1,260	100.0

The estimates of swamp land and lakes in the Perham, Vergas, Battle Lake, Underwood, and Fergus Falls topographic sheets,[1] so far as they fall within this district, have been computed section by section, and their

[1] These topographic sheets are obtainable at 10 cents each, or $6.00 per hundred sheets, from the Director U. S. Geological Survey, Washington, D. C.

aggregate for each township follows. The border between lake and swamp is in many cases so indefinite on the topographic sheets that separate estimates have not been made.

Percentage of Lakes and Swamps in Certain Townships of Northern Ottertail County

	Sq. miles	Per cent lakes and swamps
Western third of T. 137, R. 38 W.	3.6	30
Western third of T. 136, R. 38 W.	5.6	47
Western third of T. 135, R. 38 W.	6.2	51.6
Western third of T. 134, R. 38 W.	1.7	14
T. 137 N., R. 39 W.	11.4	32
T. 136 N., R. 39 W.	5.9	17
T. 135 N., R. 39 W.	16.6	46
T. 134 N., R. 39 W.	18.9	52.5
T. 137 N., R. 40 W.	14.6	40
T. 136 N., R. 40 W.	16.2	45
T. 135 N., R. 40 W.	20.4	56.6
T. 134 N., R. 40 W.	20	55.5
T. 137 N., R. 41 W.	9.5	27
T. 136 N., R. 41 W.	14.6	40.5
T. 135 N., R. 41 W.	23.1	64
T. 134 N., R. 41 W.	12	33.3
T. 137 N., R. 42 W. (two thirds of township)	10.6	44
T. 136 N., R. 42 W. (five sixths of township)	20.9	70
T. 135 N., R. 42 W. (33 square miles)	12.8	39
T. 134 N., R. 42 W.	12.5	34.7
T. 135 N., R. 43 W. (south half)	3.6	20
T. 134 N., R. 43 W.	11.9	33
T. 135 N., R. 44 W. (15 square miles)	2.8	18.66
T. 134 N., R. 44 W. (30 square miles)	6.7	22.3

BECKER COUNTY

Becker County lies north of Ottertail County and embraces 40 townships, or 1,440 sections. The number of square miles, as estimated by Upham in his report on Becker County for the Geological Survey of Minnesota, is 1,445.41. Upham also estimated the area of lakes in this county to aggregate 137.5 square miles, thus leaving a land area of 1,308 square miles. The swamp land as estimated by the present writer amounts to about 250 square miles.

Becker County includes the continuation of the same series of moraines, till plains, and outwash gravel plains, which have been described in northern Ottertail County. There is a bowlder-strewn till plain in the southeast part. North and west of this are extensive plains of outwash gravel, and beyond these the very rugged sandy moraine, while farther west are gently undulating clayey moraines and till plains. In the midst of the great sandy moraine there is an outwash plain setting in immediately north of the city of Detroit and extending southwestward into northwestern Ottertail County, with a general width of 4 or 5 miles. Its surface is more undulating than the ordinary outwash plains, and lakes of considerable size lie in it or on its border. It contrasts strikingly with the neighboring moraines in its freedom from bowlders, and it also lacks the loam which is generally present on the moraines. A similar gravelly outwash tract is present in the midst of the great sandy moraine in the northern part of the county a few miles east of the White Earth Agency.

The White Earth Indian Reservation occupies twelve townships in the northern part of the county. In this reservation considerable land is cultivated on the till plains and clayey moraine along and west of the Soo Railroad, and a small tract is cultivated on the outwash gravel plain north of Ponsford. With these exceptions the portion of the reservation in Becker County is practically in its wild state.

The western part of Becker County is along the border line between the forest and prairie, and is practically all under cultivation, and the major portion of the land is settled as far east as Richwood, Detroit, and Frazee. There are also old settlements on the outwash gravel plains around Ponsford and Osage, a considerable part of the plain being prairie or covered by a very scrubby timber. The ease of clearing such land compared to that of the heavily forested but richer land to the south accounts for its earlier settlement. Even now there is very sparse settlement of the southeast part of the county, though it is well suited for agriculture. On the rough morainic land east from Richwood farming is scarcely yet begun. There is a belt several miles wide running southward across the county along either side of Ottertail River which seems well suited for grazing land, but much of it is rather broken for farming.

Percentages of Classes of Land in Becker County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil...	402	28.2
Clayey moraine, with pebbly clay loam soil.....	160	11.1
Outwash gravel and glacial drainage deposits.....	239	16.6

	Sq. miles	Per cent of county
Till plain, with pebbly clay loam soil	253	17.6
Swamp land	247	17.0
Lakes	137	9.5
Totals	1,440	100.0

Farm and Crop Data for Becker County from the Census of 1910

Percentage of land area in farms	41.1
Percentage of farm land improved	50.4
Average acres per farm	171.2
Average improved acres per farm	86.3
Value of all farm property	$11,795,410.00
Percentage of increase since 1900	124.2
Cereals produced in 1909	$976,176.00
Other grains and seeds	$64,545.00
Hay and forage	$300,673.00
Vegetables	$100,164.00
Fruits and nuts	$6,045.00
All other crops	$108,225.00
Total crop value	$1,556,328.00

MAHNOMEN COUNTY

Mahnomen County was organized from a part of Norman County in 1906 and embraces the greater part of the White Earth Indian Reservation, there being sixteen townships or 576 square miles in the county. The western half is almost entirely a clayey till plain and this plain extends a few miles into the eastern half, in the central portion of the county. It is diversified by a few gravelly knolls, and also by a few small lakes. The eastern half is largely morainic, the northeastern portion being a clayey moraine and the southeastern portion more sandy and gravelly. A line of glacial drainage with sandy soil runs along the east border of the northern half of the county, and then leads southwestward past Twin Lakes into northern Becker County.

Percentage of Classes of Land in Mahnomen County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil	70	12.2
Clayey moraine, with pebbly clay loam soil	146	25.5
Outwash gravel and sandy glacial drainage deposits	25	4.5

	Sq. miles	Per cent of county
Clayey till plain, with pebbly clay loam soil	309	54.0
Lakes and swamp land	22	3.8
Totals	572	100.0

The western half of the county is largely prairie and contains nearly all the land under cultivation. Fully three fourths of the prairie, however, is in a wild state, though having a very rich soil.

Farm and Crop Data for Mahnomen County from the Census of 1910

Percentage of land area in farms	11.5
Percentage of farm land improved	57.4
Average acres per farm	169.3
Average improved acres per farm	97.3
Total value of farm property	$1,234,111.00
Cereals produced in 1909	$94,707.00
Other grains and seeds	$13,248.00
Hay and forage	$23,793.00
Vegetables	$8,884.00
Fruits and nuts	$9.00
All other crops	$4,994.00
Total crop production in 1909	$145,635.00

NORMAN COUNTY

Norman County, which borders on Red River, has, since Mahnomen County was cut off, an area of 860 square miles. All of this except 125 square miles on the eastern border was covered by the waters of the glacial Lake Agassiz. Nearly half the county has the rich black clay and clay loam of the Red River Valley. On the eastern border, above the limits of the lake, there is a till plain, nearly all prairie, with rich black pebbly clay loam soil. Between the clay belt of the Red River Valley and this till plain is a sandy belt from 8 to 15 miles wide on which occur a number of successive shore lines of Lake Agassiz. These shore lines are narrow ridges of sand or sandy gravel occupying scarcely more than one tenth of the sandy belt. Just below the upper beach there are narrow strips of lake-washed till with sandy to clay loam soil. A few sand dunes occur in the northeast part of the county, and there is some sand on the till beyond the limits of the lake east of Flaming and northward to Fertile in Polk County. In the southeast part of the county outside the limits of Lake Agassiz there are scattered clusters of gravelly knolls rising

from 50 to 75 feet above the surrounding till plain. These may mark a temporary ice border and thus be of morainic character.

Percentages of Classes of Land in Norman County

	Sq. miles	Per cent of county
Gravelly glacial knolls	3	0.3
Till plain with sandy patches	14	1.6
Till plain with black pebbly clay loam soil	102	11.9
Lake shores and associated sand	265	30.9
Stony or pebbly sandy loam, lake-washed drift	50	5.8
Black clay and clay loam, lacustrine	405	47.1
Swamp land	21	2.4
Totals	860	100.0

Aside from a part of the sandy land, Norman County has an exceptionally productive soil, and as indicated by the table below, it is very largely under cultivation. Wheat, oats, and barley are raised in large amounts. Farm prices have made some advance since 1910, the average value of a farm with good buildings being now fully $50.00 per acre.

Farm and Crop Data for Norman County from the Census of 1910

Percentage of land area in farms	76
Percentage of farm land improved	75.2
Average acres per farm	253.2
Average improved acres per farm	190.4
Value of all farm property	$16,371,171.00
Average value of a farm	$9,904.00
Cereals produced in 1909	$2,013,945.00
Other grains and seeds	$146,889.00
Hay and forage	$274,104.00
Vegetables	$59,918.00
Fruits and nuts	$3,043.00
All other crops	$37,643.00
Total crop value in 1909	$2,535,542.00

CLAY COUNTY

Clay County, of which Moorhead is the county seat, has an area of 1,043 square miles and extends from Red River eastward a few miles beyond the limits of the glacial Lake Agassiz. The western third of the

county has the black clay and clay loam of the Red River Valley; but a narrow water-laid moraine with surface bowlders and looser soil traverses its southern part centrally from north to south. East of the black clay district is a strip of sandy land from 6 to 10 miles wide, in which several successive beaches of Lake Agassiz are present. There is also a water-laid moraine among the beaches and partly covered by lake sand. Barnesville stands on it and it is well developed for several miles north of that village. In the vicinity of Barnesville it is thickly strewn with bowlders, but farther north they are usually covered by lake sand. In the northeastern part of the county, outside the limits of Lake Agassiz, there is a till plain with rich prairie soil of slightly pebbly clay loam. From near Hitterdal southwestward to Muskoda there is a moraine with numerous basins and small lakes among its swells and ridges. From Muskoda it runs southward along the border of Lake Agassiz. It is generally composed of clayey till but includes some gravelly knolls and some sandy land. Outside of this moraine is a strip of gently undulating till with level patches of gravel and sand which follows down Buffalo River to Hawley, but is very narrow farther south. In the southeast part of the county is a prominent moraine which extends into Becker and Ottertail counties. It has a rich prairie soil with pebbly clay loam subsoil. Its surface is rolling, but its slopes are gentle enough for easy cultivation. It includes a number of small lakes, and a small percentage of swampy land.

Percentages of Classes of Land in Clay County

	Sq. miles	Per cent of county
Sandy moraine, with sandy to gravelly loam soil	10	1.0
Clayey moraine, with pebbly clay loam soil	157	15.0
Water-laid moraine with variable soil	16	1.5
Till plain with pebbly clay loam soil	120	11.5
Stony or pebbly sandy loam, lake-washed drift	28	2.8
Sandy deposits and old lake shores of pebbly sand	305	29.2
Black clay and clay loam, lacustrine	400	38.4
Swamp land	7	0.6
Totals	1,043	100.0

Farm and Crop Data for Clay County from the Census of 1910

Percentage of land area in farms	79.6
Percentage of farm land improved	82.0
Average acres per farm	305.8

Average improved acres per farm	250.8
Value of all farm property	$23,924,607.00
Percentage of increase since 1900	100.4
Cereals produced in 1909	$2,622,637.00
Other grains and seeds	$112,902.00
Hay and forage	$447,917.00
Vegetables	$607,158.00
Fruits and nuts	$3,840.00
All other crops	$21,634.00
Total crop value in 1909	$3,816,088.00

NORTHERN WILKIN COUNTY

An area of 381 square miles in northern Wilkin County, comprising townships 134 to 136 N., ranges 45 to 48 west, is here discussed. It falls within the limits of the glacial Lake Agassiz, except a narrow strip from 1½ to 4 miles wide on the eastern border which rises above the level of that lake. The black clay and clay loam of the Red River Valley extends only 1 to 2 miles east from the river at the southern edge of this district, and about 7 miles at the northern. There is a tract of lake-washed till extending from near the river eastward to the upper beach of Lake Agassiz in T. 134 N., Rs. 45 to 47 W., and the south part of T. 135 N., Rs. 45 to 47 W. Farther north in the northern part of T. 135 N., Rs. 45 to 47 W., and in T. 136 N., Rs. 45 to 47 W., there is a sandy coating over the till, so that it is exposed in only a few narrow strips. Several ridges of sandy gravel, marking the shores of Lake Agassiz, traverse the eastern part of this district, and scattered ridges occur farther west, there being a prominent one from 3 to 6 miles north-northeast of Kent, and less conspicuous ones a few miles farther north.

The water-laid moraine on which Barnesville stands runs southward through the eastern part of T. 136 N., R. 46 W. and has a strong beach developed on its western slope. The part of the district standing above the level of Lake Agassiz consists of a narrow till plain immediately east of the high shore line, and a clayey moraine along the eastern side of the county which extends into Ottertail County.

With the exception of a few small brushy areas along the streams this is a prairie region and the clayey portion has a rich black soil. The sandy portions vary considerably in fertility. A few square miles in T. 135 and 136 N., R. 47 W. have a light sand which is subject to drifting by the wind. The old shore lines are composed of a sandy gravel with rather light soil, but sandy tracts among them have an admixture of loam, and also have less depth to the water table, so that they are moderately productive.

Percentages of Classes of Land in Northern Wilkin County

	Sq. miles	Per cent of district
Clayey moraine, with pebbly clay loam soil	22	5.8
Till plain, with pebbly clay loam soil	28	7.4
Stony or pebbly sandy loam, lake-washed drift	102	26.7
Pebbly clay loam, lake-washed drift	58	15.2
Sandy desposits of Lake Agassiz	91	23.9
Black clay and clay loam, lacustrine	70	18.4
Swamp land	10	2.6
Totals	381	100.0

The extent of cultivation of the land in Wilkin County is about the same as in northern Clay County, and there is a similar land value and crop production.

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THE UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
W H EMMONS, DIRECTOR
IN COOPERATION WITH THE
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH DIRECTOR

SHEET 1 OF A

MAP OF THE SURFACE FORMATIONS OF MINNESOTA

BY FRANK LEVERETT, GEOLOGIST
UNITED STATES GEOLOGICAL SURVEY

With assistance of United States Bureau of Soils in Pennington County and Division of Soils, University of Minnesota, in Clay, Norman and Polk Counties. Also with much aid from reports of Prof. N H Winchell, Warren Upham and staff of earlier State Survey.

SCALE 1:500,000 = 8 miles = one inch

1914

LEGEND

Moraines

(a) Loamy
1. Sandy — MS
2. Clayey — MC
(b) Waterlaid — MD

Rolling to gently undulating deposits laid down at border of ice sheet; composition variable ranging from very sandy and sandy material to loamy clay with few stones. In each group, sandy and clayey, there is much variation. Waterlaid moraines deposited in lakes at ice border, are usually low rounded clay ridges. All classes of moraines are fair to good farm land. Some clayey hillsides and some swamps occur in the strong moraines.

Till or bowlder-clay plains

(a) Clayey — TC
(b) Mixed sand and clay — TM

The plains of bowlder clay, sometimes called till plains, sometimes ground moraines, were formed under the ice sheet. The soil ranges from clayey to stony loam, and from fair soils to good second rate. Tracts that are exceedingly clayey are drainage when from mixed or variable soils

Outwash gravel in plains or aprons — OG

Gravel or pebbly sand spread with level surfaces outside the moraines by water escaping from the ice sheet. Soil usually light and crops are it easily affected by drouth. In some places the ice rested over the outwash introducing clay enough to greatly increase the fertility, notably so in southern Wadena County. Not highly productive unless intelligently cultivated.

Gravel ridges (Eskers) — GR

Gravel ridges formed by streams in and under the ice and named eskers by geologists, are commonly known as "hog backs." They occur both in moraines and on till plains and are valuable for road material. They are more irregular to form than the lake beaches and occur outside the lake limits.

Lake beaches

Ridges of sandy gravel formed somewhat closely along shores of extinct lakes and at certain lower levels down to existing lakes. Not all are shown. Valuable for road material and roadways and building sites. Easily affected by drouth, but used successfully for truck gardening.

Lake washed till

(a) Clayey — LCT
(b) Sandy — LST

Rather stony till formed by partial removal of fine material from clayey till by wave action on old lake beds. Soil usually first class. Includes sandy phases of till and mixed soils covered by lake waves. Soil fair to good, especially where extent is heavy enough to withstand drouth. Extensive areas in southeastern Wilkin County are thickly strewn with bowlders

Lake bed, sandy — LS

Sand, probably glacial in part, and partly of late deposition. Soil usually light but varying in fairness of texture and solidness of ground water-table, crops usually shown.

Lake bed, clayey — LC

Clayey in low part of areas of extinct lakes where fine material found but partly below level of wave action. Soil generally of high fertility

Rock outcrops

Largely uncultivated and of less agricultural value. Better adapted to forest cultivation. Not all are shown.

Glacial striae

(a) Latest ice movement
(b) Earlier ice movements

Lines or grooves on the rock surface, made by passage of rock laden ice across it. In some cases striae produced by the latest ice movement are across the direction of an earlier ice movement

Swamps

Areas so mapped embrace not only deep peat and muck, but poorly drained parts of a till plain with scarcely any muck on it. These areas may be greatly reduced by heavy ditching and already consider able areas mapped on the Departmental Land survey as swamps, have thus been converted into first class agricultural land

Boundaries between soils

(a) Definite
(b) With transition zone
(c) Location approximate