NORTH DAKOTA GEOLOGICAL SURVEY

Wilson M. Laird, State Geologist

THE SODIUM SULPHATE DEPOSITS OF WESTERN NORTH DAKOTA

A Progress Report

by

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INTRODUCTION

History

In the years 1804 and 1805 the members of the Lewis and Clark expedition were slowly making their way up the Missouri River. While passing through western North Dakota, they noticed a peculiar white substance.

"The country around is much the same as that we passed yesterday; on the sides of the hills, and even on the banks of the rivers, as well as on the sand-bars, is a white substance which appears in considerable quantities on the surface of the earth, and tastes like a mixture of common salt with glauber salts; many of the streams which come from the foot of the hills are so strongly impregnated with this substance that the water has an unpleasant taste and a purgative effect." (1) And further, "From the Mandan villages to this place (confluence of Little Missouri and the Missouri) the country is hilly and irregular, with the same appearance of glauber salts and carbonated wood...."(2)

Another account mentions the following: "Delayed about one hour and proceeded on ---- passed the mouth of a large creek on the N. S. called White Earth River. (A footnote on this page reads "Lewis supposes its name to have been given because of the great quantities of alkali salts along its banks, which in many places are so thickly covered as to appear perfectly white. (Journal, April 22) He notes that the water is 'much clearer than that of the Missouri'; notwithstanding which it bears the modern name of the Little Muddy River. It flows through Williams County, with the town of Williston as its mouth") (3)

Nearly 70 years later, Bell, working in Canada reported on "a saline lake at the base of the escarpment (Dirt Hills) whose bed was covered with white salts, and another about eleven miles to the southeast. (4) Another, later report by Bell reads: "I might mention in connection with this subject that the same year in which I brought home the above samples of water, I collected specimens of the white efflorescing salt of alkali" which every traveller observes around many of the lakes and covering the dry beds of ponds in the region drained by the western branch of the Assiniboine, and found that it consists principally of sulphate of sodium and magnesium, together with chlorides of calcium and sodium." (5)

A considerable period of time was to elapse, however, before it was discovered that in the region lying north of the Missouri and west of the Assiniboine there lay a vast and continuous area embracing North Dakota, Montana, Saskatchewan and Alberta containing over a hundred million tons of valuable sodium sulphate.

Table 1 shows by chronological arrangement how interest in these deposits has gained momentum, especially in the last few years.

Table 1

Significant Events in the Development of the Sodium Sulphate Deposits of North Dakota

1805 -- Lewis and Clark group notes occurrence of white "glauber salts" in western North Dakota during expedition of the Missouri River.

1873-4--Bell records white salts in saline lakes in Canada.

1878-9--Bell collects samples from region drained by western branch of the Assiniboine. Analysis reveals sodium and magnesium sulphate with calcium and sodium chloride.

1907(?)--Daniel E. Willard deduces that dried Lake bottoms containing valuable quantities of mineral salts might be present in the western part of the state. His deduction, in "The Story of the Prairies" (1907) based on resemblance of North Dakota's geology to that of states further west. (6)

1918-19--Canadian Salts and Potash Company of Canada, Ltd. formed to produce sodium sulphate at Muskiki Lake, Saskatchewan. (7)
Other Canadian companies formed in the next few years.

1921 (Field Season)--Investigation of western Canadian deposits by Canadian Mines Branch resumed. (Work since has continued (8)

1929 (Fall)--"Mr. Quarne of Grenora, North Dakota accidentally finds that a hard, solid bottom of crystals, upon which one could walk, lies a few inches under the surface of an entire lake about 6½ miles from Grenora. Chemical analysis proved these crystals were glauber's salt."(9)

1934(Summer)--Group of engineers and chemists organized by Dr. Irvin Lavine in an FERA survey of the many dried lakes in western North Dakota. Many valuable deposits discovered and mapped.

1937(Summer)--Ozark-Mahoning Company of Tulsa, Oklahoma drills satisfactory well near Grenora #2 deposit for water to be used in processing sodium sulphate. It had already acquired land around this deposit.(10)

1937(Oct.8)--Ozark-Mahoning Company commences suit against the State of North Dakota to settle title to the land within the meander lines of the original government survey of Grenora #2.

1947(June)--North Dakota Geological Survey resumes field and laboratory study of the deposits in four northwest counties.

1947(Summer)--Interior Department announces at Washington that it will offer sodium deposits in 80 acres of public lands in North Dakota for rental in the fall. Bids were to be opened in Washington September 25 for leasing the land in Divide County, west of Crosby. The lease offer was subject to a 5% royalty, a minimum investment of $20,000 during the first three years of the lease and a minimum production beginning with the fourth lease year averaging not less than $20 an acre in value.

1947(Oct.5)--North Dakota State Board of University and School Lands approves lease on Grenora #2 Lake to Ozark-Mahoning Company of Tulsa, Oklahoma.

1947(Nov.)--Dr. Edward L. Tullis of the U. S. Bureau of Mines begins study of the sodium sulphate deposits of Saskatchewan and North Dakota "as a background for an investigation of the possibility of a sodium sulphate industry in North Dakota."(11)

1947(Oct.)--Montana State Bureau of Mines and Geology sponsors a short reconnaissance survey of the alkali lakes in eastern Montana.(12)

1948(Feb.)--Grenora #2 case tried at Williston. Decision rendered for Ozark-Mahoning Company on June 2, 1948.

1948(Summer)--Sodium Corporation of America announces plans to build a plant at Westby, Montana to exploit the North Dakota deposits at Miller and North Lakes.

1948(Sept.)--Attorney General's Department appeals Grenora #2 decision to State Supreme Court. Decision pending.

During the drought of 1934, the FERA organized an investigation (project S-F2-47) of the deposits lying in the northwest corner of the state. A number of engineers and chemists working under Dr. Irvin Lavine, were aided by laborers taken from the relief rolls, the whole group totalling more than 70 men. This study outlined seven deposits having total reserves of over 20 million tons. This is a conservative estimate, however, for in another article Lavine and Feinstein speack of "eight large deposits.....estimated at nearly 25,000,000 tons."(13) (It must be remembered that reserves can be calculated on the basis of either hydrous or anhydrous sodium sulphate. The former will yield tonnages more than twice as high as the latter. All calculations in the 1934 study are on the basis of the hydrous salts.) "Many smaller ones were located but their importance could not be completely investigated because of lack of funds. (14) Lavine also stated that "there are probably still more in counties that were not prospected."(16)

Following these discoveries, an expanding market resulted in an increase in production on the part of the Canadian producers who were obtaining sodium sulphate from nearby deposits across the international boundary. Renewed interest in the North Dakota deposits prompted the North Dakota Geological Survey to undertake a restudy of the area lying north and west of Stanley, including all of Divide and Burke Counties and the northern halves of Williams and Mountrail Counties. Most of the field work was done during the summer of 1947. The writer, assisted by Eric Engbrecht, sought to discover new deposits and ascertain the origin of the sodium sulphate.(17)

Although field work was handicapped by the heavy rainfall, some new bitter lakes were discovered. The rains converted many of the deposits to brackish or fresh water lakes and necessitated duplication of field work. Promising deposits had to be revisited in dry weather.

Table 2, transcribed from data supplied by Mr. Frank Bavendick of the United States Weather Bureau shows the total precipitation over a 10 to 18 year period for three stations at Grenora, Crosby, and Stanley respectively. The data from Stanley is incomplete, this being a new station started in 1938. In all cases the 1947 total falls within, or close to, the wettest 25%.

By contrast, the 1934 total (the year of the FERA study) is the lowest recorded for this period.

Table 2

Total Yearly Precipitation (in inches)

Williams County, N. D. Station: Grenora		Divide County, N. D. Station: Crosby		Mountrail County, N. D. Station: Stanley	
Year	Precip.	Year	Precip.	Year	Precip.
1931	7.25	1934	5.39	1938	16.46
1932	14.70	1935	9.63	1939	12.81
1933	14.06	1936	9.06	1940	16.26
1934	5.93	1937	9.16	1941	27.66
1935	12.38	1938	17.28	1942	11.49
1936	13.78	1939	9.52	1943	21.32
1937	9.90	1940	18.41	1944	22.70
1938	21.54	1941	16.49	1945	15.08
1939	11.12	1942	15.30	1946	14.35
1940	11.78	1943	15.19	1947	18.37
1941	15.61	1944	16.80	1948	data pending
1942	data unavailable	1945	15.07		
1943	data unavailable	1946	13.45		
1944	16.53	1947	15.32		
1945	12.41	1948	data pending		
1946	12.83				
1947	14.67				
1948	data pending				

In spite of the weather a great deal of information was obtained, much of it due to the help and cooperation of many individuals.

Acknowledgments

Dr. Wilson M. Laird, State Geologist, first suggested the subject and allocated the necessary funds and equipment. Dr. Grant Smith loaned the hydrometer used in making the specific gravity readings and also provided other chemical equipment. Dr. George Abbott not only provided equipment but gave most generously of his time and energy, especially in the work on the brine analyses. Most of these analyses were made by Mr. W. D. Waldschmidt and Mr. Jack Thompson. Specific credit is given with each summary.

In obtaining ownership records, the writer received the friendly cooperation of Mr. Huseby (Williston), Mrs. Hawkinson (Crosby), and Messers. Dennis (father and son) of Stanley, all from the Register of Deeds offices in the respective counties. The Ward County office likewise helped with local records.

The writer is also indebted to Professor Vera Facey, who consented to study the specimens of Salicornia rubra (?).

Assistant Attorney General C. E. Brace summarized the proceedings of the Grenora #2 case. Mr. Robert Tomkins provided several pbulications (including his own) dealing with the Saskatchewan deposits. The plant managers at Ormiston and Sybouts graciously allowed the writer to inspect their deposits and workings. Mrs. Irving Grossman transcribed some of the ownership data and helped with the typing. Dr. Francis A. Thompson, President of the Montana School of Mines, furnished a copy of Sahinen's report and granted permission to quote certain sections.

The detailed glacial geology of some of the areas was mapped by Richard Lemke, Irving J. Witkind, Garland Gott, Robert M. Lindvall and Wallace R. Hanson all of the United States Geological Survey. The writer is especially indebted to Mr. Lemke and Mr. Witkind.

Mr. George LaRoque of the United States Geological Survey, Ground Water Branch (Bismarck) provided results of several water analyses and the Soil Conservation Service made many aerial photos available. The United States Geological Survey (Topographic Division) permitted the use of its topographic maps. The Geologic Division of the Survey and especially Dr. Charles Hunt was especially helpful in making available maps, reports and other useful information.

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Mineralogy

Although sodium combines with the sulphate radical to form a number of minerals, only a few of these are abundant. It is known that mirabilite and thenardite are the most important minerals in the North Dakotan and Canadian deposits. However, other rarer minerals are doubtless present. These can only be detected by detailed laboratory analysis, but this phase of the investigation has barely begun.

The Missouri Valley Development Program raises the possibility of cheap electric power. This may make possible the manufacture of a number of compounds, not only from the mirabilite and thenardite, but also from the more uncommon minerals, thus increasing their importance. The following list includes only those minerals which contain both sodium and the SO_4 radical. (18)

Table 3

Naturally Occurring Sodium Sulphate Minerals
(All mineral names from reference 18 unless otherwise indicated.)

Natroalunite, (19) $Na_2O.Al_2O_3.4SO_3.6H_2O$
Tamarugite, (20) $Na_2SO_4.Al_2(SO_4)_3.12H_2O$
Leonite, (21) $MgSO_4(KNa)_2SO_4.4H_2O$ (?) see
Burkeite, (22) Na_2CO_3 $2Na_2SO_4$
Tychite, $2MgCO_3.2Na_2CO_3.Na_2SO_4$
Dawsonite, $Na_3AL(CO_3)_3.2Al(OH)_3$
Noselite, $2Na_2Al_2Si_2O_8.Na_2SO_4$
Darapskite, $NaNO_3.Na_2SO_4.H_2O$
Nitroglauberite, $6NaNO_3.2Na_2SO_4.3H_2O$
Thenardite, Na_2SO_4
Aphthitalite, $(K,Na)_2.SO_4$.(Glaserite)
Glauberite, $Na_2SO_4.CaSO_4$
Vanthoffite, $3Na_2SO_4.MgSO_4$
Schairerite, $Na_2SO_4.Na(F,Cl)$
Sulphohalite, $3Na_2SO_4.NaCl.NaF$
Caracolite, $Pb(OH)Cl.Na_2SO_4$
Hanksite, $9Na_2SO_4.2Na_2CO_3.KCl$
Lecontite, $(Na,NH_4,K)_2SO_4.2H_2O$
Mirabilite, $Na_2SO_4.10H_2O$
Löweite, $MgSO_4.Na_2SO_4.2\frac{1}{2}H_2O$ (Loeweite)
Blödite, $MgSO_4.Na_2SO_4.4H_2O$ (Bloedite - Astrakanite)
Soda Alum, $NaAl(SO_4)_2.12H_2O$ (Mendozite)
Kröhnkite, $CuSO_4,Na_2SO_4.2H_2O$
Natrochalcite, $Cu_4(OH)_2(SO_4)_2.Na_2SO_4.2H_2O$
Ferrinatrite, $2Na_2SO_4.Fe_2(SO_4)_3.6H_2O$ (Ferronatrite)
Sideronatrite, $2Na_2O.Fe_2O_3.4SO_3.7H_2O$
Slavikite, $(Na,K)_2SO_4.Fe_{10}(OH)_6(SO_4)_{12}.63H_2O$
Natrojarosite, $Na_2Fe_6(OH)_{12}(SO_4)_4$.
Palmierite, $(K,Na)_2Pb(SO_4)_2$.
Almeriite, $Na_2SO_4.Al_2(SO_4)_3.5Al(OH)_3.H_2O$

Hydrous sodium sulphate exists as a solid or in solution in the form of a brine. Mirabilite crystallizes out of the saturated brines at a temperature below 33°C. Above this temperature, thenardite, the anhydrous form precipitates out. More commonly, however, the thenardite forms from mirabilite after its exposure to the atmosphere (especially during dry periods). Mirabilite being unstable under these conditions, loses its water and changes to a surface crust of thenardite. North Dakota thenardite typically forms reniform or irregular crusts and masses. The mirabilite commonly forms long acicular crystal frequently many inches in length.

Mirabilite (Glauber Salt) (23)

Monoclinic. Crystals like pyroxene in habit and angle. Usually in efflorescent crusts.

Cleavage: a(100), perfect; c(001), b(010) in traces. H.= 1.5-2. G.=1.481. Luster vitreous. Color white. Transparent to opaque. Taste cool, then feebly saline and bitter. Optically-. Ax. pl. (010). Z c axis - +26° to 31°. = 1.437. (On recrystallized material = 1.395).

Comp.-Hydrous sodium sulphate, $Na_2SO_4.10H_2O$ = Sulphur trioxide 24.8, soda 19.3, water 55.9 = 100.

Thenardite (24)

Na_2SO_4. In orthorhombic crystals, pyramidal, short prismatic or tabular; also as twins. (No microscopic crystals have yet been found in North Dakota I.G.). Basal cleavage. H.=2.7. G.=2.68. Easily fusible. Soluble in water. White to brownish. Optically +. Ax. pl. (001). Z=a axis. a=1.471, =1.477, =1.484. 2V=83°. Changes on heating at 235°C to a negative uniaxial form, metathenardite. Often observed in connection with salt lakes, as on the shores of Lake Balkash in Semipalatinsk, Siberia, and at Shermakha northwest of Baku in Azerbaijan, Caucasus Mts.

Specific Gravity

Readings were taken on most of the new deposits and some weakly saline lakes as well as some of the previously known ones. (Table 4). Table 5 indicated the range in specific gravity of aqueous solutions of Na_2SO_4 at different concentrations and temperatures. It is not to be construed, however, that a brine with a specific gravity of, say 1.189 and a temperature of 25°C, necessary contains 20% Na_2SO_4 for the presence of other salts affects the results. These readings are frequently misleading for they vary markedly from time to time.

Table 4

Specific Gravity of Saline Lake Brines (surface: at various dates)

Name	County	Location	S. Gravity	Temp. in Deg. C.	Remarks
Westby A "Freund" Lake	Divide	T162N-R103W sec. 14	1.23*	63°	North Shore of lake, West of road.
Westby B	Divide	T162N-R103W sec.3 T163N-R103W sec.4	1.100	77°	Southeast shore of lake
Westby C	Divide	T162N-R103W sec. 3, 10	1.12	67.5°	South shore of lake
McKone Lake	Divide	T 163N-R103W secs. 11, 12, 14 23	1.065	63°	North shore. West of road
Miller Lake	Divide	T162N-R102W secs. 19, 20, 21, 28, 29, 30	1.35*	64°	Recent rains
Stink Lake	Williams	T159N-R103W secs. 5, 8	1.235*	77°	Strong salt showing. East shore
Upper Lostwood Lake	Burke	T159N-R91W secs. 21, 27, 28, 33, 34	1.042	64°	South shore
Upper Lostwood Lake	Burke	T159N-R91W secs. 21, 27, 28, 33, 34	1.060	60°	South shore
Lower Lostwood Lake	Mountrail	T158N-R91W secs. 4, 5, 8, 17	1.055	67°	South shore
White Lake	Mountrail	T157N-R91W-secs. 19,20,27,28,29, 30,31,32,33,34	1.075*	71°	North shore. Recent rains.
White Lake	Mountrail	35,-T157N-R92W sec.25,T156N-R91W secs. 5, 6	1.085	67°	East shore.
Stanley A	Mountrail	T156N-R89W secs. 6,7	1.120	74°	West shore, near road. Surface.
Cottonwood Lake	Mountrail	T157N-R92W secs. 5, 6, 7, 8, 9, 16, 17	1.010	65°	East shore. Fresh enough for bathing.
Stady D	Divide	T161N-R101W secs. 27, 34	1.130*	75°	
Stady F	Divide	T160N-R99W secs. 5, 8	1.175*	75°	

* Approximate only.

Table 5

Specific Gravity of Aqueous Solutions of Na_2SO_4 (25)

% Na_2SO_4					Temperature of Solution					
	0°C	10°C	20°C	25°C	30°C	40°C	50°C	60°C	80°C	100°C
1	1.0094	1.0089	1.0073	1.0061	1.0046	1.0010	0.9969	0.9919	0.9805	0.9671
2	1.0189	1.0182	1.0164	1.0151	1.0135	1.0098	1.0057	1.0007	0.9892	0.9758
4	1.0381	1.0370	1.0348	1.0332	1.0315	1.0276	1.0236	1.0184	1.0068	0.9934
6	1.0576	1.0560	1.0535	1.0515	1.0497	1.0456	1.0415	1.0363	1.0246	1.0112
8	1.0773	1.0753	1.0701	1.0701	1.0682	1.0639	1.0598	1.0544	1.0426	1.0292
10	1.0972	1.0948	1.0915	1.0890	1.0870	1.0825	1.0783	1.0728	1.0609	1.0475
12	1.1174	1.1145	1.1109	1.1083	1.1062	1.1015	1.0971	1.0915	1.0795	1.0661
14	1.1378	1.1345	1.1306	1.1279	1.1257	1.1209	1.1162	1.1105	1.0984	1.0850
16	1.1575	1.1548	1.1506	1.1479	1.1456	1.1406	1.1366	1.1299	1.1176	1.1042
18	1.1795	1.1754	1.1709	1.1683	1.1659	1.1608	1.1563	1.1496	1.1371	
20	1.2005	1.1963	1.1915	1.1890	1.1866	1.1813	1.1753	1.1693	1.1569	
22	1.2224	1.2175	1.2124	1.2102	1.2076	1.2023				
24	1.2445	1.2390	1.2336	1.2318	1.2292	1.2237				

OCCURRENCES IN OTHER AREAS

General

Sodium sulphate minerals occur abundantly in many different parts of the world. In the western hemisphere, deposits are known in Canada (including British Columbia, Alberta, Saskatchewan and Manitoba), the United States and Mexico. A few deposits are known from South American countries, including Chile and Argentina. In Europe, Hungary, Germany, Rumania, Soviet Russia, Austria, Czechoslovakia and Spain have recorded deposits. China and the Soviet Union in Asia and Egypt in Africa also have reported occurrences of sodium sulphate within their borders.

In the United States, deposits are found in Arizona, California, Colorado, Idaho, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, Texas, Utah, Washington and Wyoming. Like North Dakota, virtually all of these areas (at least in part) have, or once had, an arid or semi-arid climate.

The occurrence of sodium sulphate in arid regions, usually far removed from urban consuming centers, presents a transport problem shared by these western and mid-western states with foreign producers.

Saskatchewan

"In the Province of Saskatchewan, more than 200 alkali deposits have been located which are composed almost entirely of sodium sulphate."(26) Tomkins (27) has recently listed the major and minor Saskatchewan deposits. For more detailed information on these lakes the reader is referred to his report.

The origin of the Saskatchewan deposits has been explained as follows: "The retreating glaciers left glacial lakes and depressions which had no outlet. River valleys were cut, only to be abandoned for other and newer valleys as the ice melted and retreated northward. These valleys, for a long time after the glaciers disappeared, served to carry off the heavy precipitation which is believed to have fallen during the early post-glacial period. As time went on the rainfall decreased and many of the drainage valleys carved by the melting ice ceased to serve as river channels for through flowing streams but instead became interior drainage basins.

* * * *

"Mineral salts carried into these more or less stagnant reservoirs having no outlet to larger lakes or rivers, remained in solution in the lakes. In time the concentration of the salts in the lakes increased and in some cases the evaporation so nearly balanced the inflowing drainage that the lake became saturated, whereupon deposition of the mineral salts on the lake bed began to take place(28)."

This problem of the origin of the extensive Canadian deposits, cannot help but have an important bearing on the genesis of the North Dakotan bitter lakes. The latter are merely the southeastern extension of the larger Saskatchewan groups, the trend running NW-SE roughly parallel to the so-called "Altamont moraine."

Montana

Like the Saskatchewan deposits, the "alkali" lakes of Montana are closely related to those of North Dakota. The Canadian deposits trend southeastward to the international boundary where they cross into northeastern Montana and northwestern Dakota. Little work has been done on the Montana lakes except for a recent brief study in Chouteau and Sheridan Counties by Uuno M. Sahinen of the Montana State Bureau of Mines and Geology.

One group of intermittent lakes in Chouteau County lies in a topographically low area known as the Shonkin Sag, believed to be the former course of the Missouri River.

It is emphasized that the report is preliminary in nature and that reconnaissance drilling should be resorted to before detailed work in Montana is undertaken.

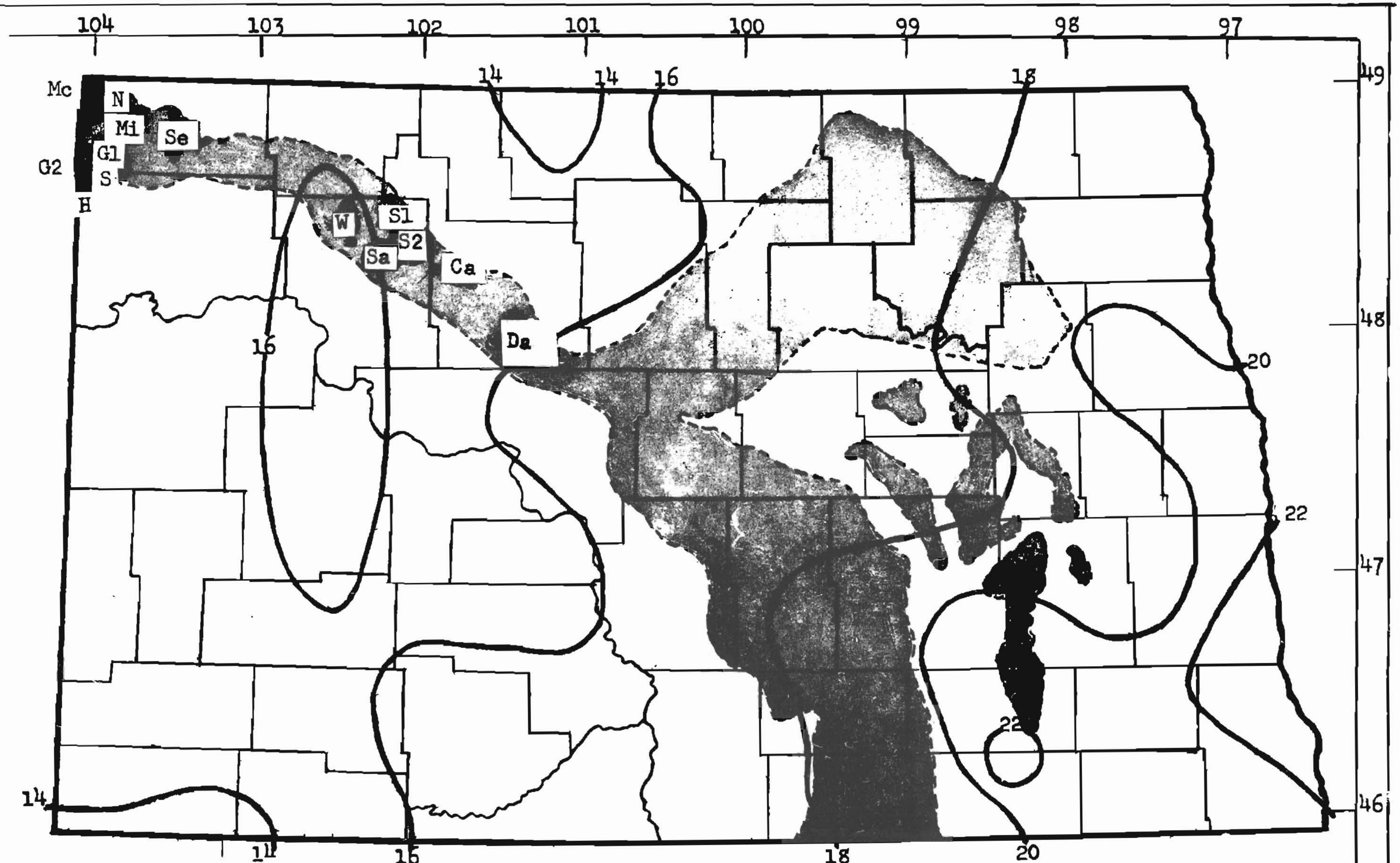
OCCURRENCES IN NORTH DAKOTA

General Description

At an early stage in the investigation of the bitter lakes of North Dakota, it was observed that they occured in basins having no drainage outlet. Further study has served to confirm the view that the area of interior drainage (see map p. 9) includes all the previously known and recently discovered deposits. Cole likewise reports that the glacial ice which once spread over vast areas of Canada undoubtedly altered many of the pre-glacial valleys, and where the terminal moraines are thickest, formed areas in which undrained basins are numerous and in which lakes with no apparent outlet are very abundant. Sahinen says for the saline lakes in Montana that for the most part these lakes have no outlets and may practically dry up during the summer months. In North Dakota, as in Saskatchewan, the lakes are associated with terminal or recessional moraines, or related at least to covered bedrock highs simulating such features. Whether this is due to the fact that the interior drainage belt roughly coincides with these bedrock highs and moraines or to the fact that these exercise an independent influence is a point which is not yet entirely settled.

Precipitation has had an important influence on the localization of the mineral salts. A glance at the map (p. 9) shows that all the deposits thus far reported occur west of the 18-inch rainfall line. The importance of an arid or semi-arid climate is well known. Such a climate inhibits plant growth, thus preventing the formation of a complete protective coat of vegetation on the soil. It also extends the life of the closed basins by retarding the reestablishment of integrated drainage with resultant loss of salts to the sea. Finally, it contributes to the rapid evaporation which facilitates concentration of the salts.

The close correlation between the saline deposits and former stream valleys is so striking that it was noticed at an early date. Alpha(29) writes that "the present lakes are depressions in partly filled pre-glacial valleys. These depressions are the result of the typically uneven and undulating character of the ground moraine. The general depression of the pre-glacial valley still persists causing the lakes to have a roughly linear arrangement." This pronounced alignment of the saline lakes has been noticed by Cole, Lemke, Witkind, and others.



PROVED & POSSIBLE DEPOSITS

Mc-McKone Lake	Se-Stady E
N-North Lake	Da-Douglas A
Mi-Miller Lake	Ca-Carpenter Lake
G1-Grenora #1	S1-Stanley #1
G2-Grenora #2	S2-Stanley #2
S-Stink Lake	Sa-Stanley A
H-Horseshoe Lake	W-White Lake

PRECIPITATION AND INTERIOR DRAINAGE IN NORTH DAKOTA

INTERIOR DRAINAGE-R. SINKBEIL 12-7-48

scale--statute miles

0 20 40 60 80

PRECIPITATION TRACED BY D.HANSEN

COURTESY U.S.DEPT.AGRICULTURE

Areas of Interior Drainage (Incomplete in Turtle Mts.& East)

48 Average Precip. in inches/year

In the ensuing description of these deposits it will be shown that wherever the detailed geology has been mapped, the saline lakes have been found to be genetically related to partially-filled glacial valleys, outwash channels, and other sorted deposits.

Gott, Lindvall and Hanson(30)(31) found at least seven small saline lakes which are marked "Sal" in their two maps of the Zahl area. It can be seen by the parts of their maps on p. 11, that with one exception, all these lakes, and also Grenora #1 lie in, or adjacent to, the Stady Channel. This channel has been described by Gott as follows:

> "The Stady Channel-This is another outwash train filling a low, gentle sag which crosses the extreme northwest corner of this quadrangle and extends toward the west for at least twenty miles. It has a gently undulating surface with some kettles of moderate depth and size. Along the north edge of the channel in NE$\frac{1}{4}$ sec. 32, T. 161 N., R. 101 W. the ice-contact face is well preserved. This, together with the kettles, indicates that "Altamont" ice was still present during deposition of the outwash. The outwash consists of stratified sand and gravel, is similar in character and composition to the Zahl Outwash Plain and was undoubtedly deposited in much the same manner."(32)

In the Kermit #3 quadrangle, Lindvall and Hanson (33) mapped three small and one moderately-sized saline lakes all lying either in, or close to, a valley train. Their description of a portion of the area follows:

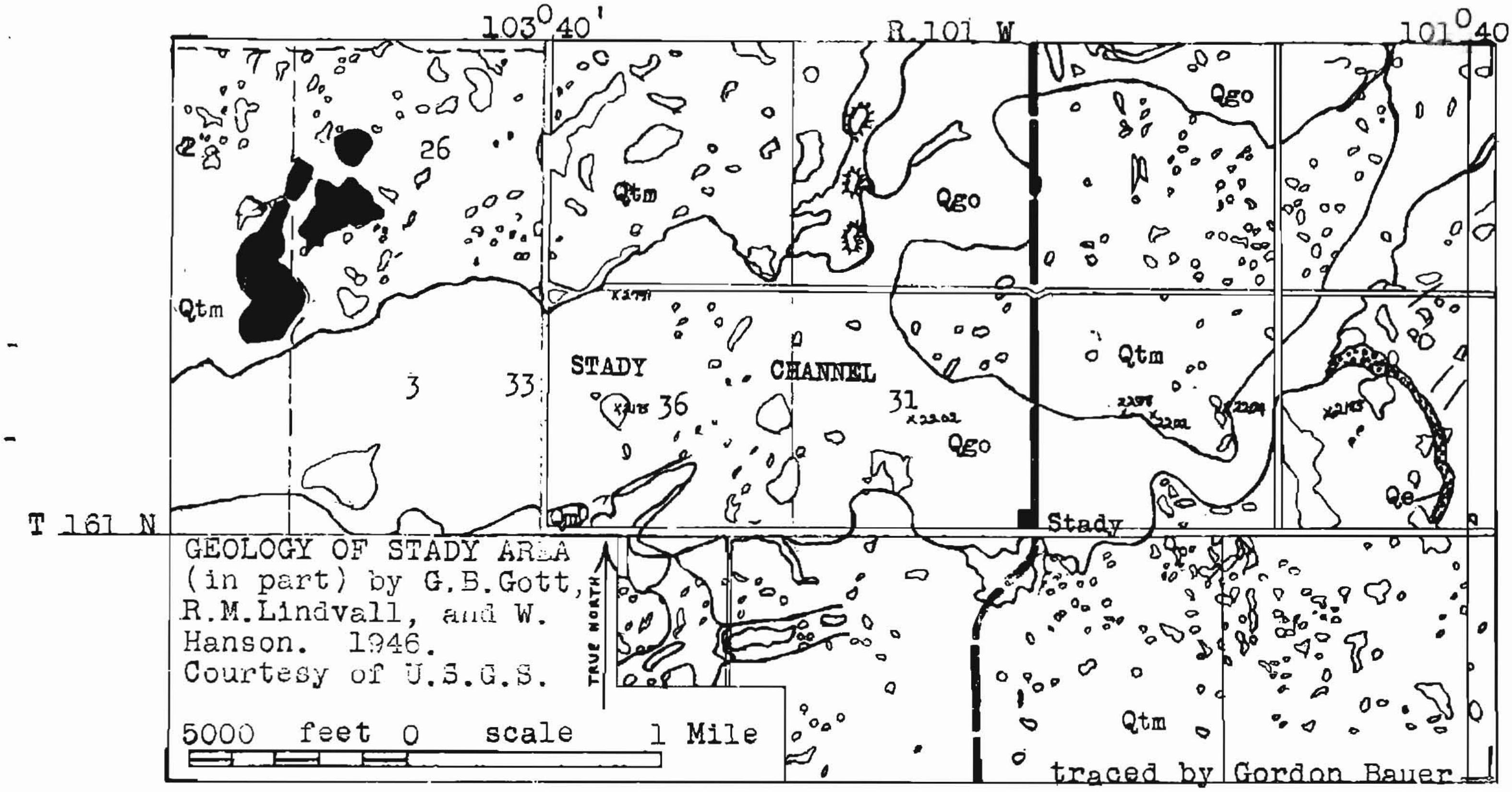
> "Fluvio-glacial deposits-Meltwaters discharging from the late Wisconsin ice front deposited outwash gravels and sands as extensive valley trains in Alamo Valley and in the northwest corner of the quadrangle in the topographic low believed to be the buried channel of the pre-glacial Yellowstone River. Nearness of the ice front during deposition of the outwash material is indicated by the pitted nature of the outwash surface. Ice blocks, large and small, must have been partially to completely buried under loads of debris. Cottonwood Lake east of Alamo appears to have had just such an origin, for it is completely enclosed by fluvio-glacial gravels."

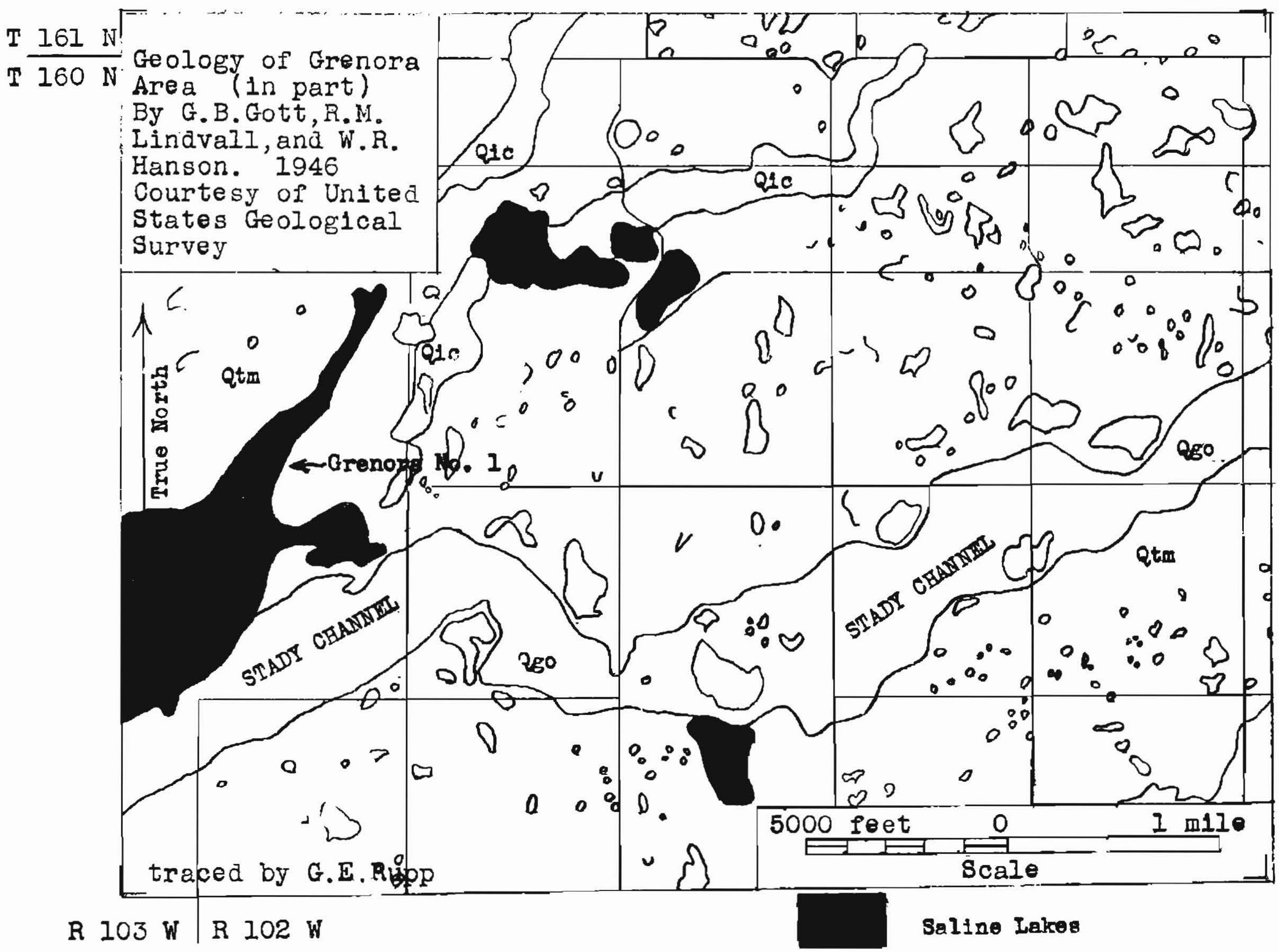
The rocks which outcrop in this area are Tertiary strata of the Fort Union formation. Gott(34) has listed the following partial section of the Tongue River member as being representative in this area.

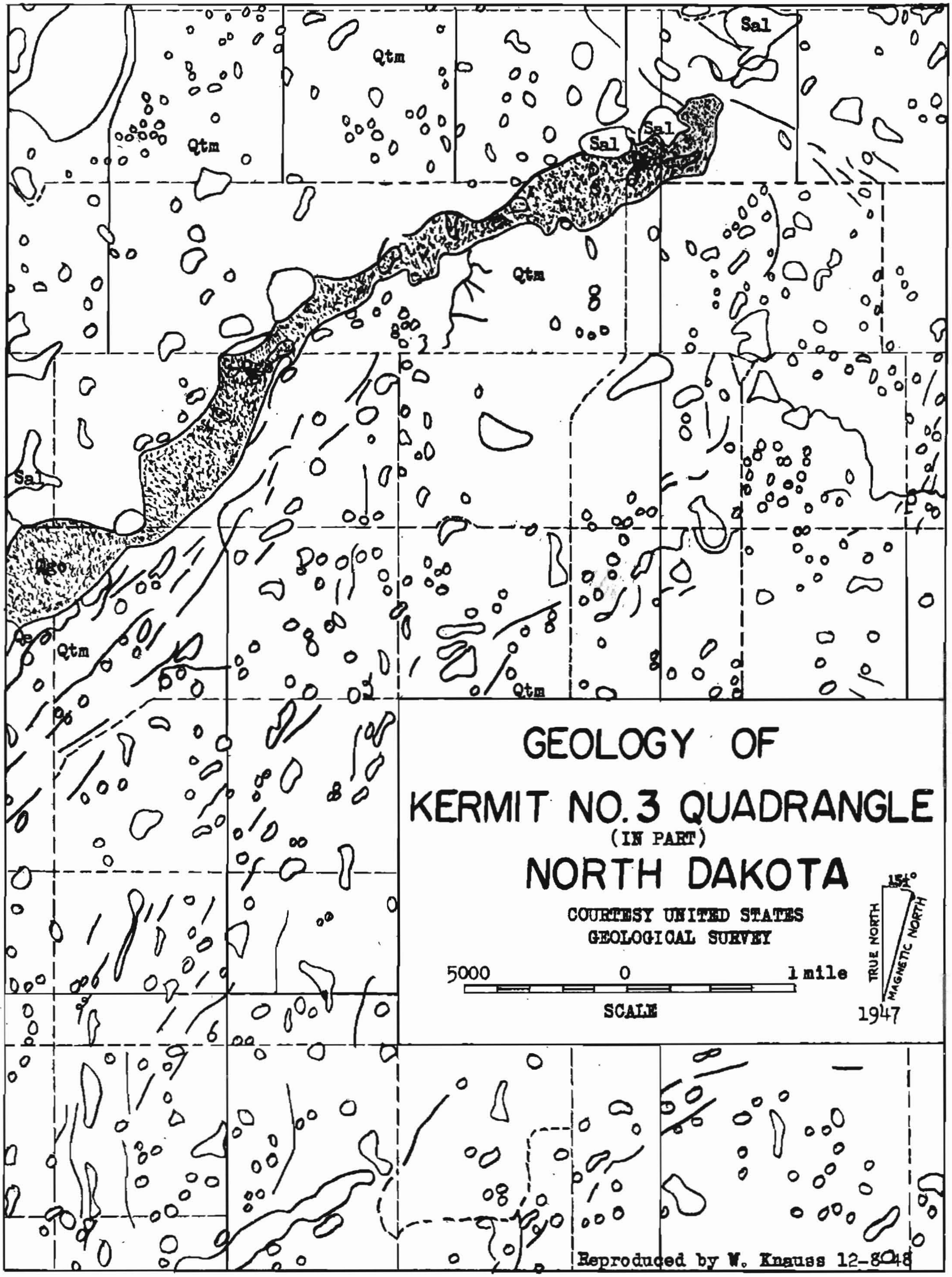
"Fort Union Formation (Tongue River member)

The Tongue River member is the only bedrock which crops out within this quadrangle. Although the ground moraine is thin over the southern and southwestern part, there are very few good exposures of Tongue River. This is because the slightly consolidated beds of clays, shales, and sand are so soft that they stand up no better in exposures than the till. The best exposure of Tongue River within the quadrangle is along Pat's Coulee within the immediate vicinity of the Norveson lignite mine. Here, in sec. 9, T. 158 N., R. 101 W., the following section was measured:

Thickness Feet	Depth Feet	Top of Exposure Description
6	6	Till, buff, calcareous; contains limestone, dolomite and granite pebbles.
6	12	Sandstone, cross bedded, fine-grained, angular; contains calcareous concretions and heavy iron-stained streaks.
3.2	15.2	Shale, gray, somewhat sandy at top; weathers gray-white.
.6	15.8	Lignite, contains clay streaks at top and bottom.


103°40'
R 101 W
101°40
T 161 N
Qtm
Qgo
Qe
26
3
33
36
31
STADY CHANNEL
Stady
GEOLOGY OF STADY AREA (in part) by G.B.Gott, R.M.Lindvall, and W. Hanson. 1946. Courtesy of U.S.G.S.
TRUE NORTH
5000 feet 0 scale 1 Mile
traced by Gordon Bauer


T 161 N
T 160 N
Geology of Grenora Area (in part) By G.B.Gott, R.M. Lindvall, and W.R. Hanson. 1946 Courtesy of United States Geological Survey
Qic
Qtm
Qgo
True North
Grenora No. 1
STADY CHANNEL
5000 feet 0 1 mile
Scale
traced by G.E.Rupp
R 103 W
R 102 W
Saline Lakes


GEOLOGY OF
KERMIT NO. 3 QUADRANGLE
(IN PART)
NORTH DAKOTA
COURTESY UNITED STATES
GEOLOGICAL SURVEY
5000
0
1 mile
SCALE
TRUE NORTH
MAGNETIC NORTH
15½°
1947
Qtm
Sal
Qgo
Reproduced by W. Knauss 12-8-48

Thickness Feet	Depth Feet	Top of Exposure Description
2.4	18.2	Shale-clay, dark-gray; contains thin limonite-stained streaks.
4.6	22.8	Shale-clay, dark-gray; very thin lignite streaks.
6.0	28.8	Clay-shale, medium-gray, plastic; slacks into small blocks.
6.0	34.8	Lignite"

The 1934 study demonstrated that in many of the lakes a permanent, as well as a temporary bed is present. The "permanent" bed ranges from a few inches to scores of feet in thickness and does not go into solution each summer. In some cases this is due to a newly deposited overlying clay or silt layer. The "intermittent" or "harvest" layer is relatively thin and goes into solution each spring when melting snow and rain raise the ground water table. Most of it stays in solution throughout the summer. As fall approaches, however, the temperature of the water drops, and at the same time, the rate of evaporation exceeds the inflow of water to such an extent that the brine becomes saturated and precipitation takes place. At first crystallization is more pronounced near the shores where small embayments dry up completely. Later, a carpet of crystals may extend out over the entire lake. Parts of the "crystal-carpet" may break and sink to the bottom.

Most of this crystallization takes place at relatively low temperatures (below 89°F) and the resulting mineral is mirabilite. As already mentioned, most of the thenardite forms by the dehydration of the mirabilite which is unstable as soon as it is exposed to dry air. The former is very powdery and is light enough to be picked up and carried for some distance by the wind. Local farmers report that during the drought years, "summer snowfalls" fell in the areas near the lakes, the "alkali" forming great clouds of white "snow". Deflation results in the removal of some of the salts from the basins and exposes fresh mirabilite to further dehydration. Much of the salt falls back in the catchment area, however, and finds its way back to the lake.

At still higher temperatures (above 92°F), mirabilite liquifies by dissolving in its own water of crystallization.

Solution in the intermittent beds may be due to precipitation, to a rise in temperature, or both. The pressure factor plays a subordinate role.

These climatic changes fluctuate from time to time within the framework of diurnal, seasonal, and longer cycles.

Previously Known Deposits

Most of the deposits discovered in the 1934 FERA study, which are listed in Table 6, have been carefully studied and described in detail. For further information the reader is referred to Lavine(6), Lavine and Feinstein(28) and Cooley(15). The present report will serve to bring the developments up to date. Maps are also provided for those deposits for which only inadequate maps or no maps at all have been published.

Table 6

Previously Known Deposits of Glauber Salt in North Dakota

Modified from Cooley(15) after Lavine

Name of Deposit	Location	Area Acres	Maximum Depth of Permanent Bed, Ft.	Average Depth of Bed, In.	Total Calculated Quantity, Tons	Distance to RR Miles	Distance to Lignite Miles
Grenora Group (Divide County)							
Grenora #1	Northwest of Grenora, N.D. T160N-R103W secs. 15, 16, 20.	500	30	30.6	1,750,000	7	12
Grenora #2	Northwest of Grenora, N. D. T160N-R130W secs. 23, 29 32, 33	500	80	144	11,000,000	$5\frac{1}{2}$	12
Alkabo Group (Divide County)							
Miller Lake	Southwest of Alkabo, N. D. T162N-R102W secs. 5, 6, 17, 18.	550	50	84.8	5,000,000	2	8
North Lake	Southwest of Alkabo, N. D. Westby tp. R102W, secs. 8, 17.	200	80	40	1,000,000	$1\frac{1}{2}$	8
McKone Lake	Northwest of Alkabo, N. D. Elkhorn tp., R103W-secs. 11,12,13,23.	275	20	120	3,000,000	5	10
Stanley Group (Mountrail County)							
Stanley #1	Northeast of Stanley, N.D. T157N-R89W secs. 21, 22 27, 28.	250	10	68.3	1,000,000	7	15
Stanley #2	East of Stanley, N.D. T156N-R89W, secs. 4,5,8,9.	200	5	30	600,000	$2\frac{1}{2}$	15
					23,350,000 Total tonnage hydrous salt.		

Grenora #2

This deposit, the largest of any yet found in North Dakota, has become the subject of a court case. The legal proceedings were summarized by Assistant Attorney General C. E. Brace (somewhat modified) as follows:

"After the exploration of Grenora Lake, #2, and other sodium sulphate deposits in Divide County, by Dr. Lavine, the Ozark-Mahoning Company of Tulsa, Oklahoma, interested itself in these deposits. It sent its engineer to North Dakota to investigate, and later employed a purchasing agent to acquire title to all the patented lands surrounding the Grenora #2 deposit. It acquired title to all the patented lands, taking title in the name of an individual rather than of the company.

"In the summer of 1937, it began search for water for use in processing the minerals and drilled a satisfactory well near the lake.

"The company learned that the attorney general's department believed that the state held title to the bed of the lake and the minerals thereon. After some negotiation, the company took a lease from the state for mining the lake bed, and commenced a suit against the state to quiet its title to the land within the meander lines of the government survey; the complaint was dated October 8, 1937. The case was tried at Williston before Judge A. J. Gronna on February 26 and 27, 1948. A memorandum decision finding for the company was rendered by the Court on June 2, 1948. Judgment was entered in the District Court of Divide County on June 8, 1948, pursuant to the decision of the Court.

"The attorney general's department immediately proceeded with an appeal, and the appeal was heard by the Supreme Court on September 14, 1948, but no decision has been rendered as yet.

"This case involves the question of the ownership of an estimated 11,000,000 tons of sodium sulphate in this one lake alone, and there are probably other deposits, the ownership of which may be determined by the decision of this case."

Dated October 5, 1948

Signed C. E. Brace
Assistant Attorney General

Cooley published information on the ownership of all the land surrounding Grenora #2 and #1. Much land has changed hands since that time, however, and more up-to-date data are therefore included.

Recorded Owners of Land, Grenora #2

Section 28-N$\frac{1}{2}$SW$\frac{1}{4}$-Ozark-Mahoning Company
NW of SE$\frac{1}{4}$-Ozark-Mahoning Company
SW of SE$\frac{1}{4}$-Ozark-Mahoning Company

Section 29-SW of SE$\frac{1}{4}$-Ozark-Mahoning Company
NE of SE$\frac{1}{4}$-Ozark-Mahoning Company
SE of SE$\frac{1}{4}$-No record

Section 32-NE of NW$\frac{1}{4}$-Ozark-Mahoning Company
N$\frac{1}{2}$ of NE$\frac{1}{4}$-No record of ownership
SW of NE$\frac{1}{4}$-Ozark-Mahoning Company
SE of NE$\frac{1}{4}$-Ozark-Mahoning Company

Section 33-NW$\frac{1}{4}$-Ozark-Mahoning Company
NE$\frac{1}{4}$-Ozark-Mahoning Company
SW$\frac{1}{4}$-Ozark-Mahoning Company
SE$\frac{1}{4}$-Ozark-Mahoning Company

Section 34-W of NW$\frac{1}{4}$-Ozark-Mahoning Company

Recorded Owners of Land, Grenora #1

Detailed investigations of this lake are likewise available in the reports already mentioned.

Section 10-SW of NE$\frac{1}{4}$-Divide County, North Dakota
SE of NW$\frac{1}{4}$-Ethel M. Quam
SW of SW$\frac{1}{4}$-Divide County, North Dakota
SE of SW$\frac{1}{4}$-Divide County, North Dakota
NW of SE$\frac{1}{4}$-Divide County, North Dakota

Section 15-E$\frac{1}{2}$NW$\frac{1}{4}$-Divide County, North Dakota
SW of NE$\frac{1}{4}$-Divide County, North Dakota
N$\frac{1}{2}$ of NE$\frac{1}{4}$-Divide County, North Dakota
SW$\frac{1}{4}$-Ernest P. Jensen
SE of SE$\frac{1}{4}$-Divide County, North Dakota
SW of SE$\frac{1}{4}$-Ernest P. Jensen
N$\frac{1}{2}$ of SE$\frac{1}{4}$-Kathleen Ringdahl

Section 16-NE$\frac{1}{4}$-North Dakota School Land
NW$\frac{1}{4}$-North Dakota School Land
SE$\frac{1}{4}$-North Dakota School Land
SW$\frac{1}{4}$-North Dakota School Land

Section 21-SE$\frac{1}{4}$ of NW$\frac{1}{4}$-Divide County, North Dakota (rest of $\frac{1}{4}$ no record)
E$\frac{1}{2}$ of SW$\frac{1}{4}$-Divide County, North Dakota (rest of $\frac{1}{4}$ no record)
W$\frac{1}{2}$ of NE$\frac{1}{4}$-Divide County, North Dakota
E$\frac{1}{2}$ of NE$\frac{1}{4}$-Jens G. Jensen
W$\frac{1}{2}$ of SE$\frac{1}{4}$-Divide County, North Dakota
E$\frac{1}{2}$ of SE$\frac{1}{4}$-Jens C. Jensen

Section 28-N$\frac{1}{2}$ of NE$\frac{1}{4}$-Mildred Lucille Sneva and Adolph Sneva

Miller and North Lakes

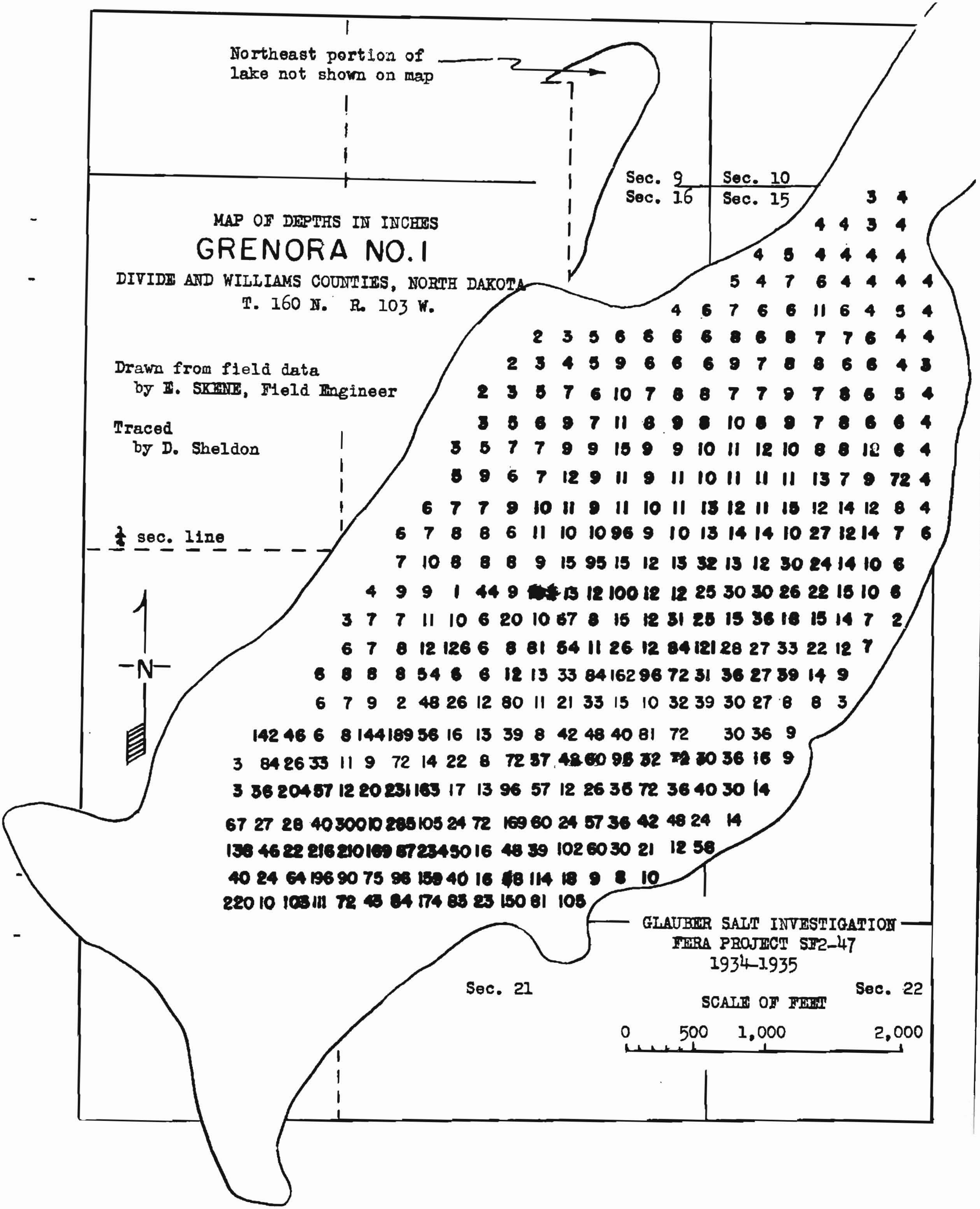
In 1948, the Sodium Corporation of America announced plans to construct a plant at Westby, Montana (just across the state border) for the purpose of exploiting the glauber salts of these two North Dakota lakes. The company apparently planned to pump the brine from Miller Lake to the southern end of North Lake. The south end of North Lake was to be dammed off to provide a precipitation tank from which the crystals were to be harvested.

The area was visited by the writer in November, 1948. At that time the 1,200 foot earth dam across the south shore of North Lake had already been completed. A diesel-powered pump capable of 15,000 g.p.m. had been installed at the north end of Miller Lake and had been successfully tested. Leading from the pump to the storage reservoir in North Lake was a 32-inch discharge pipe which had already been hooked up.

Other information, recently released(36), discloses that the site selected for the processing plant will be $\frac{1}{4}$ of a mile southeast of the dam and not in Westby as previously reported. The $500,000 plant will have two large drying kilns and spray towers, among other equipment.

An access road 3$\frac{1}{2}$ miles long, connecting the development with the Alkabo road is virtually completed. A 1$\frac{1}{2}$-mile spur track from the plant site to the Flaxton-Whitetail branch of the Soo Line railroad has been staked out.

It is reported that the enclosed portion of North Lake forms a reservoir 7,500 feet in circumference and eight feet deep.


Northeast portion of lake not shown on map
Sec. 9
Sec. 16
Sec. 10
Sec. 15
MAP OF DEPTHS IN INCHES
GRENORA NO. 1
DIVIDE AND WILLIAMS COUNTIES, NORTH DAKOTA
T. 160 N. R. 103 W.
Drawn from field data
by E. SKENE, Field Engineer
Traced
by D. Sheldon
¼ sec. line
N
GLAUBER SALT INVESTIGATION
FERA PROJECT SF2-47
1934-1935
Sec. 21
Sec. 22
SCALE OF FEET
0 500 1,000 2,000

George Krem, president of the Holland America Company, Chicago, has been directing construction. Another firm interested in the project is the Goric Chemical Company, also of Chicago. They plan to employ at least 80 men to operate the plant three full 8-hour shifts daily. The brines will be pumped to North Lake and there allowed to precipitate. The excess water will then be drained out of the reservoir after which large scrapers will scoop out the salt. Most of this will be done during the favorable winter months and the mineral stockpiled to insure the processing plant a year-round supply.

The accompanying map (made by the 1934 FERA survey) shows the extent of the permanent bed in Miller Lake.

Recorded Owners of Land, Miller Lake

Section 19-SE$\frac{1}{4}$-E. C. Ferguson, Westby, Montana

Section 20-SE$\frac{1}{4}$-Allison Stewart (Jane Stewart Estate)?
NW$\frac{1}{4}$-No record
SE$\frac{1}{4}$ of NE$\frac{1}{4}$-Divide County, North Dakota
SW$\frac{1}{4}$-No record
W$\frac{1}{2}$ of NE$\frac{1}{4}$-No record
NE$\frac{1}{4}$ of NE$\frac{1}{4}$-No record

Section 29-NW$\frac{1}{4}$-No record
NE$\frac{1}{4}$-Jane Stewart Estate (?)
N$\frac{1}{2}$ of SW$\frac{1}{4}$-Mads Madsen, Westby, Montana
W$\frac{1}{2}$ of SE$\frac{1}{4}$,-Mads Madsen, Westby, Montana
E$\frac{1}{2}$ of SE$\frac{1}{4}$-Mary Tonneson, Alkabo, North Dakota
S$\frac{1}{2}$ of SW$\frac{1}{4}$-Martin O. Felland, Westby, Montana

Section 30-N$\frac{1}{2}$ of NE$\frac{1}{4}$-Sam O. Felland
SW of NE$\frac{1}{4}$-Sam O. Felland
NE$\frac{1}{4}$ of SE$\frac{1}{4}$-No record
SE of NE$\frac{1}{4}$-Sam O. Felland

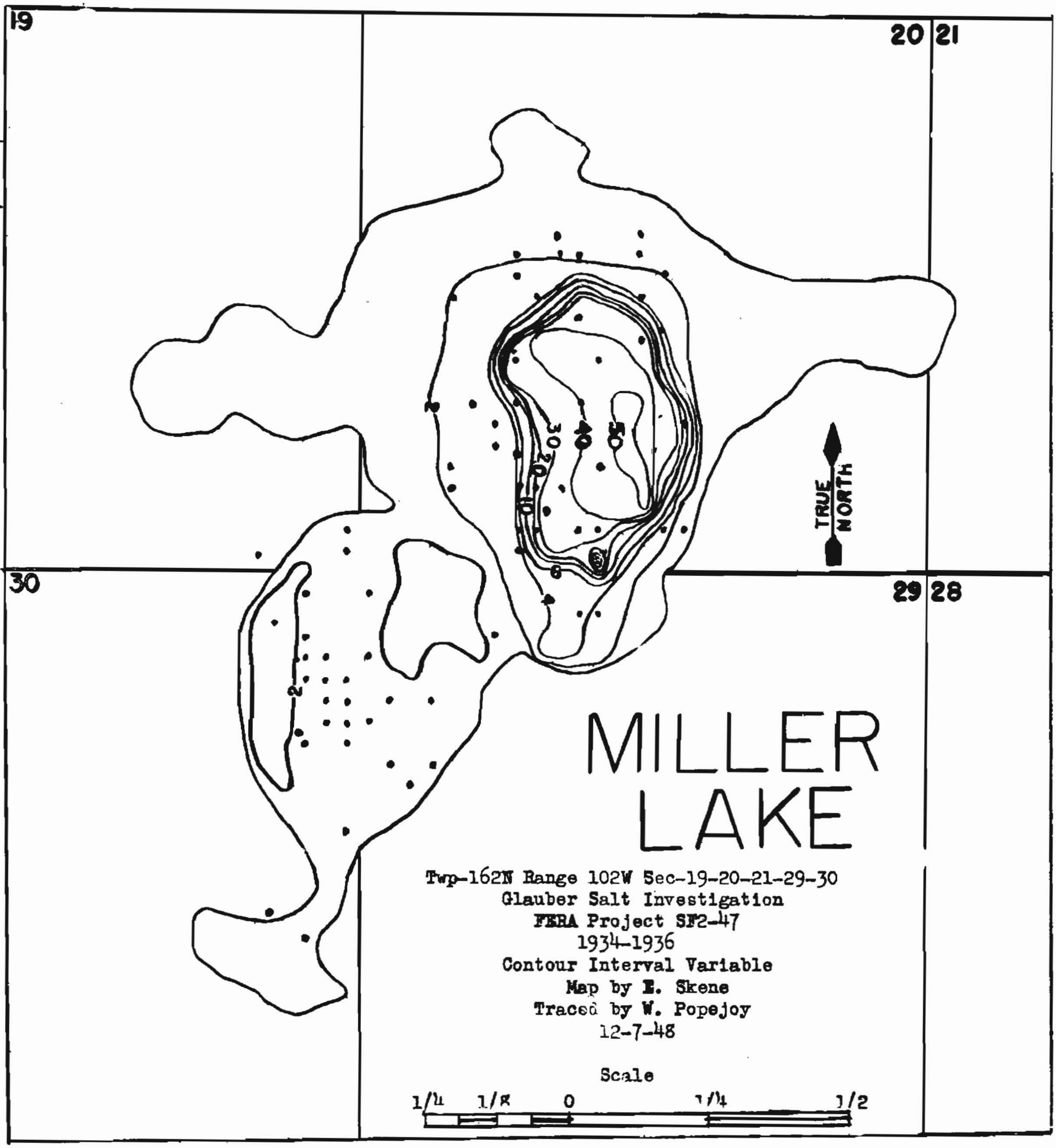
Recorded Owners of Land, North Lake

Section 5-S$\frac{1}{2}$ of SW$\frac{1}{4}$-Stanley O. Thorpe, Westby, Montana
Eloise C. Berg and Irma Marx, 4644 14th Street South.
Minneapolis, Minnesota

Section 7-NE$\frac{1}{4}$-George Herman, Westby, Montana

Section 8-SW$\frac{1}{4}$ of NW$\frac{1}{4}$-No record
N$\frac{1}{2}$ of SW$\frac{1}{4}$-Divide County, North Dakota
SW$\frac{1}{4}$ of SW$\frac{1}{4}$-Lydia Maeirt, Westby, Montana
E$\frac{1}{2}$ of NW$\frac{1}{4}$-Stanley Thorpe, Westby, Montana
NW$\frac{1}{4}$ of NW$\frac{1}{4}$-Stanley Thorpe, Westby, Montana
SE$\frac{1}{4}$ of SW$\frac{1}{4}$-August Johnson, Alkabo, North Dakota

Section 17-W$\frac{1}{2}$ of NW$\frac{1}{4}$-E. C. Ferguson, Westby, Montana
SE$\frac{1}{4}$ of NW$\frac{1}{4}$-E. C. Ferguson, Westby, Montana
NE$\frac{1}{4}$ of NW$\frac{1}{4}$-E. C. Ferguson, Westby, Montana
SW$\frac{1}{4}$-Gudrun Rostad, Crosby, North Dakota
SE$\frac{1}{4}$-Gunder Rust and Nora Rust, Alkabo, North Dakota
NE$\frac{1}{4}$-August Johnson, Alkabo, North Dakota


19
20
21
30
29
28
TRUE NORTH
MILLER LAKE
Twp-162N Range 102W Sec-19-20-21-29-30
Glauber Salt Investigation
FERA Project SF2-47
1934-1936
Contour Interval Variable
Map by E. Skene
Traced by W. Popejoy
12-7-48
Scale
1/4 1/8 0 1/4 1/2

McKone (Westby Lake)

The last member of the so-called "Alkabo Group" was not completely studied in 1934-5 due to the limited time available for field investigation. The site was briefly revisited in 1948 at which time a brine sample was collected and a specific gravity determination made. Specific gravity at 63°C = 1.065.

Brine Analysis

McKone Lake. . . . . (Surface, Northeast shore)
Sample collected . . . . September 9, 1948
Sample analyzed . . . . November, 1948
Analyst. . . . . Jack C. Thompson

1.	Total dissolved solids.	142,600 P.P.M.
2.	Total alkalinity.	7,750
	Alk: to phenol	2,730
3.	Chloride.	3,905
4.	Silica.	68
5.	Iron and Alumina.	32
6.	Calcium	13.23
7.	Magnesium	13.1
8.	Sulphate.	82,506
9.	Sodium (calculated)	46,748.2
10.	Carbonate	4,650
11.	Bicarbonate	2,290

Hypothetical Combinations (in per cent)

Sodium sulphate.	86.27
Calcium carbonate.	7.905
Sodium chloride.	4.52
Magnesium.	.037
Water of hydration, organic matter, and undetermined residue.	1.27

Recorded Owners of Land, McKone Lake

Section 11-SE¼ of SE¼-Palmer Levin

Section 12-SW¼ of SW¼-Olaf Nilson

Section 13-NW¼ of SW¼-La Verne Haugen
SW¼ of SW¼-La Verne Haugen

Section 14-NE¼-Federal Farm Mortgage Corp., Washington, D. C.
SE¼-Federal Farm Mortgage Corp., Washington, D. C.

Section 23-NE¼-Oscar Bjorgen
SE¼-Oscar Bjorgen
SE¼ of NW¼-Divide County, North Dakota
NE¼ of SW¼-Divide County, North Dakota
SE¼ of SW¼-Divide County, North Dakota

Stanley Group

The only deposits in the state lying outside of Divide County which were investigated and described prior to this study consist of two lakes lying northeast of Stanley known as number 1 and 2 respectively.

Stanley No. 1 and Stanley No. 2

Hitherto unpublished maps are herein provided. Also included are data on land ownership. Detailed information on these lakes may be obtained from the publications already mentioned.

Recorded Owners of Land, Stanley No. 1 (Big Lake)

Section 21-NW$\frac{1}{4}$ of NE$\frac{1}{4}$- Federal Farm Mortgage Corp., St. Paul, Minnesota
SW$\frac{1}{4}$ of NE$\frac{1}{4}$-Federal Farm Mortgage Corp., St. Paul, Minnesota
NE$\frac{1}{4}$ of SE$\frac{1}{4}$-Federal Farm Mortgage Corp., St. Paul, Minnesota
SE$\frac{1}{4}$ of SE$\frac{1}{4}$-No record

Section 22-NW$\frac{1}{4}$ of NW$\frac{1}{4}$-Nellie P. Johnson
SW$\frac{1}{4}$ of NW$\frac{1}{4}$-Nellie P. Johnson
NW$\frac{1}{4}$ of SW$\frac{1}{4}$-Nellie P. Johnson
SW$\frac{1}{4}$ of SW$\frac{1}{4}$-Soren J. J. Nygaard
SE$\frac{1}{4}$ of SW$\frac{1}{4}$-Nellie P. Johnson

Section 27-NE$\frac{1}{4}$ of NW$\frac{1}{4}$-A. H. Nelson
SW$\frac{1}{4}$ of NW$\frac{1}{4}$-A. H. Nelson
SE$\frac{1}{4}$ of NW$\frac{1}{4}$-A. H. Nelson

Section 28-N$\frac{1}{2}$ of NE$\frac{1}{4}$-A. H. Nelson
SW$\frac{1}{4}$ of NE$\frac{1}{4}$-A. H. Nelson
SE$\frac{1}{4}$ of NE$\frac{1}{4}$-Nellie P. Johnson

Recorded Owners of Land, Stanley No. 2 (Blaisdell Deposit)

Section 4-NW$\frac{1}{4}$ of SW$\frac{1}{4}$-George C. Olson
SW$\frac{1}{4}$ of NW$\frac{1}{4}$-No record
SE$\frac{1}{4}$ of NW$\frac{1}{4}$-No record
NW$\frac{1}{4}$ of SW$\frac{1}{4}$-George C. Olson

Possible New Deposits and Other Saline Lakes

Divide County

General

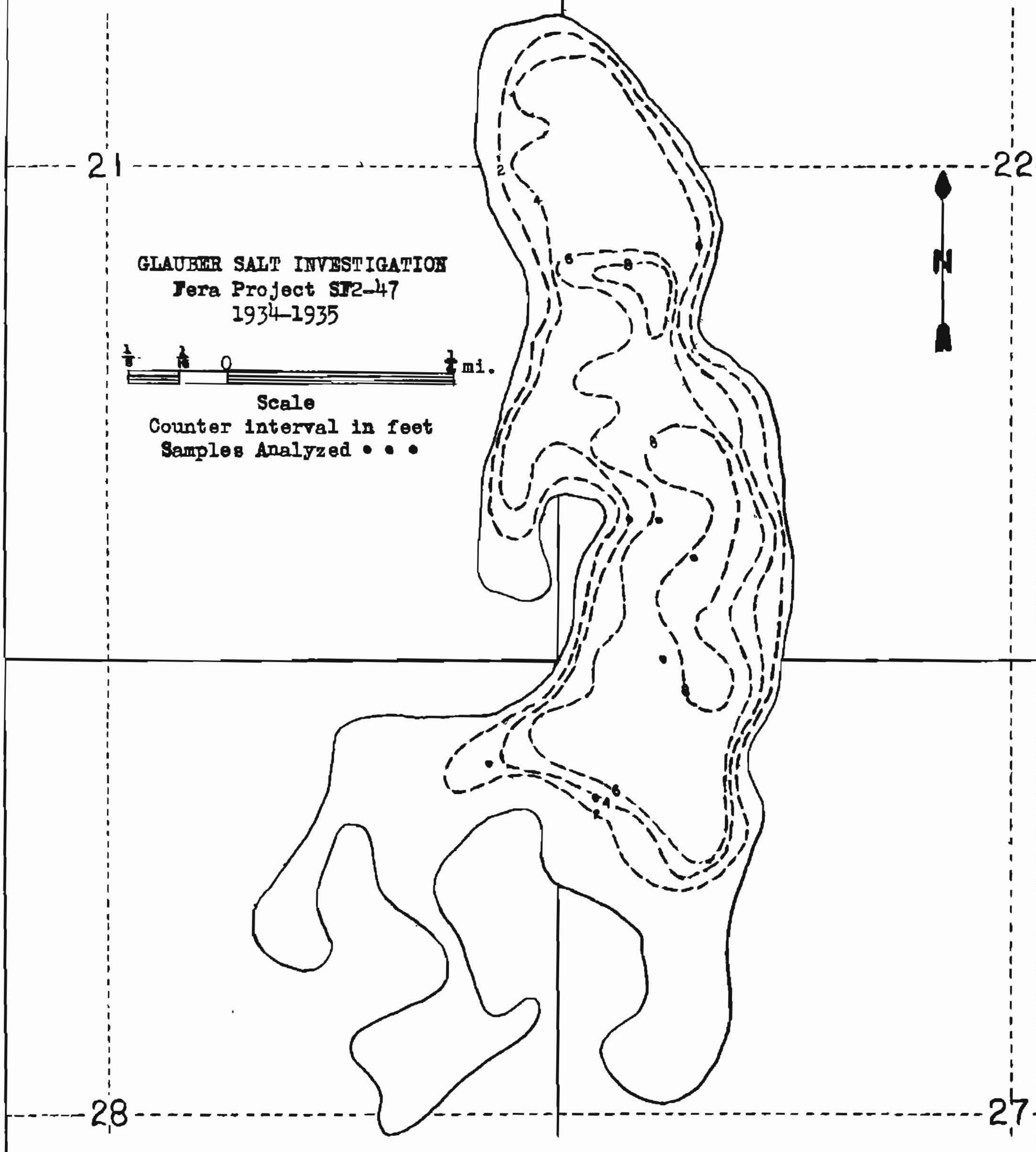
Located in the extreme northwest corner of the state, this county contains the greatest number of valuable deposits thus far discovered in North Dakota. In view of the fact that Divide County is closest of all to the huge Saskatchewan deposits, this is not altogether surprising. The Grenora and Alkabo groups have already been briefly mentioned. A new group (Westby) and one more isolated lake have recently been added to the list of potential deposits.

The relatively steep northern face of the so-called "Altamont Moraine", popularly called the Missouri Coteau, strikes diagonally across the county, from the Canadian border (at a point not far from Colgan) to the Burke County border (about 8 miles southeast of Noonan). The southernmost margin of supposedly "very thick" glacial deposits extends from south of Grenora to the northeast corner of Williams County, just west of Temple. The term "very thick" should perhaps be

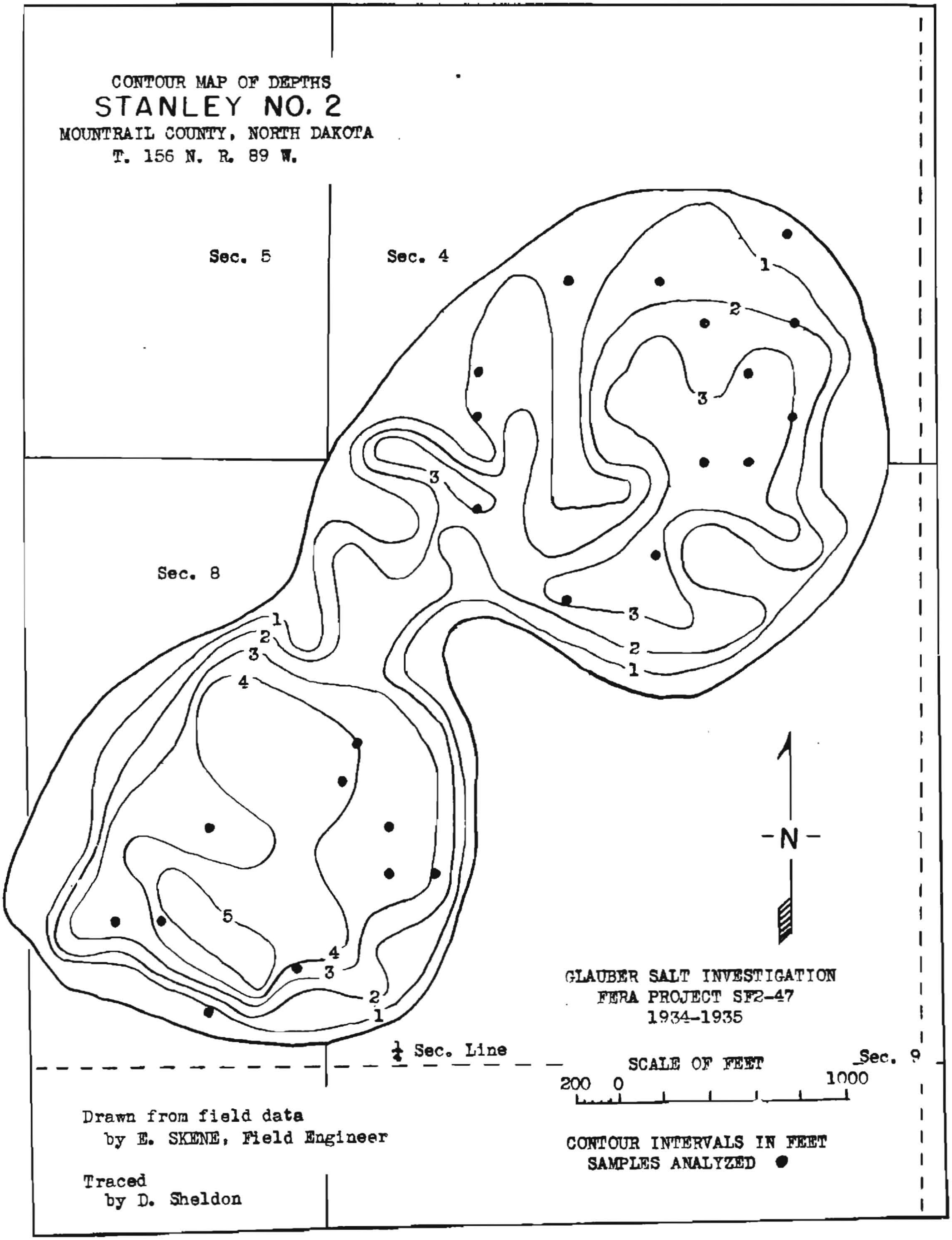
CONTOUR MAP OF DEPTHS

STANLEY NO I

MOUNTRAIL COUNTY, NORTH DAKOTA
Twp. 157N. Range 89W.



Drawn from field data by E. Skene.
Traced by K. Hanson 12-9-48.


CONTOUR MAP OF DEPTHS
STANLEY NO. 2
MOUNTRAIL COUNTY, NORTH DAKOTA
T. 156 N. R. 89 W.
Sec. 5
Sec. 4
Sec. 8
Sec. 9
N
¼ Sec. Line
GLAUBER SALT INVESTIGATION
FERA PROJECT SF2-47
1934-1935
SCALE OF FEET
200 0 1000
CONTOUR INTERVALS IN FEET
SAMPLES ANALYZED ●
Drawn from field data
by E. SKENE, Field Engineer
Traced
by D. Sheldon
1
2
3
4
5

changed to read "most recent" for the work done by the United States Geological Survey demonstrates that a bedrock high has been the controlling factor here and that there are few places where the glacial debris has any great thickness. All of the saline lakes in Divide County lie southwest of the Coteau and in the area of these young glacial deposits. To the north and east of the Coteau, intermittent youthful streams converge on the Souris River which provides drainage to the sea. South of the "younger" deposits, the Little Muddy and other streams drain into the Missouri River. Between these two areas, interior drainage prevails and it is here that the sulphate brines are found.

It is emphasized that all of the following are only "possible" deposits. Drilling is necessary before it can be established that they have proven reserves. The maps based on aerial photos should also be taken with reserve for no corrections for distortion have been made.

Westby A (37)

This lake occupies an irregular shallow basin which is partly surrounded by several smaller lakes. It is slightly more than a mile in length parallel to its main axis which strikes northeast. The town of Westby (which is just across the state border, in Montana) is only about a mile and a half to the northwest. Approximately two miles to the east are the rich North Lake and Miller Lake deposits. Westby is reached by railroad (Soo Line) and by U. S. Highway 5. The lake covers an area of about 140 acres. A brine sample collected from the west shore had a specific gravity of 1.23 at 68°C.

Brine Analysis

Sample collected	8-30-47
Sample analyzed	5-18-48
Analyst	W. D. Waldschmidt

All results are expressed as parts per million (P.P.M.)

1.	Total dissolved solids	191,524.0 P.P.M.
2.	Total alkalinity	160.0
	Alk: to phenol.	460.0
3.	Chloride.	947.23
4.	Silica.	3,344.0
5.	Iron and aluminum	2,169.0
	Iron.	00.0
6.	Calcium.	1,720.0
7.	Magnesium.	6,022.2
8.	Sulphate	124,308.6
9.	Sodium.	46,747.7
10.	Carbonate.	196.0
11.	Bicarbonate.	366.0
12.	Nitrogen	2.7352
13.	Total hardness	29,063.0
14.	Non-carbonate hardness	28,603.0

Hypothetical Combinations (in per cent)

Sodium sulphate.	74.14
Calcium Carbonate.	.16
Sodium Chloride.	.82
Magnesium Sulphate	10.39
Calcium Sulphate	1.71
Water of hydration, organic matter and undetermined residue	12.78

Recorded Owners of Land, Westby A

Section 11-SE$\frac{1}{4}$-Jorgen Peter Neve, 661 4th Avenue West, Eugene, Oregon

Section 14-E$\frac{1}{2}$ of NE$\frac{1}{4}$-Emanuel Maeirt, Westby, Montana
SE$\frac{1}{4}$ of NW$\frac{1}{4}$-Palmer O. Freund, Westby, Montana
SE$\frac{1}{4}$-M. V. Anderson, Westby, Montana
S$\frac{1}{2}$ of SW$\frac{1}{4}$-A. L. Tarvestad (?), E. M. Freund, Westby, Montana
NE$\frac{1}{4}$ of SW$\frac{1}{4}$-Palmer O. Freund, Westby, Montana
W$\frac{1}{2}$ of NE$\frac{1}{4}$-Christ Holm Nelson, Westby, Montana

Section 15-SE$\frac{1}{4}$ of SE$\frac{1}{4}$-Hans Urdahl, Lake County, South Dakota

Section 22-NE$\frac{1}{4}$-Theodore Lasen, Westby, Montana

Section 23-NE$\frac{1}{4}$-Christ Holm Nelson, Westby, Montana
NW$\frac{1}{4}$-E. M. Freund, Westby, Montana

Westby B Lake

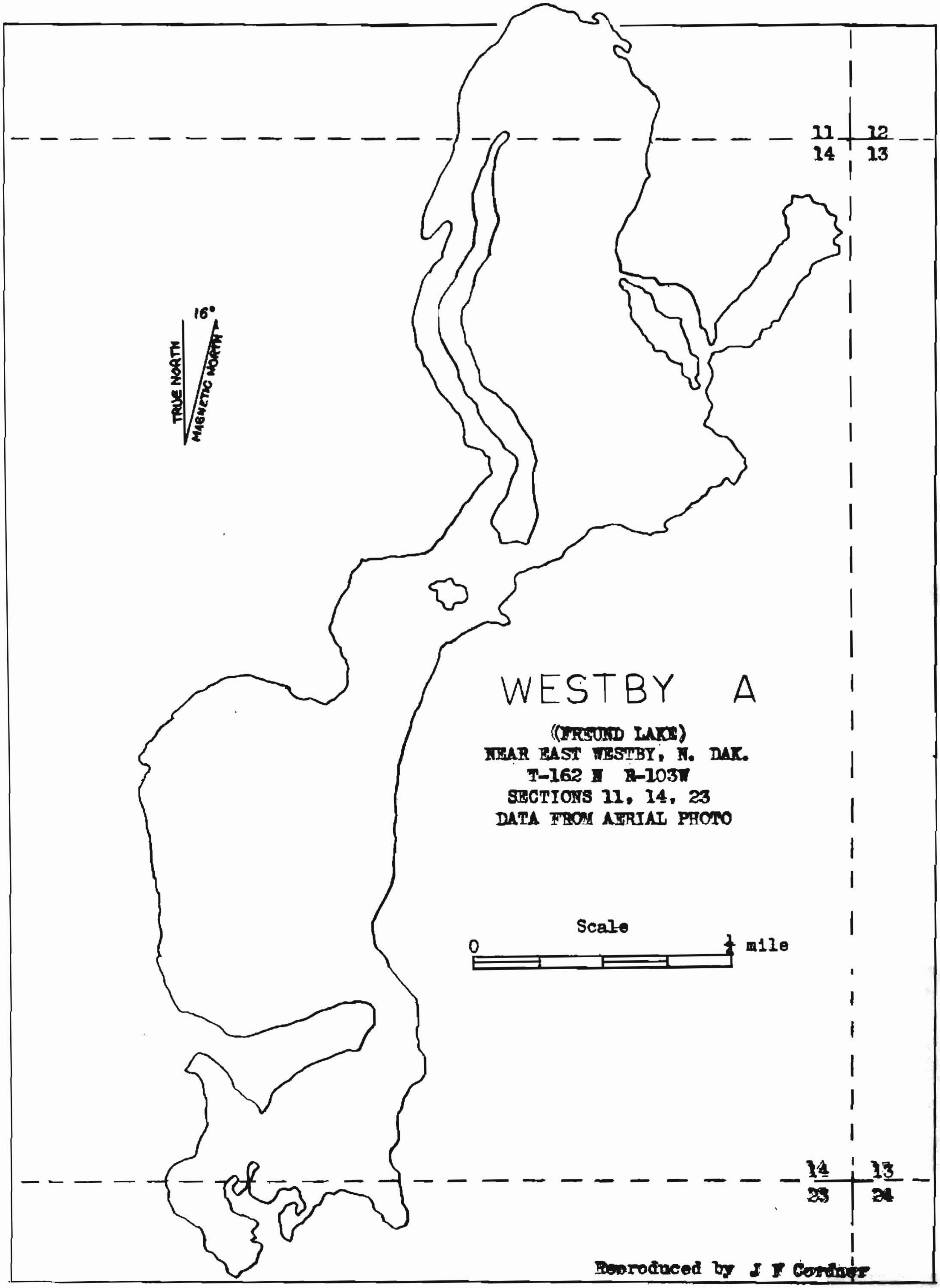
Westby B occupies a broad basin, the flooded part of which covers about 390 acres. It is surrounded by a number of smaller fresh or saline lakes and extends into Montana. It was visited in September, 1947 at which time a brine sample was collected from the west shore (in Montana). This shore is strewn with glacial erratics. The lake border is marked by an abundance of *Salicornia rubra* in the summer.

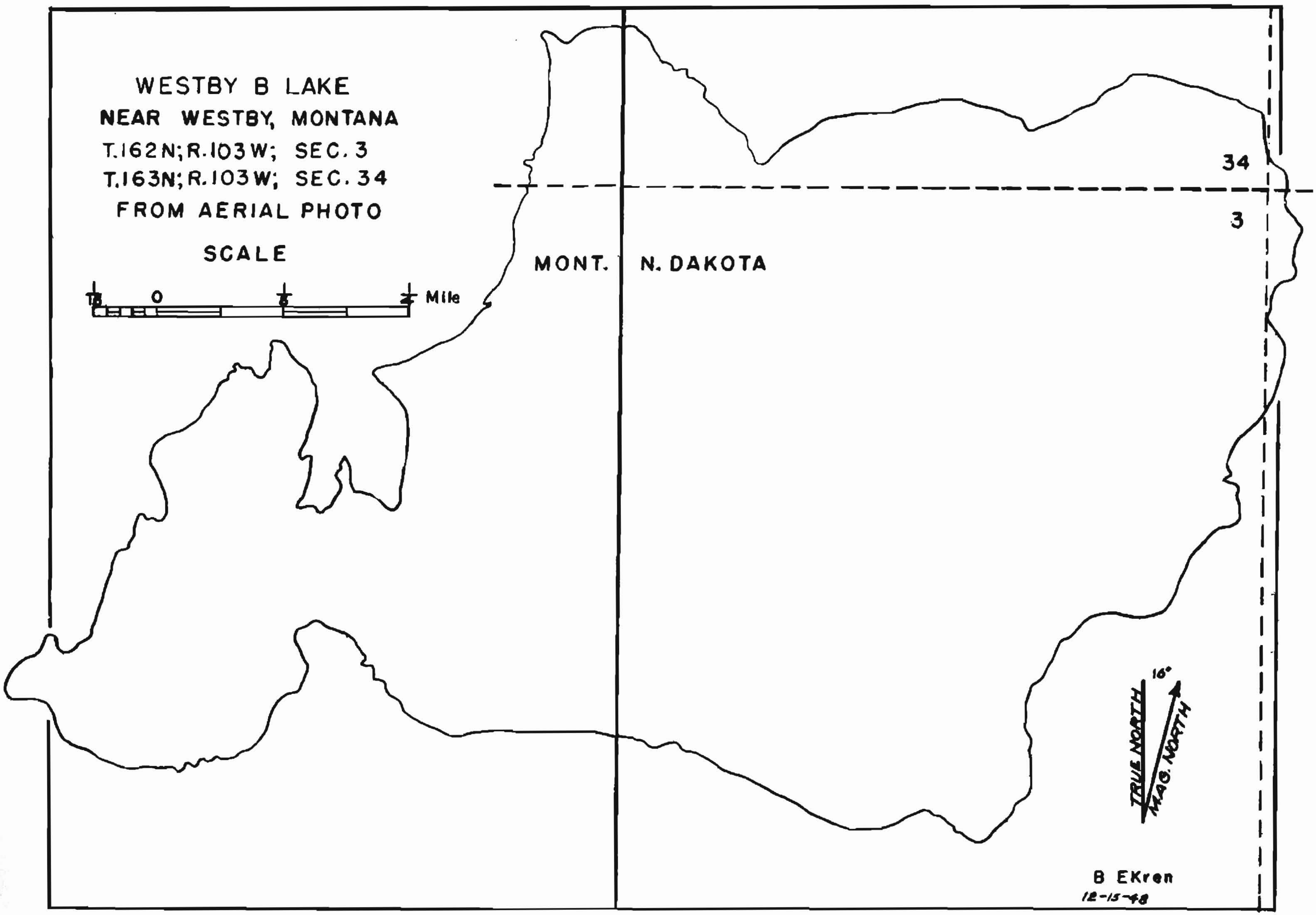
When revisited on October 23, 1948, the lake floor was completely dry and hard enough to walk on. The dry bed was covered by a thin layer of white anhydrous sodium sulphate (thenardite) beneath which was a layer of mud mixed with clear transparent crystals of mirabilite. No drilling has yet been done and it is not known if this lake has a permanent bed. The town of Westby, with its railway station, lies only about one mile to the south. North Dakota Highway 5 approaches to within less than $\frac{1}{2}$ mile at its closest point. The specific gravity of the brine at 70°F was 1.110.

Brine Analysis

Westby B Lake	(Surface, Southeast shore)
Sample collected	8-30-47
Sample analyzed	4-28-48
Analyst	R. W. Taintor

1.	Total dissolved solids	157,132.5 P.P.M.
2.	Total alkalinity	13,450
	Alk: to phenol	4,800
3.	Chloride	2,318
4.	Silica	1,382.5
5.	Iron and aluminum	167.5
	iron	Trace
6.	Calcium	12.30
7.	Magnesium	29.27
8.	Sulphate	81,488
9.	Sodium	42,642.6
10.	Carbonate	9,600
11.	Bicarbonate	3,850
12.	Total hardness	00.0


11
12
14
13
16°
TRUE NORTH
MAGNETIC NORTH
WESTBY A
(FREUND LAKE)
NEAR EAST WESTBY, N. DAK.
T-162 N R-103W
SECTIONS 11, 14, 23
DATA FROM AERIAL PHOTO
Scale
0
½ mile
14
13
23
24
Reproduced by J F Cordner


WESTBY B LAKE
NEAR WESTBY, MONTANA
T.162N; R.103W; SEC. 3
T.163N; R.103W; SEC. 34
FROM AERIAL PHOTO
SCALE
0
Mile
MONT.
N. DAKOTA
34
3
TRUE NORTH
MAG. NORTH
16°
B EKren
12-15-48

Recorded Owners of Land, Westby B

Section 2-$NW\frac{1}{4}$ of $NW\frac{1}{4}$-E. C. Ferguson
$SW\frac{1}{4}$ of $NW\frac{1}{4}$-E. C. Ferguson

Section 3-$NE\frac{1}{4}$-No record
$SE\frac{1}{4}$-of $NW\frac{1}{4}$-No record

Westby C Lake

This lake is too small to be considered as a commercial possibility for it only covers about 50 acres. Because of its nearness to some of the other deposits however, (Westby B for example) it might serve as a precipitation reservoir.

Although this report is not concerned with the technological aspects of recovery, it can be said that the experience of the Chaplin Lake development, among others, demonstrates that sodium sulphate can be successfully recovered from brines by precipitation in suitable reservoirs under the proper conditions. The close proximity of this small basin to Westby (less than $\frac{1}{2}$ mile) and its nearness to State Highway 5 (approximately 100 yards) are features worth noting.

The long axis of the lake strikes northeast, pointing in the general direction of McKone Lake. In the absence of detailed geologic maps, it may be surmised that both lakes (as well as Westby B) lie in an abandoned channel, dubbed the Dagmar Channel by Witkind. The possibility of connecting McKone Lake (with its estimated reserves of three million tons) with Westby B or C by a suitable pumping system can be better explored after more is known of the topography of this area. Local farmers, however, report that in the winter time one can ski from the northeast end of McKone Lake clear through to the town of Westby crossing only one or two high points en route.

Specific gravity of brine collected from surface, south shore was 1.12 at 67.5°C. Another sample collected from the southeast shore had a specific gravity of 1.13 at 68°C.

As in the case of Westby B, this lake was dry when revisited (10-23-48) after being covered with brine all summer.

Brine Analysis

Westby C Lake. . . . . (Surface, South shore)
Sample collected 8-15-47
Analyst . . . . Christopher Dahl, Jr.

		P.P.M.	Equivalents
1.	Total dissolved solids. . .	128,125.0 . . .	
2.	Total alkalinity.	1,835.0 . . .	
	Alk: to Phenol . . .	232.0 . . .	
3.	Chloride.	3,844.47 . . .	85.3509
4.	Silica.	25.0 . . .	
5.	Iron and aluminum	200.00 . . .	
	Iron.	Trace . . .	
6.	Calcium	219.474. . .	10.9737
7.	Magnesium	5.8968 . .	.4847
8.	Sulphate.	30,443.6 . . .	630.1825
9.	Sodium.	16,886.6 . . .	734.2042
10.	Carbonate	278.4 . . .	9.2774
11.	Bicarbonate	1,955.66 . . .	20.7300
12.	Nitrate	6.93 . . .	.1118

Hypothetical Combinations

Sodium Sulphate	630.1825
Calcium Carbonate	10.9737
Sodium Chloride	85.3509
Magnesium	.4847
Sodium Bicarbonate	9.2716
Sodium Carbonate	9.2774
Sodium Nitrate	.1118

Per cent of Sodium Sulphate in T.D.S. 52.1

Recorded Owners of Land, Westby C

Section 3-SE$\frac{1}{4}$-Anna Johnson

Section 10-NW$\frac{1}{4}$ of NE$\frac{1}{4}$-M. V. Anderson

Stady E Lake

This small lake is somewhat unique in that it is not a member of a group of other bitter lakes of comparable size.

Topographic maps of the surrounding area are available (Smoky Butte and Bright Water Lake quadrangles)(38). In addition, maps showing the glacial geology have been prepared but have not yet been released for general distribution at the time of this writing. Several springs feed this slough which is so strongly saline that when visited in September 1948 an almost solid carpet of sodium sulphate had already crystallized out. This was at a time when most of the other deposits, even the major ones, still showed appreciable amounts of water.

Large needle-like crystals collected from the extreme northeast short (surface, near road) were examined in the laboratory and found to be monoclinic crystals of mirabilite.

This deposit is extremely close to the proposed Crosby reservoir which apparently will not flood the lake basin itself. The approximate maximum depth of water is eleven feet and the surface of the lake is 2015 feet above mean sea level.

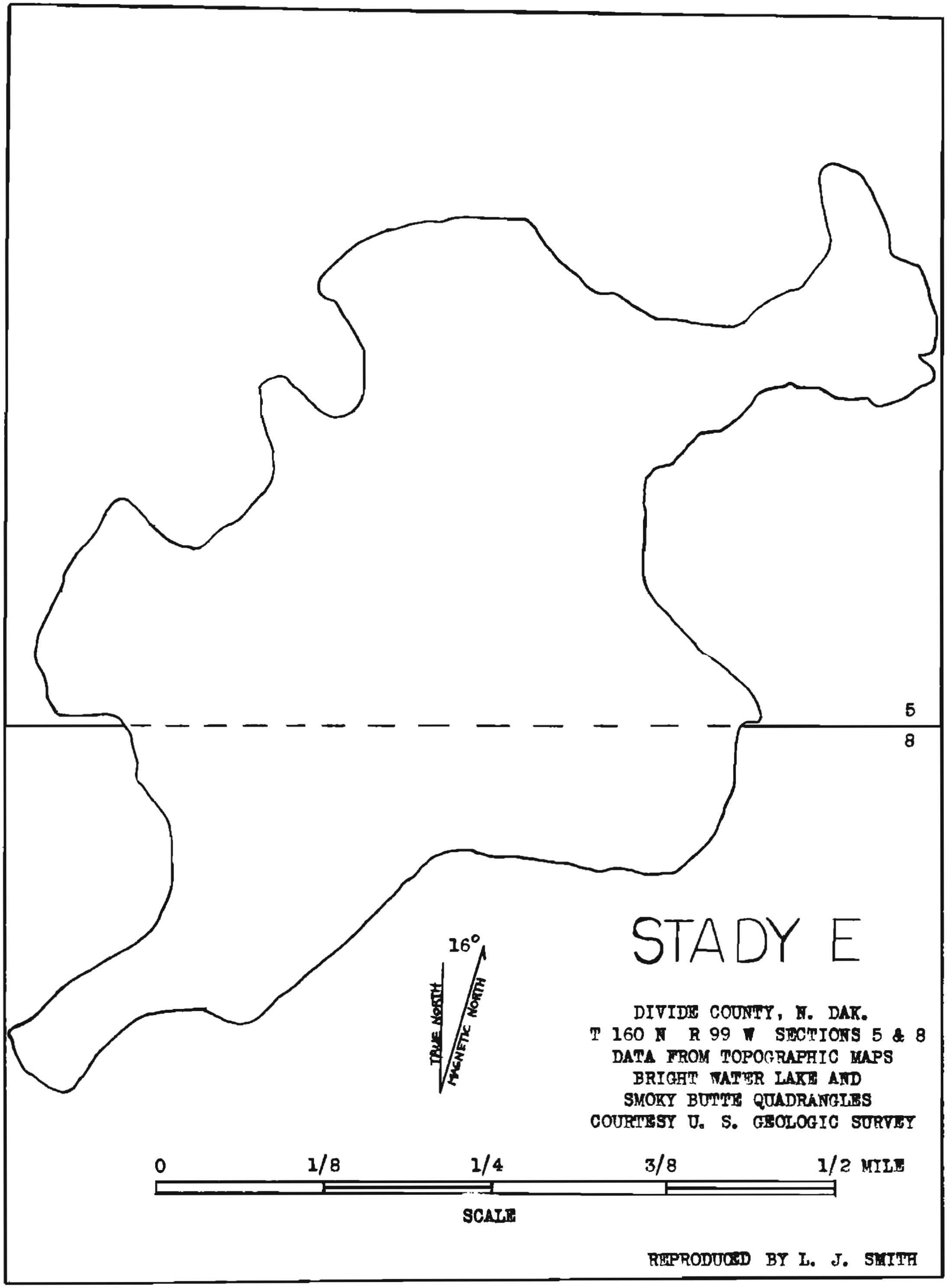
Stady E has a length of about 3/4 of a mile in a northeast-southwest direction and covers an area of 120 acres. It is located about 9 miles north of the town of Alamo which is reached by a secondary road. Alamo itself is served by the Great Northern Railway and can also be reached by State Highway 50.

Recorded Owners of Land, Stady E

Section 5-NE$\frac{1}{4}$-Edmund Eide and Ruth Eide
NW$\frac{1}{4}$-Albert B. Anderson and George H. Anderson
E$\frac{1}{2}$ of SE$\frac{1}{4}$-Edmund Eide and Ruth Eide
NW$\frac{1}{4}$ of SE$\frac{1}{4}$-Edmund Eide and Ruth Eide
S$\frac{1}{2}$ of SW$\frac{1}{4}$-Frans Oscar Magnusson
NW$\frac{1}{4}$ of SW$\frac{1}{4}$-Frans Oscar Magnusson
SW$\frac{1}{4}$ of SE$\frac{1}{4}$-No record

Section 8-NE$\frac{1}{4}$-Owned by County
NE$\frac{1}{4}$ of NW$\frac{1}{4}$-Frans Oscar Magnusson

Divide County also contains the largest number of small or weakly saline lakes thus far observed.



STADY E
DIVIDE COUNTY, N. DAK.
T 160 N R 99 W SECTIONS 5 & 8
DATA FROM TOPOGRAPHIC MAPS
BRIGHT WATER LAKE AND
SMOKY BUTTE QUADRANGLES
COURTESY U. S. GEOLOGIC SURVEY
16°
TRUE NORTH
MAGNETIC NORTH
5
8
0
1/8
1/4
3/8
1/2 MILE
SCALE
REPRODUCED BY L. J. SMITH

Saline lakes of no economic importance(39)

Name	Location
Nelson Lake	T161N R95W secs. 27, 34
Unnamed Lake	T160N R96W Secs. 32,33
Unnamed Lake (small)	T163N R95W Secs. 26, 35
Unnamed Lake (small)	T163N R95W Secs. 21, 22, 27, 28
Unnamed Lake (small)	T160N R96W Secs.3, 10
Unnamed Lake	T160N R96W Secs. 7, 17, 18
Unnamed Lake	T160N R96W Secs. 17, 18, 19, 20
Unnamed Lake	T160N R96W Sec. 31 large, extends into R97W
Unnamed Lake	T160N R97W Secs. 26, 35
Unnamed Lake	T161N R98W Secs. 24, 25
Unnamed Lake	T162N R98W Sec. 12
Unnamed Lake	T161N R99W Sec. 21
Unnamed Lake	T161N R99W Secs. 23, 24
Bright Water Lake	T161N R99W Sec. 36 and T161N R98W Sec. 31
Unnamed Lake	T160N R100W Sec. 36 (extends into Williams County)
Smoky Butte Lake	T160N R100W Sec. 22 (S.G. 1.125; at 77°C.)
Unnamed Lake	T161N R101W Sec. 26 north ½ (small but strongly saline)
Unnamed Lake	T161N R101W Secs. 26, 27 (small but strongly saline)
Unnamed Lake	T161N R101W Secs. 26, 35 (small but strongly saline)
Unnamed Lake	T161N R191W Secs. 27, 34 (small but strongly saline)
Unnamed Lake	T163N R102W Secs. 26, 27, 34, 35
Unnamed Lake	T163N R192W Secs. 25, 26
Unnamed Lake	T163N R102W Secs. 13, 24
Unnamed Lake (Lake Johnson?)	T162N R102W Secs. 22, 23 (S.G. 1.035; at 62.5°C.)
Unnamed Lake	T163N R103W Secs. 10, 11
Unnamed Lake	T161N R103W Secs. 14, 23
Unnamed Lake	T161N R103W Secs. 14, 23 (east of above)
Unnamed Lake	T161N R103W Secs. 23, 24, 25, 26
Unnamed Lake	T161N R98W Sec. 28 NE¼ and another SW¼
Unnamed Lake	T161N R98W Sec. 29 (SE¼)
Unnamed Lake	T161N R103W Secs. 22, 27
Unnamed Lake	T161N R101W Secs. 17, 19, 20
Musta Lake	T160N R100W Sec. 3
Unnamed Lake	T160N R103W Secs. 18, 19 (extends into Montana) (Reported by Walovnick)
Unnamed Lake	T160N R103W Secs. 1, 2
Unnamed Lake	T160N R103W Secs. 2, 11
Unnamed Lake	T160N R103W Secs. 1, 12
Unnamed Lake	T160N R103W Sec. 24
Lake Johnson	T162N R102W Secs. 22, 23

Williams County

General

No deposits have been previously reported from this area. In 1947 one group of two lakes was discovered in the northwest corner of the county, southwest of Grenora #2. Horseshoe Lake lies in the "Grenora Channel", mapped and named by Witkind (40) as another abandoned channel (possibly of the old Missouri). The Grenora and Stady channels also include the Grenora #1 and Grenora #2 deposits (at least in part). Stink Lake lies only a short distance from the Grenora channel. Both Horseshoe and Stink Lakes are surrounded by several small ponds and swamps. This knob-and-kettle topography also characterizes the areas surrounding the other deposits.

Stink Lake

This slough occupies an elongated basin which points northward towards the larger Grenora #2 deposit. The southern margin of the latter just crosses the county line. Stink Lake is only 4½ miles west of the town of Grenora, and is connected to it by State Highway 50. The Great Northern Railway branch line, however, ends at the town of Grenora. Stink Lake is almost a mile in length, covers an area of 150 acres, and its surface is 1949 feet below sea level. The sides of the basin are covered with glacial boulders. When revisited in September 1948, the lake was almost dry, there being but a small patch of water remaining near the center. Large acicular crystals of mirabilite could be observed on the lake bed, the outer surface of which was fringed with pulverulent thenardite.

Nothing is known about the depth of water or the presence of a permanent bed. If subsequent investigations prove that reserves are too small, this deposit might still serve as a collection reservoir for one of the larger nearby deposits. Its closeness to the state highway enhances its value in this report. The specific gravity of the brine at 77°C was 1.235.

Brine Analysis

Stink Lake. . . . . (Surface, south shore)
Sample collected. 11-18-48
Sample analyzed 12-16-48
Analyst . . . . W. D. Waldschmidt
All results are expressed in parts per million (P.P.M.)

1. Total dissolved solids.	120,334 P.P.M.
2. Alkalinity to Phenol.	120
3. Chloride.	1, 298
4. Calcium	915
5. Magnesium	2,975
6. Sulphate.	61,970
7. Sodium.	23,794
8. Carbonate	144

Hypothetical Combinations (in per cent)

Percentages are based on total dissolved solids.

Sodium Sulphate	58.82
Calcium Carbonate	.20
Sodium Chloride	1.78
Magnesium Sulphate.	12.23
Calcium Sulphate.	2.32
Water of hydration, Organic matter, and undetermined residue.	24.65

Recorded Owners of Land, Stink Lake

Section 5-SW¼-Henry C. Thomas

Section 8-NE¼-No title

Horseshoe Lake

This lake which crossed the state line into Montana, occupies a large horseshoe shaped basin. It covers an area of 100 acres, and is 1964 feet above sea level. A topographic map of this area which shows both Horseshoe Lake and most of Stink Lake is available. (41) Witkind's geologic map of the Dagmar No. 4 quadrangle, which covers this area, also includes Stink Lake.

This deposit is not as accessible as Stink Lake. It is about 1.7 miles south of highway 50 and approximately 7 miles southwest of the town of Grenora with its railroad. Either of the arms of Horseshoe Lake could easily be dammed off to provide a precipitation basin.

When Horseshoe Lake was visited in September 1948, it too was almost completely dry. Like Stink Lake, it showed large, needle-like crystals of hydrous sodium sulphate a short distance from the shore. Near shore, powdery dry thenardite formed a fringe around the grayish mirabilite. A brine sample yielded a strong odor of hydrogen sulfide after standing about two months.

Recorded Owners of Land, Horseshoe Lake

Section 17-SW$\frac{1}{4}$-No title

Section 18-NE$\frac{1}{4}$ of NE$\frac{1}{4}$-Lots 1 and 2
SE$\frac{1}{4}$-No title
SE$\frac{1}{4}$ of NE$\frac{1}{4}$-Guy Larson, Grenora, North Dakota

Saline lakes of no economic importance

Name	Location		
Nyston's Lake	T159N	R95W	sec. 6
Unnamed Lake (small)	T159N	R96W	secs. 3, 9
Unnamed Lake (small)	T159N	R96W	secs. 9, 10
Unnamed Lake (small)	T159N	R96W	sec. 4
Unnamed Lake	T159N	R100W	secs. 22, 23
Unnamed Lake	T159N	R100W	secs. 22, 27
Unnamed Lake	T159N	R100W	sec. 1 (already listed, extends into Divide County)
Green Lake	T159N	R100W	secs. 4, 5, 9 (S.G. 1.07, temp. 66°F.)
Three Mile Lake (Twin Lakes)	T159N	R103W	secs. 8, 9, 16
Unnamed Lake	T159N	R103W	secs. 8, 17
Unnamed Lake	T159N	R100W	sec. 18
Unnamed Lake	T159N	R100W	secs. 20, 29
Unnamed Lake	T159N	R100W	secs. 20, 21
Unnamed Lake	T159N	R103W	sec. 9 (small but strongly saline)

Burke County

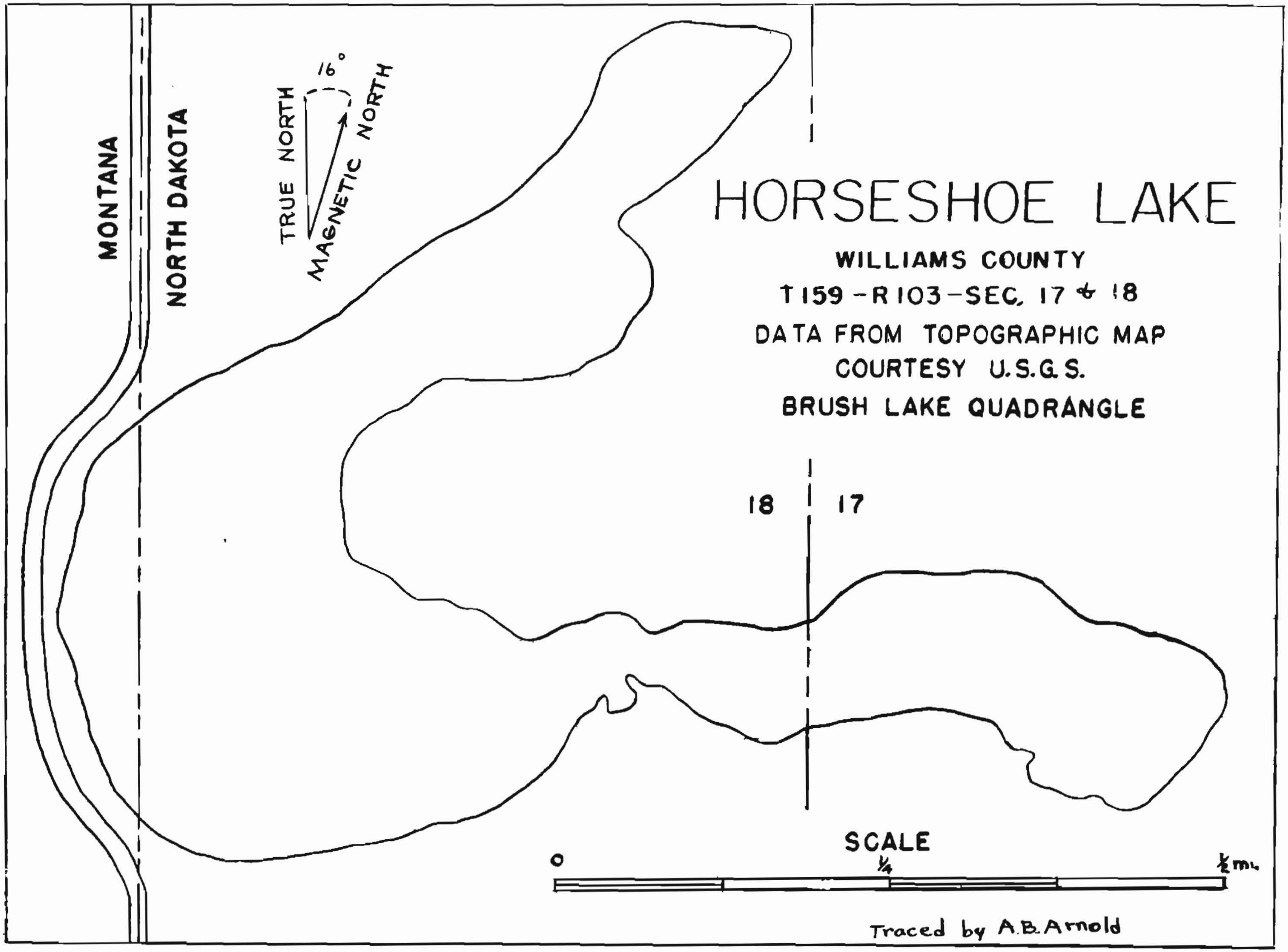
General

More than half of this area lies northeast of the Missouri escarpment where no interior drainage is present. A few saline lakes are found southwest of the Coteau but only one is large enough to merit mention.

Upper Lostwood Lake

This curbed elongated body of water is about two miles long and about a half mile wide. It can be reached from the town of Lostwood by following a gravel road, State Highway 8, northward to highway 50 and then westward for a combined total of 7 miles. Stanley, the county seat, is 11 miles south of Lostwood. Both of these towns (as well as nearby Lunds Valley) are served by the Great Northern Railway.

This lake does not dry up and it is not believed that a permanent bed exists. It is also dilute enough to be used as a game refuge. (All the land is owned by the Federal Government). It is not a major deposit, but was briefly studied for evidence bearing on the origin of the sodium sulphate.


MONTANA
NORTH DAKOTA
TRUE NORTH
MAGNETIC NORTH
16°
HORSESHOE LAKE
WILLIAMS COUNTY
T159-R103-SEC. 17 & 18
DATA FROM TOPOGRAPHIC MAP
COURTESY U.S.G.S.
BRUSH LAKE QUADRANGLE
18
17
SCALE
0
1/4
1/2 mi.
Traced by A.B. Arnold

The south shore of this lake has a thin veneer of sand underlain by silt and clay (at least locally). The lake shores and valley sides are strewn with glacial erratics. Several springs contribute their waters to the lake brine which showed a specific gravity of 1.060 at 58.5°C. During dry weather and during the fall, a thin white crust of mirabilite forms on the lake shores.

Brine Analysis #1

Upper Lostwood Lake. . . . . (South shore, surface)
Sample collected 8-15-47
Sample analyzed. 5-1-48
Analyst. . . . . Jack C. Thompson

1.	Total dissolved solids.	44,310 P.P.M.
2.	Total alkalinity.	4,105
	Alk: to Phenol	1,014
3.	Chloride.	420.5
4.	Silica.	20
5.	Iron and alumina.	10
	Iron	Trace
6.	Calcium.	43.09
7.	Magnesium	13.14
8.	Sulphate.	25,122
9.	Sodium (calculated)	14,570
10.	Carbonate	2,028
11.	Bicarbonate	2,077
12.	Nitrogen.	.1
13.	Total hardness. (soap method) . . .	910

Hypothetical Combinations (in per cent)

Sodium Sulphate	83.8
Calcium Carbonate	14.35
Sodium Chloride	1.56
Magnesium Carbonate	.17
Sodium Nitrate.	.0004
Water of hydration, Organic matter and undetermined residue	.1196

A second brine sample was collected and analyzed about a year later to determine the variations in concentration of dissolved salts.

Brine Analysis #2

Upper Lostwood Lake. . . . . (South shore, surface)
Sample collected 9-2-48
Sample analyzed. . . . . November, 1948
Analyst. . . . . Jack C. Thompson

1.	Total dissolved solids.	45,540 P.P.M.
2.	Total alkalinity.	4,610
	Alk: to Phenol	1,585
3.	Chloride.	438.09
4.	Silica.	42
5.	Iron and alumina.	32
6.	Calcium	12,83
7.	Magnesium	10.92
8.	Sulphate.	26,090
9.	Sodium. (calculated).	15,745.35

10. Carbonate . . . . 3,170 P.P.M.
11. Bicarbonate 1,440

Hypothetical Combinations (in per cent)

Sodium Sulphate	82.5
Calcium Carbonate	15.5
Sodium Chloride	1.46
Magnesium Carbonate	.14
Water of hydration, Organic matter Undetermined residue.	.4

Saline lakes of no economic importance

Name	Location
Seven Mile Slough	T164N R93W secs. 35, 36
Hank's Lake	T162N R92W sec. 22
Sletton Lake	T159N R94W secs. 25, 26, 35, 36
Unnamed Lake (small)	T162N R94W sec. 13
Unnamed Lake (small)	T162N R94W sec. 15
Unnamed Lake (small)	T162N R94W sec. 17
Unnamed Lake (small)	T161N R90W secs. 7, 8
Unnamed Lake (small)	T162N R94W sec. 4
Thompson Lake	T160N R91W secs. 26, 27, 34, 35
Unnamed Lake	T159N R91W sec. 21 (N½)
Unnamed Lake	T159N R91W sec. 16
Unnamed Lake	T159N R91W sec. 34

Mountrail County

General

The area of young glacial deposits whose northern border is marked by a topographic high, cuts diagonally across Divide and Williams and enters Mountrail County from the northwest. It narrows as it approaches Stanley. Between Stanley and Tagus, however, it widens again, a lobe extending southwestward in the direction of the Little Knife River. Northeast of this lobe, in the vicinity of Palermo and Blaisdell, are the two deposits known as Stanley #1 and #2. These were investigated in 1934 and detailed descriptions of them are available. The maps (p. 21 and p. 22) will serve to supplement the earlier work.

Lower Lostwood Lake

This lake lies in the same valley as Upper Lostwood and strongly resembles it in its linear, curved appearance. The south shore is floored in part by a thin veneer of fine and overlying silt and a wide variety of glacial erratics are present. Crystalline metamorphic and igneous rocks are prominent among the large boulders. During dry weather the boulders near the shore are covered with white salts.

The lake itself is more than two miles long and is only six miles northwest of Lostwood. The first three miles out of Lostwood are covered by gravel road (No. 8), the other three by a rough prairie road. As in Upper Lostwood, no permanent bed is believed present. The lake remains liquid (except for freezing) the year round. It lies on the game refuge which included Upper Lostwood Lake and is likewise owned by the Federal Government. Although the flooded part of the basin is more than 2 miles in length it is only slightly more than nine feet in depth at its deepest point. The specific gravity of the brine at 66°C was 1.050. An analysis is included below.

Brine Analysis

Lower Lostwood Lake. . . . . (South shore, surface)
Sample collected 8-14-48
Sample analyzed. 11-8-48
Analyst. . . . . W. D. Waldschmidt
All results expressed in parts per million (P.P.M.)

1.	Total dissolved solids	93,180 P.P.M.
2.	Alkalinity to Phenol	2,512
3.	Chloride	702
4.	Calcium	14
5.	Magnesium	1,022
6.	Sulphate	36,033
7.	Sodium	17,537
8.	Carbonate	3,014

Hypothetical Combinations (in per cent)

Sodium Sulphate	56.89
Calcium Carbonate	.000004
Sodium Chloride	.13
Magnesium Carbonate	3.75
Sodium Carbonate	.81
Water of hydration, Organic matter and undetermined residue	38.42

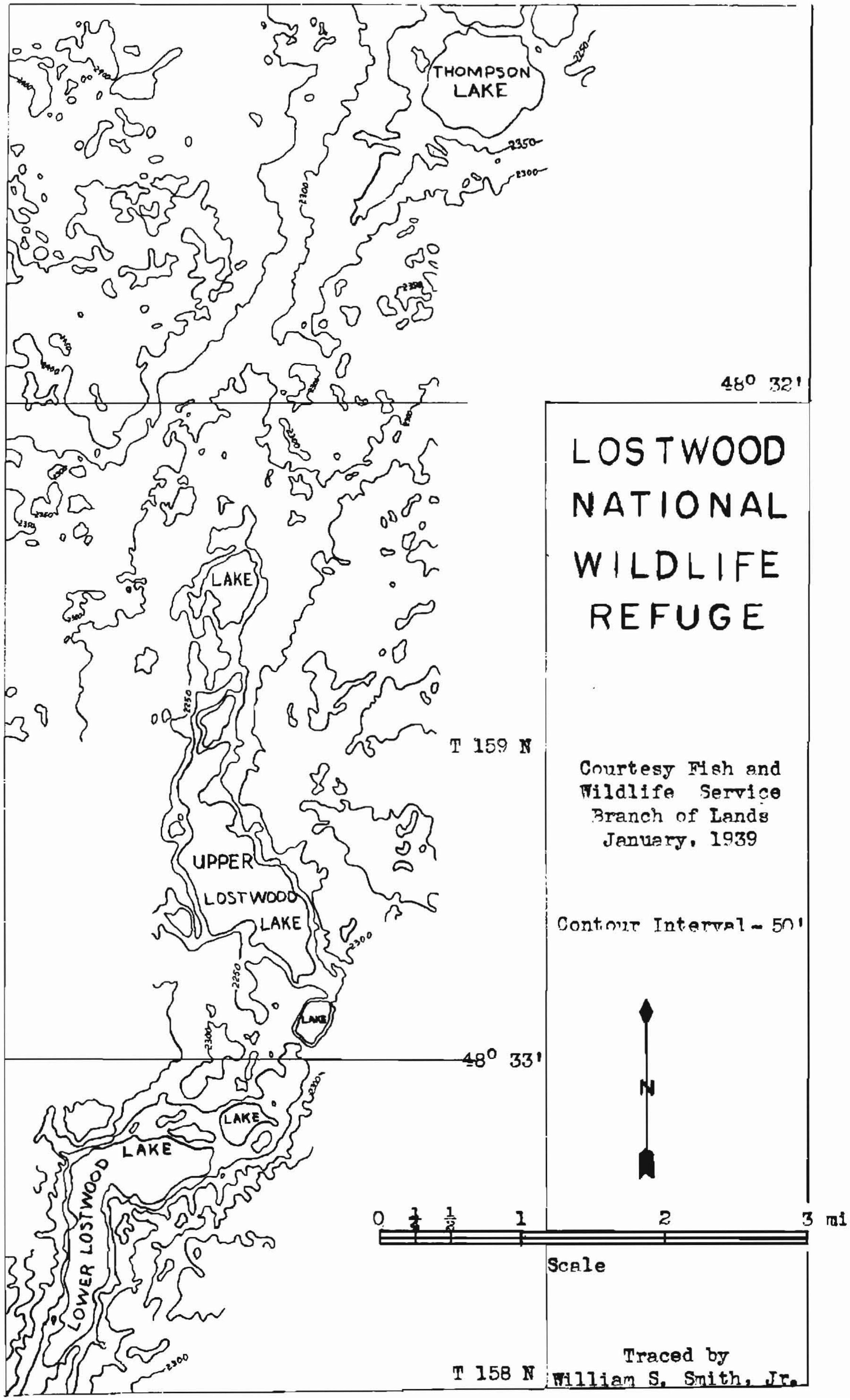
A topographic map of the Lostwood Migratory Waterfowl Refuge (p.37) is available. The contour lines clearly bring out the serpentine meanders of the old stream channel which includes both Lower and Upper Lostwood Lakes.

Stanley A

This lake lies outside the area studied in 1947 but was seen from U. S. Highway 2, which runs only a few yards south of it. From the lake a short trip of 2½ miles along the highway brings one to Palermo. Stanley lies another 9½ miles southwestward. Although the nearest railroad station (Great Northern) is at Palermo, the railroad itself passes within less than ½ mile of the south shore. The lake has a length of a little more than a mile and covers an area of approximately 230 acres. Its northwest corner narrows and is partially isolated by a narrow constriction, giving the lake a bottle-shaped appearance. It would not be difficult to seal the neck of this bottle with a small dam, thus providing an excellent basin for "harvesting". From this constriction a gravel road runs south one mile to U. S. 5.

Stanley A is slightly less than a mile west of Stanley #2 so that a joint extraction system connected by pumps and pipeline is possible.

Like its sister deposits (Stanley No. 1 and No. 2) Stanley A lies close to a southwestward extending lobe of the glacial deposits. The lake was visited in September 1947, at which time a heavy white coating had formed along its shores and along a fence running across the south margin. A specific gravity reading of 1.120 at 74°C was recorded at this time. The brine left a heavy white precipitate on the glass cylinder and on the hands.



LOSTWOOD NATIONAL WILDLIFE REFUGE
Courtesy Fish and Wildlife Service Branch of Lands January, 1939
Contour Interval - 50'
N
0 1/4 1/2 1 2 3 mi.
Scale
Traced by William S. Smith, Jr.
THOMPSON LAKE
2350
2300
2250
48° 32'
LAKE
T 159 N
UPPER LOSTWOOD LAKE
LAKE
48° 33'
LAKE
LAKE
LOWER LOSTWOOD
T 158 N

The sides of the valley are marked by an abundance of glacial boulders. At least two springs are present, one on the west shore at the point of closest approach of the lake to the road running north. The spring water is quite potable. It had a temperature of 53.6°C when checked. Bubbles of a colorless, odorless gas could be seen rising constantly through the gravel and the green algae of the spring, whose floor is topographically higher than the lake.

An analysis of the spring water yielded the following results:

Brine Analysis

Stanley A. . . . . (West shore, surface, near road)
Sample collected 9-8-48
Sample analyzed. 10-12-48
Analyst. . . . . W. D. Waldschmidt
All results expressed in parts per million (P.P.M.)

1.	Total dissolved solids.	199,813 P.P.M.
2.	Total alkalinity.	23,680
	Alk: to Phenol	10,028
3.	Chloride.	57.81
4.	Silica.	1,343
5.	Iron and aluminum	139
6.	Calcium	20.04
7.	Magnesium	198.74
8.	Sulfate	80,638
9.	Sodium.	49,931
10.	Carbonate	12,033
11.	Bicarbonate	16,655
12.	Total hardness.	867.87
13.	Non-carbonate hardness.	0.00

Hypothetical Combinations (in per cent)

Percentages are based on total dissolved solids

Sodium Sulphate	59.357
Calcium Carbonate	.025
Sodium Chloride.	.047
Magnesium Carbonate	.337
Sodium Carbonate.	12.099
Water of hydration, Organic matter and undetermined residue	28.135

By comparison, a sample of the spring water collected at the same time had the following proportions:

Spring Water Analysis

Stanley A. . . . . (West shore of lake, at point of nearest approach of lake to road going north, T156N-R89W-Secs. 6, 7)
Sample collected 9-2-48
Sample analyzed. 10-8-48
Analyst. . . . . W. D. Waldschmidt
All results expressed in parts per million (P.P.M.)

1.	Total dissolved solids.	1,961
2.	Total alkalinity.	880
	Alk: to Phenol	88
3.	Chloride.	7.75
4.	Silica.	48.0
5.	Iron and aluminum	13.0
6.	Calcium	16.03
7.	Mangesium	8.96
8.	Sulphate.	636.22
9.	Sodium.	353.59
10.	Carbonate	105.60
11.	Total hardness.	40.9

Hypothetical Combinations (in per cent)
Percentages are based on total dissolved solids

Sodium Sulphate	48.75
Calcium Carbonate	2.05
Sodium Chloride	.64
Magnesium Carbonate	1.54
Sodium Carbonate.	5.34
Water of hydration, Organic matter, and undetermined residue.	41.68

Recorded Owners of Land, Stanley A

Section 11-Lots 5, 6 W½ of SE¼-Mathias Knutson, Palermo

Section 12-NE¼-Florence Gunnar Nelson, Edna Helen Nelson Nigro, and Harriet F. L. Nelson Montgomery

White Lake

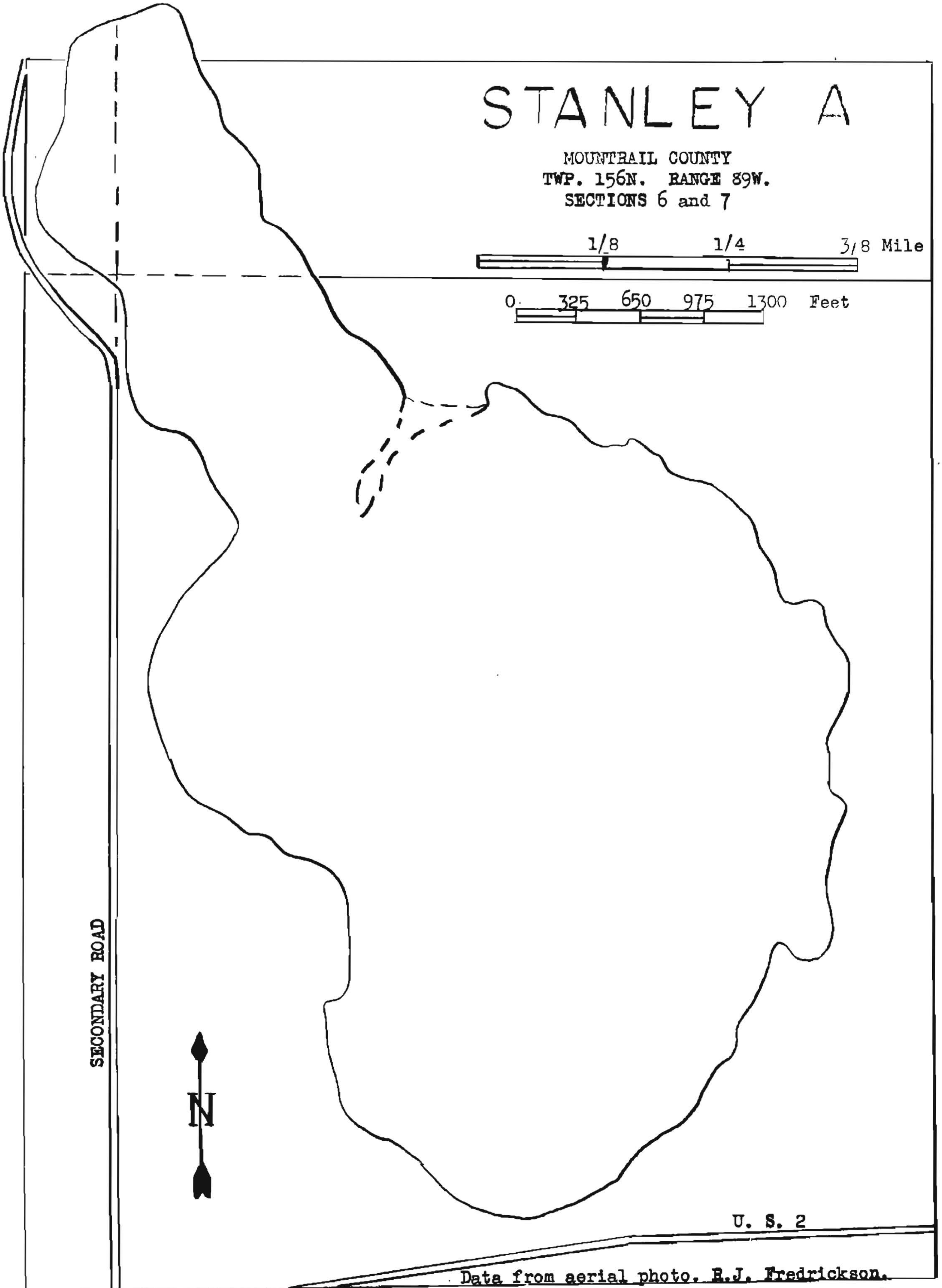
This is the largest and thus far the most promising deposit discovered in the 1947-48 study. Its northwest axis is almost five miles long and its width averages nearly a mile. It covers an area of 2,300 acres and lies only four miles northwest of Stanley. A branch of the Great Northern Railway passes the east shore of the lake at a distance of slightly more than 2 miles. In addition, highway 8 runs northward in plain view of the east shore (at a distance of ½ mile).

A few holes were drilled in White Lake in 1934 but lack of funds apparently prevented any further exploration. If the data based on the original field notes (on file in the North Dakota Geological Survey offices) are accurate, there are reserves of about two and one-half million tons of hydrous sodium sulphate in the permanent bed alone. In addition, there is an extensive intermittent bed.

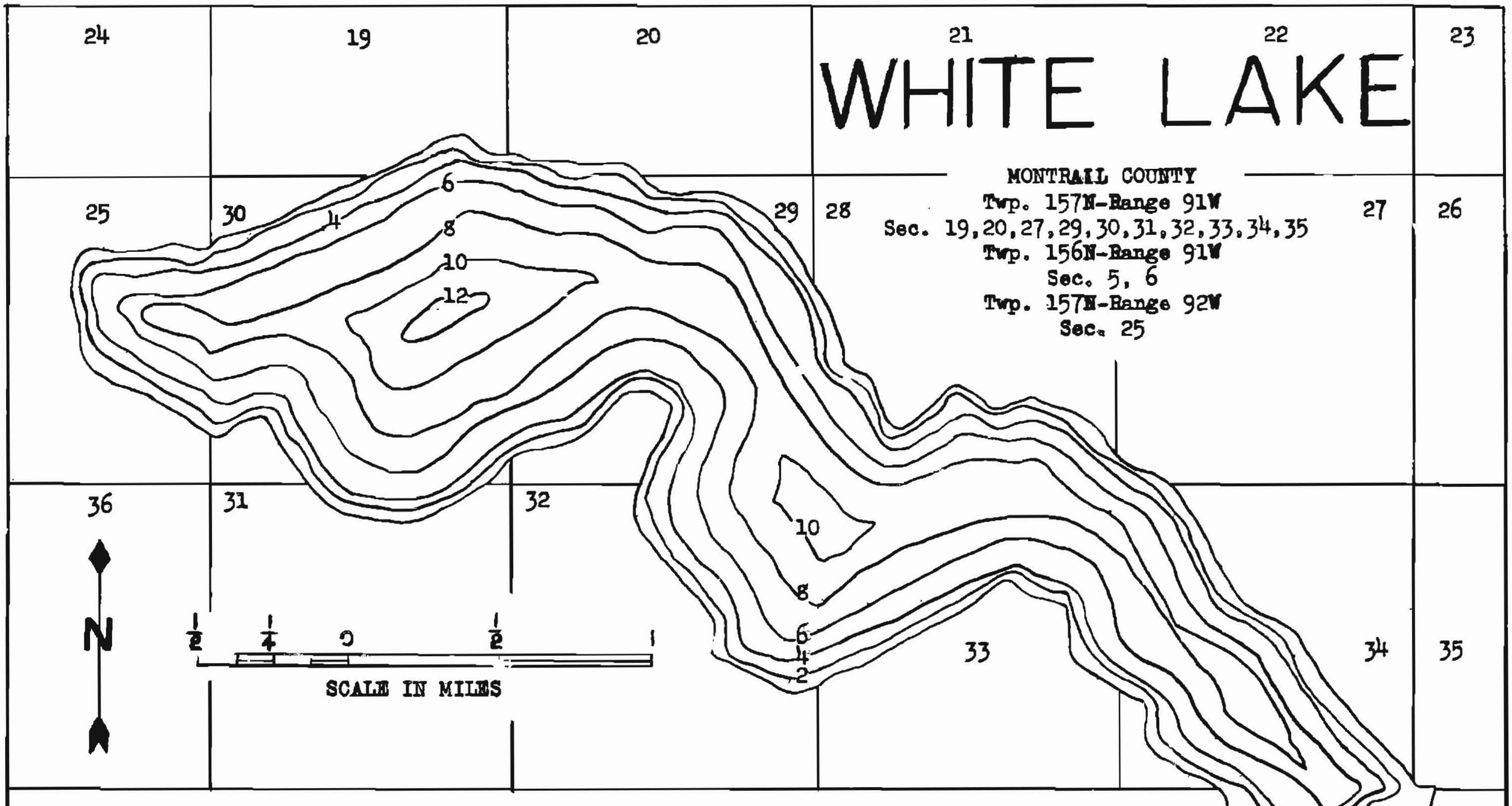
A small channel leading into the lake from the east is covered with salts in dry weather. It would require little deepening to make a reservoir here which would bring the brine close to the highway and railroad and also serve as a precipitation basin.

When examined the brine contained green algae and the shores were covered by *Salicornia* sp. The specific gravity of the brine at 67°C was 1.085.

On the basis of one brine analysis (admittedly, the concentration varies considerably) and a map showing the depth of water in various parts of the lake, (p.41) rough estimates of the amount of glauber's salt in the intermittent bed can easily be made.


STANLEY A
MOUNTRAIL COUNTY
TWP. 156N. RANGE 89W.
SECTIONS 6 and 7
1/8
1/4
3/8 Mile
0 325 650 975 1300 Feet
SECONDARY ROAD
N
U. S. 2
Data from aerial photo. R.J. Fredrickson.

12-7-48.



Depths of Brine in Feet
Traced from Duplicate (I.G.) 8-23-47
Surveyor General's Office, Bismarck, N. D.
10-18-1898
Reproduced by R. Harris 12-9-48

Brine Analysis

White Lake . . . . (Surface, east shore)
Sample collected 9-2-48
Sample analyzed. 10-26-48
Analyst. . . . . W. D. Waldschmidt
All results expressed in parts per million (P.P.M.)

1.	Total dissolved solids.	94,327 P.P.M.
2.	Total alkalinity.	2,580
	Alk: to Phenol	700
3.	Chloride.	268
4.	Calcium	58
5.	Magnesium	125
6.	Sulfate	58,688
7.	Sodium.	28,453
8.	Carbonate	840
9.	Total hardness.	658

Hypothetical Combinations (in per cent)

Percentages are based on total dissolved solids

Sodium Sulphate	91.49
Calcium Carbonate	.15
Sodium Chloride	.43
Magnesium Carbonate	.45
Sodium Carbonate.	.83
Water of hydration, Organic matter, and undetermined residue	6.65

Recorded Owners of Land, White Lake

Cottonwood Township

Lot 1, Sec. 25 Mostafa Osman, Stanley, North Dakota
Lot 2, Sec. 24 Mostafa Osman, Stanley, North Dakota
Lot 3, Sec. 25 Mountrail County, Stanley, North Dakota. Deeded to Hamid Juma (Sam is father). Not recorded, Stanley, North Dakota.
Lot 4, Sec. 25 Same as above
Lot 5, Sec. 25 Bertha Liebl, Stanley, North Dakota

James Hill Township

Lot 2, Sec. 30 Mostafa Osman, Stanley, North Dakota
Lot 1, Sec. 30 Mostafa Osman, Stanley, North Dakota
Lot 5, Sec. 19 Mountrail County, Stanley, North Dakota. Deeded to Hamid Juma. Not recorded, Stanley, North Dakota.
Lot 6, Sec. 19 Fredrick William Kuster, Stanley, North Dakota
Lot 1, Sec. 20 Fredrick William Kuster, Stanley, North Dakota
Lot 2, Sec. 20 Fredrick William Kuster, Stanley, North Dakota
Lot 2, Sec. 29 Fredrick William Kuster, Stanley, North Dakota
Lot 1, Sec. 29 Fredrick William Kuster, Stanley, North Dakota
Lot 1, Sec. 28 William Kuster, Stanley, North Dakota
Lot 5, Sec. 28 William Kuster, Stanley, North Dakota
Lot 4, Sec. 28 William Kuster, Stanley, North Dakota
Lot 3, Sec. 28 Argyle B. Helland, Stanley, North Dakota
Lot. 2, Sec. 28 Argyle B. Helland, Stanley, North Dakota
Lot 6, Sec. 28 Gust Rudolph & Oscar Rudolph, Stanley, North Dakota
Lot 1, Sec. 27 Gust Rudolph & Oscar Rudolph, Stanley, North Dakota

Lot 1, Sec. 34	No record
Lot 2, Sec. 34	No record
Lot 3, Sec. 34	Argyle B. Helland, Stanley, North Dakota
Lot 4, Sec. 34	Argyle B. Helland, Stanley, North Dakota
$NE\frac{1}{4}$, $SE\frac{1}{4}$, Sec. 34	Argyle B. Helland, Stanley, North Dakota
Lot 6, Sec. 34	Argyle B. Helland, Stanley, North Dakota
$SW\frac{1}{4}$, $SW\frac{1}{4}$, Sec. 35	Argyle B. Helland, Stanley, North Dakota
Lot 5, Sec. 34	Mountrail County, Stanley, North Dakota. Deeded to Andrew A Jellesed, Stanley, North Dakota. No record. Deceased.
Lot 2, Sec. 33	Same as above
Lot 1, Sec. 33	Same as above
Lot 3, Sec. 33	Same as above
Lot 4, Sec. 33	H. E. Strobeck & Mary Strobeck, Stanley, North Dakota
Lot 3, Sec. 32	Earl Jellesed, Stanley, North Dakota
Lot 4, Sec. 32	Earl Jellesed, Stanley, North Dakota
Lot 2, Sec. 32	Earl Jellesed, Stanley, North Dakota
Lot 1, Sec. 32	Earl Jellesed, Stanley, North Dakota
Lot 4, Sec. 29	Julius P. Mobraten, Carlisle, Minnesota
Lot 3, Sec. 29	Julius P. Mobraten, Carlisle, Minnesota
Lot 4, Sec. 30	Julius P. Mobraten, Carlisle, Minnesota
Lot 1, Sec. 31	Julius P. Mobraten, Carlisle, Minnesota
Lot 2, Sec. 31	Baard Hollinger, Stanley, North Dakota
Lot 3, Sec. 31	Baard Hollinger, Stanley, North Dakota
Lot 3, Sec. 30	Baard Hollinger, Stanley, North Dakota

Idaho Township - T156N, R91W

Lot 1, Sec. 6	Andrew A. Hellesed, Stanley, North Dakota (deceased)
Lot 2, Sec. 6	Andrew A. Hellesed, Stanley, North Dakota (deceased)
Lot 4, Sec. 5	Andrew A. Hellesed, Stanley, North Dakota (deceased)
Lot 3, Sec. 5	Andrew A. Hellesed, Stanley, North Dakota (deceased)

Saline lakes of no economic importance

Cottonwood Lake

Cottonwood lies in the same northwest trending valley as White lake and is only a short distance from it. It is over three miles in length and is approximately as deep as White Lake, yet it has a low concentration of salts. In fact, it is fresh enough to be used for bathing purposes. The brine analysis shows only 8,532 ppm of dissolved solids as against 94,327 for White lake. The percentage of sodium sulphate is 46 as against 91.49 for White Lake. Although the samples were collected at different times, it is believed that this relationship is a constant one and that it suggests occasional overflow of Cottonwood into White Lake in the past. This question will be dealt with in the section on origin.

Water Analysis

Cottonwood Lake.	(Surface 250 yards southeast of road which bisects lake)
Sample collected	8-21-47
Sample analyzed.	November, 1948
Analyst.	Jack C. Thompson

1. Total dissolved solids.	8,532 P.P.M.
2. Total alkalinity.	1,670
Alk: to Phenol	289
3. Chloride.	531.9
4. Silica.	90
5. Iron and alumina.	18

6.	Calcium	23.65 P.P.M.
7.	Magnesium	20
8.	Sulfate	2,635.13
9.	Sodium	2,397.3
10.	Carbonate	1,002
11.	Bicarbonate	1,092

Hypothetical Combinations (in per cent)

Sodium Sulphate	46
Calcium Carbonate	28.02
Sodium Chloride	10.28
Magnesium Bicarbonate	1.41
Water of hydration, Organic matter, and undetermined residue	14.28

Other saline lakes which are likewise of no economic importance are listed below.

Name	Location		
Unnamed Lake	T158N	R91W	sec. 4 (NE$\frac{1}{4}$)
Unnamed Lake (large)	T157N	R89W	secs. 20, 21, 28, 29, 32, 33
Shell Lake (large)	T155N	R89W	seds. 17, 18, 19, 20
Unnamed Lake	T156N	R90W	sec. 12 (E$\frac{1}{2}$)
Unnamed Lake	T155N	R88W	secs. 24, 25, 26
Clearwater Lake	T157N	R90W	secs. 15, 22

Most of the lakes in Mountrail County south and east of Stanley have not been investigated as yet. One lake lying almost on the eastern county line was visited briefly, however. It showed a strong white fringe and a brine sample was therefore collected and analyzed with the following results.

Brine Analysis

Unnamed Lake	(North shore, surface)
Sample collected	9-2-48
Sample analyzed	November, 1948
Analyst	Jack C. Thompson

1.	Total dissolved solids	44,238 P.P.M.
2.	Total alkalinity	490
	Alk: to Phenol	294
3.	Chloride	928.36
4.	Silica	70
5.	Iron and alumina	130
6.	Calcium	7.22
7.	Magnesium	11
8.	Sulfate	26,220
9.	Sodium (calculated)	13,576
10.	Carbonate	235.2
11.	Hydroxide	98

Hypothetical Combinations (in per cent)

Sodium Sulphate	87.84
Calcium Carbonate	2.05

Sodium Chloride	3.46
Magnesium Carbonate	.09
Water of hydration, Organic matter and undetermined residue	6.56

Ward County

General

This county contains several saline lakes and parts of it should be more carefully studied. A few of these lying in the interior drainage area have been examined briefly.

Lying just a stone's throw from the unnamed lake whose analysis has just been given, Carpenter Lake is genetically related to it though separated by the county line.

Carpenter Lake

This lake was called to the writer's attention by Richard Lemke. It is 1½ miles long by ¼ to ½ mile wide and covers an area of 390 acres. Carpenter Lake is six miles south of U. S. 2. From this junction it is another three miles to the town of Tagus with its railway station. A brine sample was collected and the results of the analysis are pending.

The area was briefly visited in November, 1948, at which time it did not look very promising. As usual, glacial boulders and cobbles were scattered along the sides of the valley. Aerial photos of the basin show a heavy white fringe surrounding this lake and the smaller one lying nearby in Mountrail County.

Recorded Owners of Land, Carpenter Lake

Section 17-SW¼ of NW¼ and NW¼ of SW¼-Herbert F. and Mildred A. Birdsall, Berthold, North Dakota

Section 18-NE¼ of NE¼-Vennie M. Stoops, Ontario, Wisconsin
Lots SW¼ of NE¼; NE¼ of SW¼; SE¼ of SE¼; SW¼ of SW¼, Cont. for deed to Hardie Garness from State of North Dakota, Tagus, North Dakota

Section 19-NE¼ of NE¼; NE¼ of SW¼ and SE¼ of SW¼-Otto Engen, Minot, North Dakota
NW¼ of NE¼ and SW of NE¼-Herbert F. and Mildred A. Birdsall, Berthold, North Dakota
NW¼ of NW¼-Ole Berg, Jr., Tagus, North Dakota

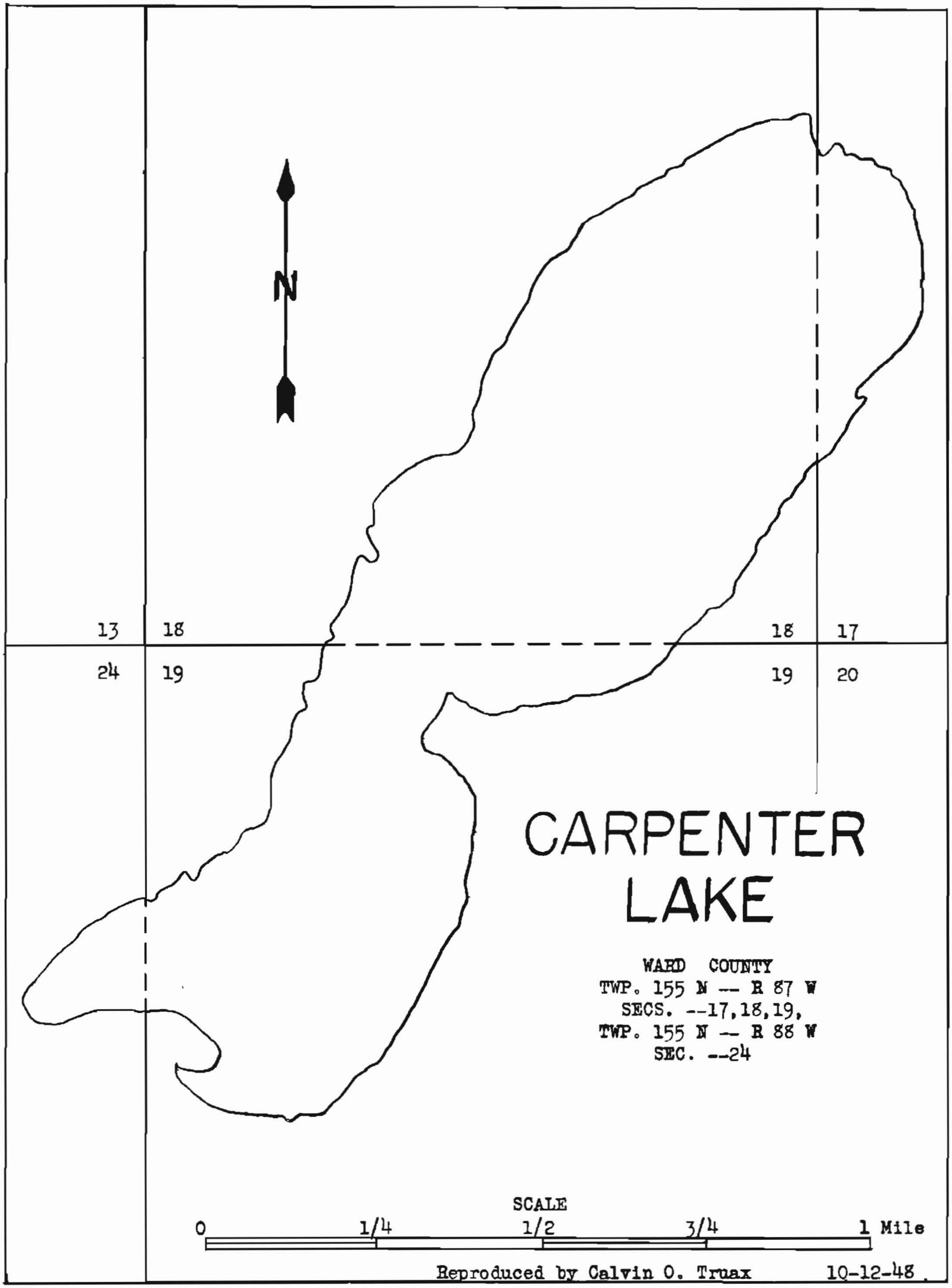
Douglas A

There is one deposit in Ward County which has been known for some time and which was described in the 1934 report as follows:

Deposit #8 "Rice Lake"

"This deposit is situated in Mountrail (incorrect, in Ward) County, sections 26, 27, 34, 35, T152N-R85W. This deposit was examined in December, 1934 by the owner of the land on which the deposit is located. Little is known of this deposit except that it is definitely glauber's salt, occupies an area of approximately 320 acres and has a layer of crystals in places as much as 11 feet in depth"(44)

A glance at the map, however, shows that Rice Lake is located in sections 2, 3 and 10 and that the unnamed lake lying in sections 26, 27, 34, 35 is the one probably referred to. This lake (Douglas A) is one of a group stretching from


N
13
18
18
17
24
19
19
20
CARPENTER
LAKE
WARD COUNTY
TWP. 155 N -- R 87 W
SECS. --17,18,19,
TWP. 155 N -- R 88 W
SEC. --24
SCALE
0
1/4
1/2
3/4
1 Mile
Reproduced by Calvin O. Truax
10-12-48

Rush Lake northwestward to State Highway 53 including more than 15 lakes and swamps. The glacial geology of the area is yet to be worked out but the arcuate alignment strongly suggests an old river valley. Another evidence of an old channel lies in what might be called the "Douglas lobe," a southwestward extension of the so-called "thick" glacial deposits similar to the lobe present at Grenora where the glacial geology has already been mapped and the existence of old channels confirmed.

Sorted material is present in this area at least locally. The west shore of Rice Lake, at the point of nearest approach of the road, is floored by clean sand and gravel. Rice Lake contains fresh water and is used as a bathing resort. Many of the other lakes in this group are strongly saline, however, and the entire region should be carefully examined.

Douglas A is approximately $1\frac{1}{4}$ miles long by about 3/10 of a mile wide and it covers an area of about 350 acres.

As in Stanley A, the northwest corner narrows considerably and comparatively little construction work is necessary to form a good reservoir.

Brine Analysis

Douglas A.	(Surface, east shore)
Sample collected	11-15-48
Sample analyzed.	12-16-48
Analyst.	W. D. Waldschmidt

All results are expressed in parts per million (P.P.M.)

1.	Total dissolved solids.	51,857 P.P.M.
2.	Alkalinity to Phenol.	560
3.	Chloride.	212
4.	Calcium	42
5.	Magnesium	1,102
6.	Sulfate	30,316
7.	Sodium.	12,861
8.	Carbonate	672

Hypothetical Combinations (in per cent)
Percentages are based on total dissolved solids

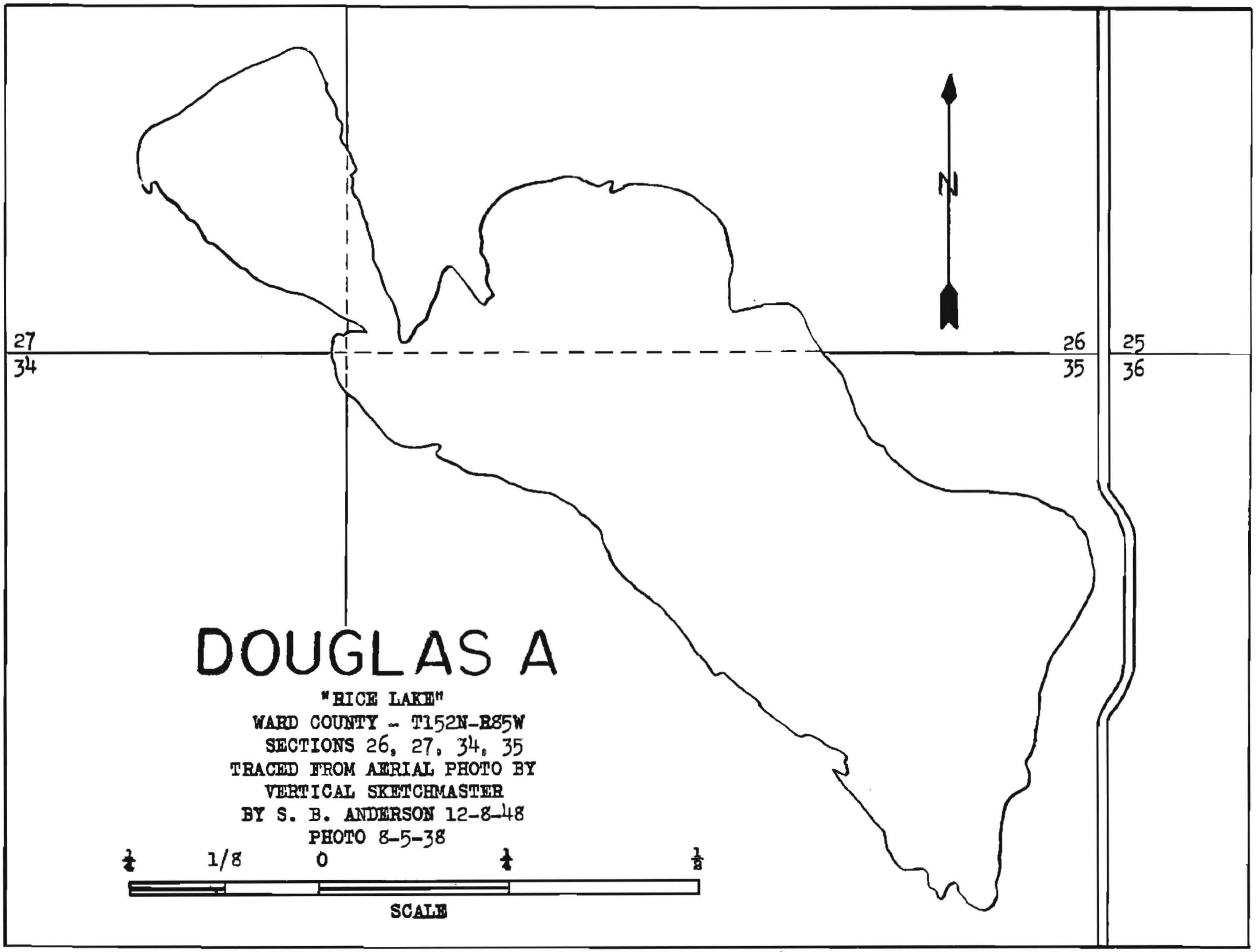
Sodium Sulphate	76.33
Calcium Carbonate	.21
Sodium Chloride	.69
Magnesium Sulfate	8.17
Magnesium Carbonate	1.61
Water of hydration, Organic matter and undetermined residue. . .	12.99

Recorded Owners of Land, Douglas A

Lot 3-John Bergum, Douglas, North Dakota
Lot 1-Waldorf O. Olson, et al - Taxes paid by Louie Olson, Douglas, North Dakota
Lots 4, 5-SE$\frac{1}{4}$-Henry Clement, 3509 Rosemary Avenue, Glendale 8, California

McLean County

No sodium investigations have been undertaken here but summer field work in 1948 by Stanley Fisher and John Manry, in connection with their studies of glacial geology for the North Dakota Geological Survey, uncovered several saline lakes.



N
27
34
26
35
25
36
DOUGLAS A
"RICE LAKE"
WARD COUNTY - T152N-R85W
SECTIONS 26, 27, 34, 35
TRACED FROM AERIAL PHOTO BY
VERTICAL SKETCHMASTER
BY S. B. ANDERSON 12-8-48
PHOTO 8-5-38
¼
1/8
0
¼
½
SCALE

Fisher (45), working in the Turtle Lake area, noted the following:

Blue Lake	T147N	R79W	secs. 16, 17, 20, 21
Pelican Lake	T147N	R78W	secs. 29, 28, 20, 19
Peterson Lake	T147N	R79W	secs. 30, 19
	T147N	R80W	secs. 36, 25, 24
Lake Williams	T147N	R80W	secs. 22, 23, 24, 25, 26, 27, 34, 35
Lake Holmes	T147N	R80W	secs. 21, 28
Lake Brekken	T147N	R80W	secs. 17, 20
Turtle Lake	T147N	R81W	secs. 27, 26, 23, 22
Nelson Lake	T148N	R80W	secs. 33, 34
	T147N	R80W	secs. 3, 4
Unnamed Lake	T147N	R80W	sec. 28
Unnamed Lake	T147N	R80W	sec. 21
Unnamed Lake	T147N	R79W	sec. 30
Unnamed Lake	T147N	R79W	sec. 29
Unnamed Lake	T147N	R81W	sec. 25
Unnamed Lake	T147N	R81W	sec. 22

Little is known about these lakes and field and laboratory work is necessary before it can be determined whether any are economic possibilities. Fisher's (46) notes on these lakes read as follows:

"The above named lakes are the larger lakes having a high alkali content and alkali border. There are several smaller bogs of a similar nature. Three flat areas, no longer actually lakes but possessing alkali, are to be found in T147N, R80W, sec. 25; T147N, R81W, sec. 2; and T148N, R81W, sec. 23.

"Lakes have alkali borders from 5-150 yards in width, through most do not extend beyond 50 yards. This border may consist of a 'terrace' gravel or may be composed chiefly of a thick, plastic, gray clay with no pebbles. Even the terrace gravels are sometimes encrusted with salts making them appear a solid white mass.

"In most places the clay is approximately 2-3 feet thick and is underlain by gravels. Water usually fills the holes at depth of 2-5 feet. The salts are crystalline or powdery but form a layer of about $\frac{1}{4}$ inch. They always react to acid and according to the local druggist (who once shipped samples to Grand Forks for analysis) the chief salt is Glauber's salt.

"These lakes vary in extent. Water-rotted fence posts show that Lake Brekken was recently 18 inches - higher than at present. Also, the northern arm of Pelican Lake has retreated recently at least $\frac{1}{4}$ mile, the exposed area being too muddy to allow approach to the water. Boulders up to 1 foot + in diameter are found. These are as smooth and rounded as cannonballs.

"Some of the lakes, usually those with more irregular outlines, are bedded completely by till."

Fisher also began work on the Coleharbor quadrangle (due west of Turtle Lake). In this area he lists the following lakes as being saline:

Name	Location	Size and Description
Unnamed Lake	Sec. 35, T148N, R83W	1/16 square mile
Crooked Lake	Sec. 20, T148N, R81W	1/3 square mile
Unnamed Lake	Sec. 28, 29, T148N, R81W	-1/8 square mile

Name	Location	Size and Location
Mud Lake	Sec. 32, T148N, R82W	+1/2 square mile. Shallow; water salty and milky; gray alkaline clay border 25± yards wide on northeast side, up to 200 yards wide opposite main body of lake (both sides). Clay to depth of at least 3 feet; boulders and gravel underlying clay in places.
Lake Nettie	Sec, 28, 29, 20, 21, T148N, R81W	3/4 square mile. White salts on surface at least 1/2 mile on either side of small lake south of Nettie. Salts extend north past school to Crooked Lake. Also some alkali ponds in Snake Creek near Sec. 7 and 13, T148N, R82W.

The salt crust forms crystalline powders 1/4 inch thick. They are underlain by medium- to light-gray colored salt-clays which are very plastic.

A brief study of a few lakes in this area in September, 1948 yielded the following information:

Name	Location	Size and Location
Unnamed Lake	Sec. 8, T147N, R82W	Both lakes are small but show a strong white fringe.
Unnamed Lake	Sec. 17, T147N, R82W	They lie in a valley which extends north to Mud Lake.
Mud Lake	Sec. 32, T148N, R82W	Does not appear promising No <u>Salicornia</u> sp. Scattered white patches of salts about 2 inches deep, roughly 50 feet from lake. Water sample collected. Analysis pending. Faint white precipitate left on jar.
Lake Nettie	Sec. 20, 21, 23, 29 T148N, R81W	Does not look promising. One water sample collected. Analysis pending. Thin white fringe along shore but water quite fresh, if judged by the flora and fauna alone.
Unnamed Lake	Secs. 29, 30, T148N, R81W	White precipitate on plants near shore. Water sample taken. Analysis pending. White fringe stronger on north shore. Moderately strong white precipitate on container. Red algae in water. Does not appear promising.

Name	Location	Size and Location
Small (unnamed) Lake		About 500 feet south of above. Only slightly saline.
Crooked Lake	Secs. 19, 20, T148N, R81W	Only a thin fringe of "alkali". Water sample collected. Analysis completed (see below). Not promising although white film left on container.
Unnamed Lake	Sec. 13, T148N, R82W	North shore, which is swampy, shows strong white border sides above slough but not much near water. May be strongly saline but too small.
Unnamed Lake (not mentioned by Fisher)	Section 14, T148N, R83W	Small, but shows a very wide fringe of salts.
Unnamed Lake	Secs. 34, 35, T148N, R83W	Showing of white in west side near road. Too small. Not promising.

Manry (47), working in the Washburn area, reported one "alkali" lake in T145N, R82W, Sec. 10, SW¼. Examination showed that it was only faintly saline and it is not likely to be of any commercial importance.

Showings of "alkali" were observed northwest of the town of Falkirk (in Washburn quadrangle) and this area, too, should be prospected more carefully.

Brine Analysis

Crooked Lake. . . . . (Surface, northwest shore)
Sample collected. 8-6-48
Sample analyzed 11-8-48
Analyst . . . . W. D. Waldschmidt
All results expressed in parts per million (P.P.M.)

1.	Total dissolved solids . .	13,973 P.P.M.
2.	Alkalinity to Phenol . . .	150
3.	Chloride	613
4.	Calcium.	20
5.	Magnesium.	2,037
6.	Sulfate.	8,380
7.	Sodium	652
8.	Carbonate.	180

Hypothetical Combinations (in per cent)

Sodium Sulphate.	5.65
Calcium Carbonate.	.37
Sodium Chloride.	2.32
Magnesium Sulfate.	46.74
Magnesium Carbonate. . . .	1.47
Water of hydration, Organic matter, and undetermined residue.	43.45

Biota

Fauna

In 1934, Dr. George Wheeler of the University Biology Department obtained some microcrustaces from Miller Lake. These were forwarded to the United States National Museum (Smithsonian Institution) and identified by Dr. E. F. Creaser as Artemia salina (L). These shrimp-like animals are found in tremendous numbers in a few lakes in North Dakota and adjacent regions. In Saskatchewan, likewise, are found ". . . minute shrimp-like animals which swarm the sulfate lakes in millions."(48) These phyllopods have been described as follows:

> "I. Artemia Leath.--Post genital region with 8 segments: I species.
> A. salina (L).--Length 10mm; body semi-transparent, red, pink or greenish; found only in salty waters and exceedingly variable, this variability being dependent upon the concentration and the chemical nature of the salts in solution: Utah, California, Connecticut."(49)

Russell, speaking of the Soda Lakes near Ragtown, Nevada, says the following about one of these lakes of the Lahontan basin.

> "The bottom, as shown by the samples obtained by the cup at the end of our sounding lead, is a fine tenacious black mud having a strong odor of sulphurated hydrogen. . . . . The organic matter impregnating these sediments is evidently derived from the millions of brine shrimps (Artemia gracilis) and the larvae of black flies that swarm in the dense alkaline waters." (50)

A fine dark mud, having a pungent odor, underlies all the North Dakota deposits thus far examined by the writer. Sometimes, black flies, similar to those mentioned by Russell, are also present during the summer. They rest near the shores in prodigious numbers.

Grabau records the occurrence of Artemia in the salt pans of the Nile Delta. "Walther found few living organisms in the salt water of the Mexican salt pan. Artemia, a small salt water crustacean, formed small red spots in the water, and another small red crustacean, about 4 mm. long, was crawling along the bottom. Artemia was found by Walther in such abundanse in the salt pans near Suez that the water looked like it was diluted blood, while beneath a bed of white salt, 5 mm. in thickness, he found a salt bed colored red by the abundant enclosure of this crustacean."(51) In the same volume, Grabau, this time speaking of the organic remains in the Karabugas Basin on the east side of the Caspian Sea, notes the following: "Living in the waters at the present time are great numbers of the brine crustacean Artemia and several algae."(52)

Both red and green algae occur in the bitter lakes of North Dakota. The green algae at least also occur in relatively fresh adjacent lakes, however.

This fauna apparently represents an ecological adaptation to a saline environment and is the result, not the cause, of the salt brines. The role that these organisms might possibly play in the further concentration of the salts after formation, however, might well be investigated.

Flora

Near many of the lakes in northwest North Dakota, the characteristic flora of the prairie gives way to a border of fox-tails. In the saline lakes these in turn are bordered by (and frequently entirely displaced by) an inner fringe of what is believed to be the distinctive halophytic plant commonly called the Glasswort. Rydberg has described this plant as follows:

SALICORNIA
(Tourn.) L. Glasswort, Samphire

"Annual or perennial, fleshy, glabrous herbs with scale-like leaves; branches and leaves opposite; internodes very short. Flowers perfect or polygamous, in cylindric spikes, sunk in cavities of the internodes, 3-7 together. Calyx fleshy, with a truncate or 3-4 toothed border. Stamens 2, rarely 1; filaments filiform or subulate. Utricle oblong or ovoid, included in the spongy perianth. Seeds erect; endosperm wanting; embryo conduplicate.

"1. S. rubra A. Nels. Stem erect, divaricately branched throughout, 1-2 cm. high; scale-like leaves short, broadly triangular, wider than long; fruited spikes 2-4 cm. long; internodes very short, scarcely exceeding the middle flower of the nodes below. Border of alkaline lakes: Sask.--Kans.--Colo.--Nev.--B.C. Plain. Au. S."(53)

Sahinen, in his brief study of the deposits in eastern Montana, noted that the vegetation changed from common grasses at the high water line to a low fern-like plant of a reddish brown color which was found to be characteristic of these soda-like bottoms. Cole pictures a mud flat showing a dry lake bed covered by white salts with "salt plants" resembling Salicornia.

Grabau includes Salicornia in his discussion of the concentration of salts by plants and makes the following remarks: "Another soda-secreting plant is the glasswort or marsh-samphire of the genus Salicornia, a succulent saline plant of the same family, with leafless jointed stems, which store a large proportion of soda. This also was formerly used for making soda ash or barilla for the manufacture of glass and soap. The genus has 8 species, all native of marshes or saline soils throughout the world, three of them occuring on the Atlantic and Pacific coasts of North America, and one in the alkaline places of the interior.

"Sodium is also taken by salt plants from the soil where it originated from the decomposition of soda minerals of igneous rocks. This may occur in regions far removed from the sea. One of the best known examples is that of the salt plants growing on the steppes and upon the plains of the Araxes in Armenia. Where the soil is rich in sodium sulphate, that salt is taken up by the plants; but where the principal salt in the soil is sodium chloride this is converted into carbonate and as such stored by the plants in their tissues. By the growth and decay of these plants, an annual enrichment of the upper layers of the soil in these concentrated salts is effected, and the leaching of this soil and the further concentration of the leachings in basins, where the waters are constantly subject to evaporation, results in the formation of salt lakes with very strong brines."(54)

Geology and Origin

A certain amount of general information on the geology of North Dakota deposits has been available since 1934. In addition, the United States Geological Survey (including both the Geologic Division and the Topographic Division) inititated an extensive mapping program in 1946 in connection with the Missouri Basin Development Program. A great deal of information on selected areas in Montana and North Dakota was obtained, some of it in areas containing known or new saline lakes. Some questions on the origin of the salt deposit still remain to be answered, however.

As Witkind(55) has pointed out, the origin of the sodium sulphate involves two problems:

1. Source Material--The geochemistry of the original form or forms in which the sodium and the sulphate "originally" existed in the parent material, and the reactions by which the combination was effected.

2. Physiography--The geomorphic conditions which facilitated solution, transportation, and deposition.

Source Material

With regard to the source of the salts, authorities in different areas have argued for either the underlying bedrock or the overlying mantle as the parent material. L. Heber Cole's summary of the different theories is singularly relavant because of the continuity of the Canadian and North Dakota deposits.

"Deposits of a very similar nature occur in other countries and many theories have from time to time been advanced as to their origin. For example, during the latter part of the 19th century it was commonly advocated that all of the alkali of the arid portions of the Western States had been formed by the decomposition of granitic rocks. It was supposed that, by decomposition of the feldspars of the granites, the alkali was changed into soluble compounds and washed into the natural depressions. Ricketts after making a study of the alkali lakes occuring in Wyoming, which appear to resemble most closely the deposits of western Canada, gave special attention to the spring theory of origin of these deposits. . .

"Knight, who made a further extensive examination of these same deposits, could not reconcile the data he gathered with the spring theory of Rickett just cited. In his opinion the alkalis were derived from the soils and the strata which surrounded the deposits and drain into them. . .

"Arnold and Johnson consider that the sodium sulfate deposited in the lowest depressions of the Carrizo plain, San Luis Obispo County, California, is being derived from the leaching out by the solvent action of rain and consequent running water, the soluble salts which occur in the large areas of soft conglomerates, sandstones, and shales, chiefly of Tertiary age, which are found in the bordering mountains.

"In the Russian or Siberian lakes, in Yeniseisk, the sodium sulfate is thought to have been primarily derived from the decompositon of igneous rocks. Connate salts and older salt beds may, however, according to Grabau, produce a part of the salinity.

"Wells sums up his ideas as to the origin of the natural sodium sulfate deposits as follows:

"The origin of sodium sulfate in certain deposits and saline lakes is easily explained. In tunnels, caves, and covered spots in recent lavas, such as those on the island of Hawaii, white coatings, powders, and efflorescences consisting largely of calcium and sodium sulfates are frequently observed. Rain water dissolves these coatings where it has access to them. This shows that basalts and lavas may furnish sodium sulfate to drainage systems. Moreover, granite and other igneous rocks are rarely free from pyrite and other sulfides. The sulfides on exposure are oxidized to sulphuric acid, which immediately dissolves some of the basic oxides, producing soluble sulfates. . . .

"Owing to the fact that soils consist largely of decomposed rock, sodium sulfate is a natural minor constituent of soils but one which is almost entirely removed by leaching where rainfall and drainage are normal. In the more arid regions, however, it accumulates and is called white alkali, as previously mentioned. Glauber's salt is a common constituent of efflorescences on clays in dry regions."(56)

Cole doubted that the underlying strata could be the source because "they are all stratified and hence were laid down in running water so that it is hard to conceive of soluble salts remaining in such deposits during the whole time of their deposition without being leached out and carried off by natural drainage to the sea".(57) He does concede, however, that concentration could take place if the drainage was blocked.

That the Fort Union formation in western North Dakota might provide the necessary constituents is shown by the following summary.

According to Abbott and Voedisch, "Waters from the Fort Union show wide variations in quality, but are usually fairly high in mineral content. With respect to solids, only 5.3 per cent contain less than 500 parts, 22.3 per cent contain from 500 to 1000 parts, 31.9 per cent from 1000 to 1500 parts, and 40.4 per cent exceed 1500 parts per million.

"In hardness the waters resemble those from the Pierre shale: 14.9 per cent contain less than 100 parts, 59.6 per cent from 100 to 500 parts, and 25.5 per cent contain over 500 parts per million. Iron content varies between wide limits even from wells of the same depths and in the same regions. Of the samples, 25.5 per cent contain less than 0.3 part, 36.2 per cent contain from 0.3 to 1.0 part, and 38.3 per cent exceed 1.0 part per million."(58)

Per cent composition of typical water from the Fort Union formation is given below: (Halliday - Dunn County)

Sulphate	29.481	Zinc	0.138
Sodium	26.105	Iron	0.041
Carbonate	24.938	Silica	2.071
Chloride	7.457	Alumina	0.697
Nitrate	0.614	Magnesium	3.404
Fluoride	0.083	Calcium	4.964
Manganese	0.007		

The following data on water analyses (Table 7) from the Fort Union in areas somewhat closer to the deposits were obtained from Mr. George LaRoque of the United States Geological Survey office in Bismarck. The figures, which show significant amounts of sodium and sulfate are presented together with water from the overlying glacial till for purposes of comparison.

Table 7. Analyses of Typical Fort Union and Glacial Till Waters

Source	Bedrock	Bedrock	Bedrock	Bedrock	Bedrock	Bedrock	Bedrock	Bedrock	Bedrock	Till	Till	Till
Location*	162-95-5dc	163-96-13da	163-97-31bc	163-98-17aa	161-89-35dc	162-89-35dc	163-88-28dd	163-93-29dd	160-87-24	163-97-13cc	163-97-35ba	163-88-24bb
County	Divide	Divide	Divide	Divide	Burke	Burke	Burke	Burke	Ward	Divide	Divide	Divide
Date of Collection	6-4-47	6-4-47	6-4-47	5-2-47	6-6-47	6-6-47	6-5-47	6-4-47	8-9-47	6-6-47	6-4-47	6-12-47
Depth(Feet)		101			237		200	80	280	459	275	440
Temperature (°F)	47	50	49½		50	50	50	48	46	47½	49	50
pH	8.8	8.6		9.2	8.3	8.0	9.0	8.3	8.7	7.7	8.1	8.5
Silica(SiO_2)	11	8.0	9.1	7.6	14	20	11	27	8.0	30	26	23
Iron(Fe)	.05	.05	.05	.05	x0.27	.1	.05	Trace	.72	Trace	.05	.05
Calcium(Ca)	14	59	10	10	8.5	235	18	89	3.2	116	76	423
Magnesium(Mg)	3.3	38	3.1	2.0	5.0	54	21	43	3.0	39	41	307
Sodium(Na)	911	729	796	586	763	400	802	517	682	155	154	245
Potassium(K)	13	11	6.0	9.6	2.4	18	7.2	10	14	0	11	23
Bicarbonate (HCO_3)	1450	854	1710	916	1010	500	1180	945	1410	809	745	375
Sulfate(SO_4)	784	1080	2.9	518	814	1170	758	653	6.0	23	18	1110
Chloride(Cl)	44	48	258	16	36	16	38	60	250	63	47	299
Fluoride(F)	2.0	1.6	1.2	.4	1.4	.4	1.2	.4	2.0	.5	.5	.4
Nitrate(NO_3)	.25	1.0	1.0	7.5	1.8	1.5	1.5	2.5	4.5	1.2	7.5	1180
Boron(B)	.14	.46	1.23	.51		.54	.52	.46		.32	.64	.23
Dissolved Solids	2510	2400	1940	1610	2150	2160	2230	1880	1670	874	810	3800
Hardness as $CaCO_3$ Total	48	303	38	33	42	808	58	399	20	450	358	2320
Hardness as $CaCO_3$ Noncarbonate	0	0	0	0	0	398	0	0	0	0	0	2010
Percent Sodium	97	83	97	97	97	51	96	73	97	43	47	18

*Letters represent quarters as follows:
Figure shows location of "dc".

b	a
c	d

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These figures are fairly typical although local variations, which are more marked in the till water exist.

Sahinen reports that the Montana deposits could also have been derived by solution from the underlying Fort Union formation, as an analysis of the sandy shales of that formation near Plentywood showed over one per cent sodium sulfate present. In Chouteau County, however, no glacial drift is present. Here the deposits lie in an area of Colorado shale. One half mile south of Highwood, in a small tributary coulee of Highwood Creek, is a bluff of massive sandstone overlying black shale. This sandstone shows a great deal of efflorescent sulfate salts of sodium, magnesium and calcium and the creek water below the bluff also contains much sulfate. Efflorescent crusts in the bottoms of the Shonkin sag one mile east of Highwood also showed over 50% and the underlying black muck over three per cent sodium sulfate as well as some calcium sulfate. Sahinen suggests this information may possibly be the source of the Chouteau County deposits.

Efflorescent salts on Fort Union outcrops were noticed as far back as 1805. Little has been done as yet in the way of analyses of these crusts but it is known that they contain mixtures of sodium sulfate with other salts. The occurrence of the relatively pure beds of sodium sulfate therefore would appear to be more a problem of segregation and concentration than "origin". LaRoque, on the basis of his ground water studies, holds that the bedrock is the source of the North Dakota sodium sulfate. Other geologists (59) who have recently studied this area believe that the Fort Union formation is the source (at least in part) of the salts. According to one tentative hypothesis (60), subsurface Fort Union water high in sodium bicarbonate mingles with glacial till water rich in calcium and magnesium sulphate. The resulting exchange yields sodium sulfate. The relatively insoluble calcium carbonate and magnesium carbonate should precipitate first, thus furnishing the necessary segregation.

Several summers of field work by members of the United States Geological Survey have resulted in the accumulation of evidence suggesting a "bedrock high" in the general area in which the deposits lie. This rise in the underlying bedrock in the vicinity of the bitter lakes appears to have been the controlling feature in forming the Missouri Coteau and tends to strengthen the theory of bedrock origin.

On the other hand, some evidence favors the glacial till as the source of at least the sodium if not also the acid radical. The water analyses already mentioned show that some sodium and sulfate are present in the glacial till as well as in the bedrock. The physiographic evidence is likewise suggestive.

Geomorphology

Most of the deposits occur in the form of "chains" of shallow basins which occupy former valleys. These are now "lows" in the bedrock. It is difficult to see how salts derived from the Fort Union should be found in some cases in these linear areas in which the Fort Union is topographically deep. It has been pointed out, however, that bedrock water may drain laterally into these sags through a thin till.

Another hypothesis suggested in explanation of the above involves large buried ice blocks which were left behind in the till when the glaciers withdrew. There is little doubt that many of the steep lake basins were formed in this way. Sidney T. Harding, in his discussion of lakes resulting from glacial action, lists as his first type:

"1. Pits resulting from the melting of buried ice blocks that were embedded in glacial debris. Such lakes generally have steep sides."(61) To which we may add, or once had steep sides. The FERA map of Grenora #2 (62) which shows the depth of the glauber salt reserves also shows the approximate outline of the former buried ice block. The isopach lines (lines of equal thickness) show a drop from 20 feet to 70 feet in a short distance. This "basin within a basin" is elongated in a north-south direction, a feature which appears to substantiate the existence of buried channels. The steep depressions in some of the other lakes, however, are roughly circular or irregular, with no marked linearity. Miller Lake, for example, shows a sub-circular or oval form for its steep interior. Stanley #2 is even more irregular. At any rate, the essential thing is that these depressions formerly extended down to, or very close to, the bedrock. This would make possible a transfer of the bedrock sodium sulfate to the lake through local openings in the thin layer of till lining the floor of the basin. It is known that sand and gravel containing water under hydrostatic head underlie the till beneath some of the lakes. The resulting springs around the strongly saline lakes are held to be the agents carrying the salts from the Fort Union to the lake basin.

In explaining the distribution of fresh and saline lakes, two kinds of valleys have been noted (63). One has a layer of sand and gravel along its length, the other is a similar valley which has been subsequently buried by a later till. If this second type of valley is drilled, a layer of sand and gravel will be found beneath the till. It is within this buried channel that most of the chemical reactions are believed to have taken place. Lakes without till linings are held to be fresh because sub-surface drainage results in loss of dissolved salts. This explanation has not yet been tested by drilling.

The Canadian workers have cast some doubts on the role of the springs as transporting agents. It is true that several North Dakota springs sampled in 1934 (64) showed the presence of dissolved solids to the extent of several thousand parts per million.

An analysis of the water from a spring at Stanley A also showed only slightly less than 2000 ppm of dissolved solids of which about 49% was sodium sulfate. In none of these, however, was any account taken of the possible contamination of the springs due to movement through the permanent bed. In the examination of some of the Saskatchewan deposits, pipes were inserted through the deposit to tap the springs below the surface and it was then shown that "in some cases, the spring water is quite fresh and free from appreciable quantities of alkaline salts."(65)

Words like "fresh" and "appreciable" are far from exact, however. Inasmuch as the springs do contain small quantities of dissolved salts (even before contamination), they may be quite capable of furnishing the required amount, or a part of the total amount known to be present, if given a sufficient length of time.

Field work has confirmed the fact that the saline lakes are floored by till and that these tight bottoms serve to prevent the loss of water and dissolved salts. Also well known is the presence of numerous perched lakes. Many adjacent lakes rise and fall independently of each other, indicating local, perched ground water tables. Mr. Carter, Ranger on the Lostwood Wildlife Refuge, reports that the level of Lower Lostwood Lake (saline) rose approximately $1\frac{1}{2}$ feet during the summer of 1947 but that Upper Lostwood Lake (also saline) did not rise at all. Nearby Thompson Lake (comparatively fresh) also rose about $1\frac{1}{2}$ feet at this time. Even more striking is the case of a small perched kettle lake which is only about 60 feet away from Thompson Lake and yet lies nearby 60 feet above it.

It is not necessary, however, to postulate that all the fresh lakes occuring in the "alkali" areas have pervious floors and owe their low salinity to subsurface drainage. Several of the fresh lakes in northwestern North Dakota show evidence of a former connection with nearby salt lakes. There is little doubt that some of these lakes are fresh because they have contributed their salts to the adjacent deposits by overflow. The following facts may be cited in support of this view:

1. Most cases of closely contiguous saline and fresh water lakes thus far studied by the writer show that the saline lake level is topographically lower than the fresh one.
2. Some form of connecting spillway is frequently present. Most of the lakes studied in North Dakota show this feature. Even in northeastern Montana these relationships are strikingly shown in the Brush Lake quadrangle. The topographic map shows not only that the surface level of Brush Lake (fresh) is 5 feet higher than the saline slough lying to the southeast, but also reveals a pronounced swale connecting the two. The same map reveals a similar situation in the Horseshoe Lake area. Here the "Twin Lakes", a chain of partly saline lakes near the Montana border, have a lower salinity than nearby Horseshoe Lake. The following is believed to be a typical analysis from the northernmost lake of this group.

Water Analysis

Three Mile Lake (Twin Lakes). . . . (T159N, R163W, Secs. 8, 9, 16)	(northwest shore, surface at northernmost lake)
Sample collected.	9-15-48
Sample analyzed	10-28-48
Analyst	W. D. Waldschmidt

All results expressed in parts per million (P.P.M.)

1.	Total dissolved solids	19,565 P.P.M.
2.	Total alkalinity	3,190
	Alk: to Phenol.	820
3.	Chloride	593
4.	Calcium.	46,092
5.	Magnesium.	68,395
6.	Sulphate	9,549
7.	Sodium	5,307
8.	Carbonate.	744

Hypothetical Combinations (in per cent)
Percentages are based on total dissolved solids

Sodium Sulphate.	71.89
Calcium Carbonate.	.68
Sodium Chloride.	4.99
Magnesium Carbonate.	1.39
Sodium Carbonate	4.39
Water of hydration, Organic matter and undetermined residue.	16.66

The map shows that the level of Twin Lakes is 1968 feet and that of Horseshoe Lake 1964 feet. The contours likewise show a pronounced linear low, still occupied by a few small water bodies, connecting Twin and Horseshoe Lakes.
3. Under these conditions all that is needed for a more integrated drainage is a more humid climate or at least a succession of wet years. That the latter has occured in North Dakota in the recent past has been demonstrated by Will.(66)

Will's tree ring data goes back 540 years which is only a very short period of time when compared to the interval since the end of the Pleistocene. It does, however, provide factual evidence of recurrent periods of humidity which might well lead to basin filling and overflow.

Basin integration may be prevented by topographic obstacles. Stink Lake, which is close to the Twin Lakes, is strongly saline because free exchange of water and dissolved salts is prevented by a high ridge.

CONCLUSIONS

It may be concluded that some of the fresh lakes have been slowly accumulating dissolved salts but that during cycles of excessive rainfall a more integrated drainage is temporarily established and the salts from one lake are lost by overflow to a nearby basin which is topographically lower. These lower basins need not be of the steep-walled, ice-block type, although it is true that the deepest and richest deposits belong here. Some of the shallower deposits have resulted from inequalities in ground moraine. These are shallow with gentle slopes. White Lake and Stanley #2 are of this type.

The hypothesis of acceleration of salt concentration by temporary basin integration serves to explain the distribution of some of the deposits. Drilling is necessary before it can be determined to what extent "sub-surface leakage" has operated. The two hypotheses are not mutually exclusive. In all probability no one theory will be found to hold true for all the deposits. The same may be said for the ice-block versus the shallow lake discussion. For reasons not yet clearly understood, the steep bottom deposits are prominent in the west, near Grenora, but are scarce or missing to the east, near Stanley. At any rate, there is no doubt that both types of "saline lakes" exist.(67)

RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

There is little that can be added to the bedrock versus mantle origin controversy. Several desirable lines of investigation must be followed further if the complete answer is to be found. Among these may be mentioned:

1. Chemical analyses of leached and unleached bedrock in key areas.
2. Large numbers of chemical analyses of the glacial deposits overlying the Fort Union. Geochemical "traverses" in horizontal and vertical directions must be undertaken.
3. More detailed water studies to determine the movement of surface and subsurface water and the position of the ground water table.
4. Studies of the bedrock and of the glacial debris by microscopic, differential thermal and x-ray analysis to discover the minerals (especially the clay minerals) present. Among other things, this should serve to demonstrate whether or not any bentonite is present. It may be recalled that Cole ascribes the sodium to the bentonite which is widespread in the clays of Saskatchewan. In addition the lignite, pyrite and gypsum must be studied. Either or both of the two latter may have furnished the sulfate radical. The limonite concretions may or may not be one of the residual end products of the oxidation of the Fort Union pyrite.
5. Geologic mapping similar to that done at Dagmar, Zahl, and Kermit should be extended to areas lying to the southeast. The lakes near Stanley for example, differ in chemical proportions and in other respects from those at Grenora and Alkabo and their relations should be studied more carefully.
6. Detailed limnological studies, including among other things, variations in specific gravity, temperature and salinity of the lakes. More important, studies of the flora and fauna are necessary before the possible role that organisms like Salicornia have played in the alteration, transportation or concentration of the salts can be determined.
7. Stratigraphic studies of the various members of the Fort Union. Little is known about the attitude of the beds and much remains to be done on the vertical and lateral variations in lithology, texture, permeability and leaching, to mention but a few.

8. Regional studies of the glacial geology and the pre-glacial and inter-glacial drainage changes. Some of this work is now being done by Arthur Howard of the United States Geological Survey.

This study has embraced only a small part of the large area known to contain saline lakes. It is also true that only a beginning has been made on the necessary laboratory investigations. Analysis of the brine samples are being continued and a start has been made on the microscopic study of the sulfate minerals.

It appears that the United States Bureau of Mines will undertake reconnaissance drilling of the possible deposits early in 1949. It is planned to summarize the more important results of this continued research and the drilling in a joint work to be published by the Bureau of Mines. The section on technology and on the drilling will be written by Dr. Tullis, the section on geology by the writer. This cooperative program will undoubtedly shed more light on the reserves and on the origin of the sodium sulfate deposits of North Dakota.

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63. Personal communication (Irving J. Witkind).

64. *op. cit.* (FERA report, Lavine and others), p. 11.

65. *op. cit.* (The natural resources of Saskatchewan). p. 58.

66. Will, George F., Tree ring studies in North Dakota: North Dakota Ag. Exp. Sta., North Dakota Ag. Coll., Bull. 338, pp. 20-22, 1946.

67. Commonly called "alkali lakes" in North Dakota. Properly speaking, "bitter lakes" are rich in sulfates, "alkali lakes" are high in carbonates.