Frontispiece

Negatives on file Mineral Resources Division

Group of mirabilite crystals from Snakehole lake, Sask. From tip to tip, 24 inches.

CANADA
DEPARTMENT OF MINES
Hon. R. B. Bennett, Acting Minister; Charles Camsell, Deputy Minister

MINES BRANCH
John McLeish, Director

Sodium Sulphate of Western Canada

OCCURRENCE, USES, AND TECHNOLOGY

BY

L. Heber Cole

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
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SODIUM SULPHATE OF WESTERN CANADA

INTRODUCTORY

The search for potash during the years of the Great War, led to the staking of claims on many of the "alkali lakes" and sloughs which occur in numerous localities in the morainic areas of the prairies, as well as in British Columbia, in the hope that potash or other valuable salts would be found in commercial quantities. Although the search for potash, up to the present, has been disappointing, the prospecting of these areas has demonstrated that Canada possesses large reserves of sodium compounds, principally in the form of sulphates, carbonates, and chlorides.

The Department of Mines first became interested in these deposits in 1911 while investigating the sodium chloride springs of northern Manitoba. In the fall of that year a number of the sulphate occurrences in Saskatchewan and Alberta were visited, but owing to the excessive rains, the deposits were under water, and only a few brines were obtained. Owing to pressure of other work, the investigation of the alkali deposits of western Canada could not be undertaken by the Mines Branch until the field season of 1921, but since that time the work has been continuous.

During the summer of 1918 the discovery of a large deposit of potash-bearing salts was reported and featured in western newspapers, and in a short time all the lakes and sloughs of the Prairie Provinces, which showed the least indication of being saline, were staked. The discovery was not substantiated on investigation and many who had staked or leased claims allowed them to lapse without the slightest effort to determine the character of the material in the deposits which they had leased.

Those, however, who kept their leases in good standing found on examination that, although there were no commercial occurrences of potash in the majority of the deposits, large quantities of Glauber's salt are present in the lake beds.

The investigation of these deposits by the Mines Branch, Department of Mines, has been conducted in the field during the past four years (1921–1924), and has furnished a large amount of valuable information. Numerous samples have been collected and analysed in the Departmental laboratories. Considerable data have been collected and compiled.

In an investigation of this nature it can readily be seen that it was impossible to make a detailed examination of all the already known deposits. Typical deposits were therefore selected in the hope that the results obtained from their careful study would be applicable to the majority of the occurrences. The data collected have fully justified this assumption, since there is a striking similarity in all those examined; the differences observed in most cases are in minor details only and are easily accounted for by local conditions.

The detailed examination was conducted on 21 different deposits, and it is hoped that the information obtained from them will be of assistance not only as applied to these deposits, but to the many others which are known to occur throughout western Canada.

Acknowledgments

The writer wishes to extend his hearty thanks to a number of gentlemen for their kindly services in supplying information and data relative to the subject of this report; especially to Mr. N. H. Gellert, Vice-president of Salts and Chemicals Ltd., and to Mr. Allison Bishopric of the Bishopric and Lent Co., as well as to a number of others associated with these and other companies; to Mr. E. T. Sterne of G. F. Sterne & Son, Chemical Engineers, of Brantford, Ont., for many helpful suggestions; to Mr. T. M. Molloy, Commissioner of Labour and Industries of the Saskatchewan Government, for many courtesies; and to many others.

Frank MacNiven acted as assistant during the seasons of 1921 and 1922, and in the summer of 1923 H. A. Leverin and M. F. Goudge each had charge of drilling-parties under the supervision of the writer. During the months of February and March of 1924 winter drilling was carried on at Muskiki by a party under the charge of M. F. Goudge, and during the summer field season of the same year both drills were operated under his direction. All these gentlemen performed their work in a satisfactory manner.

The data for the chapter included in this report on the chemistry of sodium sulphate have been compiled by H. A. Leverin. M. F. Goudge has acted as assistant in the office for the past two years. Much of the detailed descriptions of the deposits drilled by his party have been compiled by him.

Ottawa, September 10, 1925.

CHAPTER I

HISTORICAL

The element sodium finds a wide distribution in nature, and according to Clarke[1] it forms about 2·63 per cent of known terrestrial matter and is the most abundant of the alkali metals.

Sodium occurs in nature principally in combination with other elements, and its occurrence as the sulphate is the subject of this report.

Sodium compounds are used in many industries, and, with few exceptions, are manufactured products. The salts occurring naturally are generally impure and have in most cases to be refined before use.

The following table, after Wells[2], gives the trade names of a number of the commoner compounds of sodium, together with their formulæ and chemical names.[3]

TABLE I

Trade Names and Formulæ of Sodium Compounds

Trade name[4]	Formula	Composition per cent	Chemical name
Soda ash	Na_2CO_3	98 to 100 Na_2CO_3	Sodium carbonate.
Sodium sesquicarbonate	$Na_2CO_3NaHCO_3$ $2H_2O$	47Na_2CO_3 37$NaHCO_3$	Hydrated sodium, carbonate-sodium bicarbonate (*Trona*).
Sal soda, washing soda, Crystal carbonate.	Na_2CO_3 $10H_2O$	37·1 Na_2CO_3	Hydrated sodium carbonate (*Natron*).
Bicarbonate of soda, baking soda, saleratus.	$NaHCO_3$	99·5 to 99·7 $NaHCO_3$.	Sodium bicarbonate or sodium acid carbonate.
Caustic soda	$NaOH$	75 to 99 $NaOH$	Sodium hydroxide.
Borax	$Na_2B_4O_7$ $10H_2O$	52·7 $Na_2B_4O_7$	Sodium tetraborate (*Borax, tincal*).
Sodium hyposulphite, "Hypo"	$Na_2S_2O_3$ $5H_2O$	64 $Na_2S_2O_3$	Sodium thiosulphate
Salt cake	Na_2SO_4	95 to 100 Na_2SO_4	Anhydrous sodium sulphate (*Thenardite*).
Nitre cake	$NaHSO_4$	61 to 86 $NaHSO_4$	Sodium bisulphate or sodium acid sulphate.
Salt (common)	$NaCl$	99 to 100 $NaCl$	Sodium chloride (*Halite*)
Glauber's salt	Na_2SO_4 $10H_2O$	44·1 Na_2SO_4	Hydrated sodium sulphate (*Mirabilite*)
Chili saltpetre	$NaNO_3$	95 to 96 $NaNO_3$	Sodium nitrate (*soda nitre*).
Water glass	Na_2O $4SiO_2$ (approx)		Sodium silicate.
Sodium carbonate monohydrate.	Na_2CO_3 H_2O	85 to 86 Na_2CO_3	Sodium carbonate monohydrate (*Thermonatrite*).

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[1] Clarke, F. W., Data of Geochemistry, 5th ed. 1924, U.S. Geol. Surv. Bull. 770.

[2] Wells, R. C., Sodium Compounds in 1919, Mineral Resources of the U.S. 1919, Pt. II, p. 55.

[3] Where a compound also occurs in nature its mineralogical name is given in italics.

[4] These names will be used constantly throughout the text of the report.

Sodium sulphate is said to have been known as a secret medicine as early as the middle of the 16th century but the credit of its first description rests with J. R. Glauber who described it in his treatise *De Natura Salium, 1658.* He prepared it by treating common salt with sulphuric acid, and called it *sal mirabile* on account of its ascribed medicinal virtues. Later, it was called *sal mirabile Glauberi* but it is now commonly known as *Glauber's salt.* Probably the first use of sodium sulphate was for medical purposes, it being employed as an aperient.

The pure anhydrous material is usually prepared by dehydrating Glauber's salt. The salt cake of commerce is impure anhydrous sodium sulphate and the greater part is still obtained by Glauber's original method with modern improvements.

According to Cumming[1] the first production on a large scale was from salt-brine at Friedrichshall in Hildburghausen, and has been known since 1767 as *sal aperitivum Fridericiauum* or *Friedrichsalz.* At that time it was obtained by freezing-out from the brine on cold winter nights.

The early history of the salt cake industry is closely allied to the advances made in the preparation of soda (sodium carbonate). Until towards the close of the 18th century nearly all the soda used in the industries such as soap manufactures was obtained by burning certain marine plants. At that time the French Academy of Sciences offered a prize to anyone who invented a process of preparing soda from common salt. In 1787, Nicholas LeBlanc, a French physician, discovered the process which still bears his name. His process produced salt cake in one of the intermediate steps in the manufacture of soda. He erected a plant at St. Denis in 1791 which was closed down two years later owing to the Revolution. The plant was handed over to him at a later date, but owing to limited means and ill-health he was unable to operate it, and he died in 1806 without realizing the full benefits of his discovery.

However, LeBlanc's invention was the beginning of the vast alkali industry of the world and, although his process has in many cases been superseded by other methods for the production of soda, it still forms the basis of all the important processes of producing commercial salt cake.

The use of salt cake in the industries dates back many years. For a long time after LeBlanc's process for the manufacture of soda came into general use, the sodium sulphate produced in the preliminary step of this process was employed principally for the manufacture of soda, but gradually it came into use for the manufacture of window and plate glass, replacing in part the soda ash formerly used.

The use of sodium sulphate for the manufacture of kraft paper by the sulphate process, is comparatively recent, this process having been invented by Dahl in Europe about 45 years ago. Previous to that time large quantities of salt cake were thrown away at the alkali plants where it was produced as a by-product in the manufacture of hydrochloric acid.

The sulphate process was first introduced into Canada in 1907 at the plant of the Brompton Pulp and Paper Co., since which time the number of plants using the process has greatly increased. At present the demand for

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[1] Cumming, H. C., "Hydrochloric Acid and Salt Cake," p. 23. Gurney and Jackson, London, 1923.

salt cake in Canada for the paper industry alone is approximately 30,000 tons yearly.

For many years the sodium sulphate consumed in the industries was mostly the manufactured material. However, in recent years, the possibilities of using the natural deposits of sodium sulphate have engaged the attention of many investigators, and plants have been erected and large sums of money expended in endeavours to place the natural material on the market in a form suitable for the industries. The success attending these efforts has varied, and there have been many failures.

The occurrence of natural deposits of sodium salts in western Canada has been known for many years, but it was only the high cost of salt cake during the last years of the Great War and the immediate years following that drew serious attention to these natural deposits. Much money has already been expended on these deposits and it is hoped that in the end the earnest efforts of the pioneers of the industry in western Canada will be rewarded.

CHAPTER II

STATISTICS AND MARKET CONDITIONS

STATISTICS

The deposits of natural sodium sulphate in western Canada have not, as yet, been operated on a steady production basis, and the small shipments, which have been made from time to time, have been rather in the form of trial shipments in order to gauge the possibilities of a market for the natural product.

There have been many factors which have greatly hindered the rapid development of these deposits, some of which have been serious obstacles. The industries using sodium sulphate have therefore had to draw the greater part of their needs from imported material.

Annual Production

The production of sodium sulphate in Canada, both from the western deposits and the manufacture of the by-product material, is small when compared with the quantities imported. In recent years the Canadian production has rarely risen above 15 per cent of the total consumption.

In Table II is given the figures of Canadian production of sodium sulphate as furnished by the Dominion Bureau of Statistics.

TABLE II

Annual Production of Sodium Sulphate in Canada

Calendar year	—	Natural		By-product		Totals
		Crude[1]	Refined	Salt cake	Glauber's salt	
1919	Tons	(a)	....	4,153	1,417	5,570
	Value $	....	....	73,240 00	45,731 00	118,971 00
	Average per ton $	....	....	17 64	32 27	21 36
1920	Tons	181	630	5,524	1,781	8,116
	Value $	2,259 00	17,237 00	111,983 00	50,336 00	181,815 00
	Average per ton $	12 48	27 36	20 27	28 26	22 40
1921	Tons	112	512	2,418	1,239	4,281
	Value $	1,824 00	17,026 00	54,804 00	42,719 00	116,373 00
	Average per ton $	16 29	33 25	22 67	34 48	27 18
1922	Tons	164	340	2,583	1,905	4,992
	Value $	1,100 00	10,880 00	59,804 00	54,899 00	125,683 00
	Average per ton $	6 70	32 00	23 11	28 82	25 37
1923	Tons	210	523	2,376	2,315	5,424
	Value $	1,050 00	9,139 00	57,621 00	61,446 00	129,256 00
	Average per ton $	5 00	17 47	24 25	26 54	23 65
1924	Tons	965	118	2,088	1,458	4,629
	Value $	4,825 00	1,179 00	42,402 00	36,602 00	85,008 00
	Average per ton $	5 00	9 99	20 31	25 10	18 36

(*a*) No reported production from natural deposits previous to 1920.

[1] 'Crude' means material as excavated, generally crude Glauber's salt. 'Refined' means anhydrous sodium sulphate.

Exports

As yet no exports of either salt cake or Glauber's salt have been recorded. This is because the present Canadian production is comparatively small compared with the domestic requirements, and also because the deposits of the natural salts are not advantageously situated with respect to export markets. Shipments to the European market would necessitate a long and costly rail haul in addition to the ocean freights, and shipments to the middle states directly south of the Prairie Provinces would encounter keen competition from the natural deposits of sulphate in Arizona and adjacent states.

Shipments of sodium sulphate, either crude or salt cake, as well as nitre cake,[1] enter the United States free of duty, but sodium sulphate, crystallized or Glauber's salt, is dutiable at the rate of $1.00 per ton; anhydrous sodium sulphate is dutiable at a rate of $2.00 per ton.[2]

Imports

Sodium sulphate, known to the trade as "salt cake," is imported into Canada free of duty. Up to the present over 85 per cent of the total consumption has been imported. It is only since 1920 that the naturally occurring material has been placed on the market and then only in small amounts. The Canadian production of by-product material has furnished about 10 per cent of the country's requirements.

Glauber's salt, the hydrated sodium sulphate, entering Canada is dutiable at the following rates:—

Salt, Glauber's

Preferential	Treaty rates	General
15 p.c.	17½ p.c.	17½ p.c.

In the case of Glauber's salt, the Canadian production of by-product material accounts for about 80 per cent of the total consumption, the balance used being made up of shipments from the natural deposits and from imports.

Table VI shows the imports of salt cake and Glauber's salt into Canada by countries of origin.

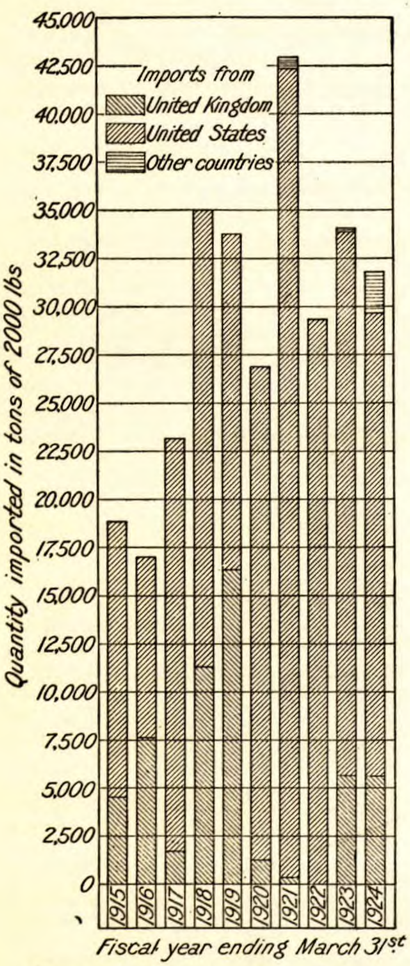

FIGURE 1. Imports of salt cake into Canada.

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[1] See Tariff Act, U.S. 1922, Para. 1667, p. 81.

[2] See Tariff Act, U.S. 1922, Para. 83, p. 11.

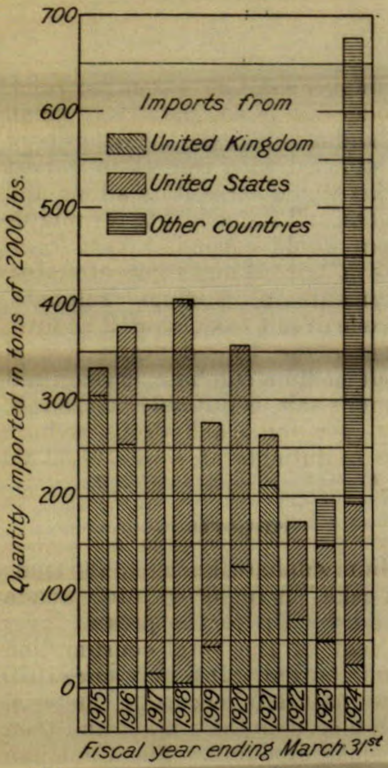

FIGURE 2. Imports of Glauber's salt into Canada.

Figures 1 and 2 show the imports of salt cake and Glauber's salt graphically.

Appreciable quantities of magnesium sulphate or Epsom salts occur with the natural sodium sulphate of western Canada and it is of interest to include a few statistics of this product. Epsom salts entering Canada is dutiable as follows:—

Magnesium sulphate, or Epsom salts

Preferential	Treaty rates	General
15 p.c.	17½ p.c.	17½ p.c.

Sodium sulphide statistics are also of interest since this material is manufactured from salt cake or nitre cake, the acid sodium sulphate. It enters Canada free, and until 1923 was all imported. It is now manufactured in Canada at Shawinigan Falls, Quebec.

Table III gives the Canadian consumption of these two materials, compiled from figures furnished by the Dominion Bureau of Statistics.

TABLE III

Canadian Consumption of Epsom Salts and Sodium Sulphide

Calendar year	Production in Canada				Imports		Exports		Total consumption	
	Crude		Refined							
	Tons	$	Tons	$	Tons	$	Tons	$	Tons	$
					Epsom Salts					
1920	1,947	39,886	....	....	....	72,709	743	3,737	....	108,858
1921	1,412	18,425	617	21,081	1,300	29,987	120	4,562	....	64,931
1922	443	4,183	578	19,834	1,398	44,499	142	4,838	2,277	63,678
1923	....	....	121	6,580	1,867	47,155	20	830	1,968	52,905
1924	....	....	....	....	2,239	54,139	....	....	2,239	54,139
					Sodium Sulphide					
1920	....	....	....	....	1,434	154,294	....	....	1,434	154,294
1921	....	....	....	....	864	74,201	....	....	864	74,201
1922	....	....	....	....	1,216	86,292	....	....	1,216	86,292
1923	....	....	(1)		1,346	89,011	....	....	1,346	89,011
1924	....	....	(2)	....	930	50,246	....	....	....	....

---

[1] Now being manufactured in Canada at Shawinigan Falls, Quebec.
[2] Figures not available.

Current Prices

Figures 3 to 7 inclusive show the price variation respectively of salt cake, Glauber's salt, Epsom salts (U.S.P.), Epsom salts (Technical) and sodium sulphide, 60 per cent and 30 per cent, as quoted in the Oil, Paint and Drug Reporter, New York. These prices are the New York quotations and are lower than the Canadian market prices by the amount of freight and duty where the material is dutiable.

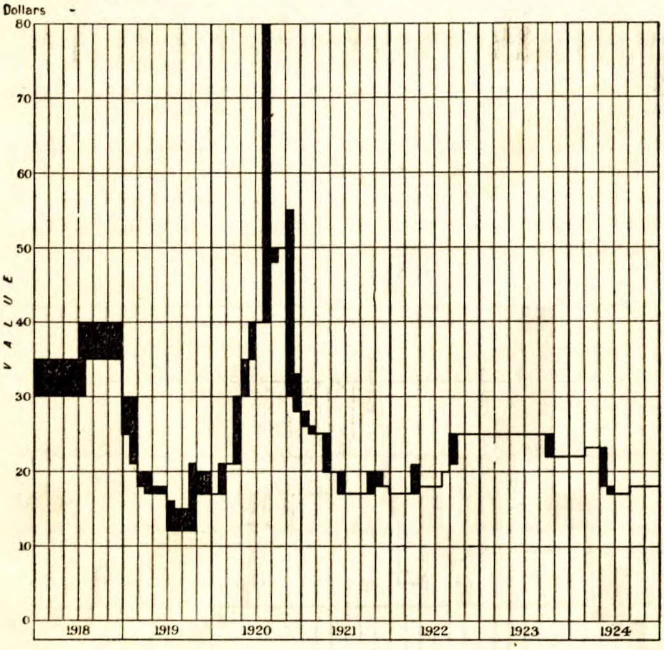

FIGURE 3. Salt cake (ground, bbls.) New York market price per ton (2000 lbs.)

MARKET CONDITIONS

The sodium sulphate in the western deposits occurs as mirabilite (Glauber's salt) in varying degrees of purity. The natural product, in its crude state, contains approximately 56 per cent of water of crystallization, and for most uses it is necessary to convert it into the dry anhydrous form of "salt cake" or "anhydrous sodium sulphate" before it is placed on the market.

In order to thoroughly explain the market conditions as they affect the material from these Canadian deposits, it is necessary to summarize briefly a number of its uses.

Markets for Salt Cake and Glauber's Salt

Sodium sulphate finds many applications in the chemical industries. It is used extensively in the pulp and paper, glass, dye, textile, and nickel industries, and to a smaller extent in medicinal and tanning preparations and the manufacture of sodium sulphide.

PULP AND PAPER INDUSTRY

The largest consumers in Canada are the manufacturers of kraft paper, who, in past years, have required approximately 30,000 tons of salt cake each year. The production of kraft paper in Canada is steadily increasing, the figure for 1923 being the highest yet recorded. The consumption of salt cake per ton of pulp produced by the sulphate process varies, according to different practice, from 425 to 500 pounds. Taking the higher figures as a basis for calculations, 1 ton of salt cake will be required for every 4 tons of sulphate pulp produced. Figure 8 shows graphically the production of sulphate pulp in Canada since 1915. The graph A-B shows the amount of salt cake used each year figured on the above basis of 1 to 4.

A study of the graph shows that with the exception of the years 1919 and 1921, there has been a steady increase in the production of sulphate pulp. This increase has caused a corresponding demand for salt cake, so that one may reasonably expect a steadily increasing market for salt cake for a number of years to come.

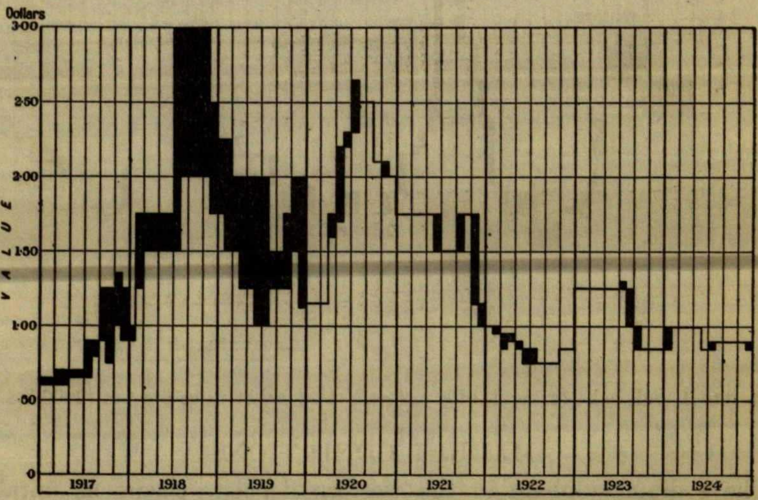

FIGURE 4. Glauber's salt (crystals) New York market prices per hundredweight.

GLASS INDUSTRY

Manufacturers of glass bottles and other containers use small amounts of sodium sulphate or salt cake, in some cases only about 40 pounds per ton of product. Slightly larger quantities are employed for the manufacture of plate glass. At the present time none of the glass factories in Canada employ salt cake.

Apart from chemical and mechanical differences in the use of salt cake or soda ash in glass manufacture, the main factor governing the use of salt cake in place of soda ash appears to be purely a matter of cost, based on the percentage of sodium oxide in each material. On this basis the ratio of the price of salt cake to soda ash should be as 1 to 1·4; conversely, the ratio of the price of soda ash to that of salt cake would be as 0·72 to 1.[1] This is shown graphically in Figure 9.

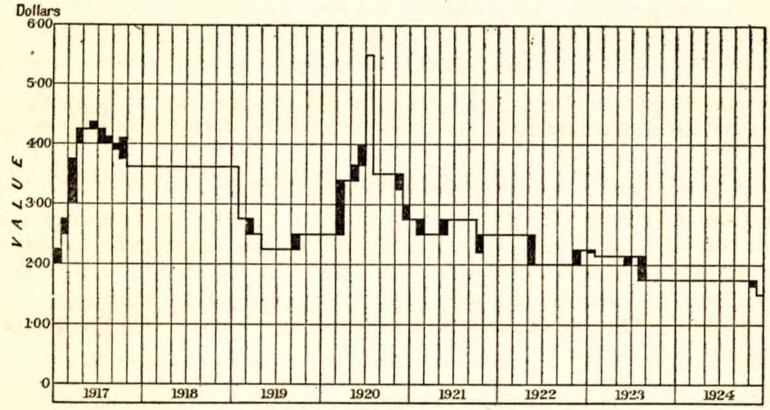

FIGURE 5. Epsom salts (U.S.P.) New York market prices per hundredweight.

TANNING

Sodium sulphate is not used in the tanning industry proper, but large amounts are employed advantageously in the curing of hides, superseding common salt. It is difficult to arrive at the exact requirements of this industry, but it is probable that 1,000 tons per year would be a safe estimate. Large amounts of sodium sulphide, however, are used, either mixed with lime or alone, and, generally, sodium sulphide is obtained by the reduction of sodium acid sulphate.

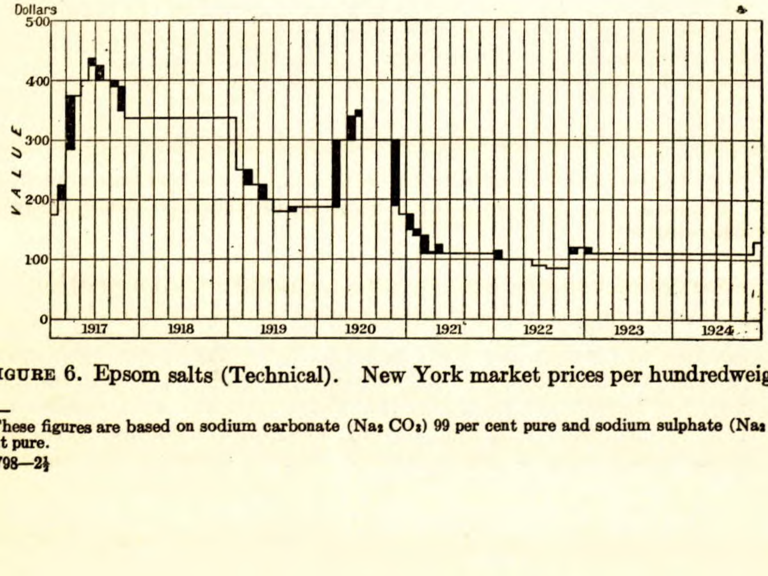

FIGURE 6. Epsom salts (Technical). New York market prices per hundredweight.

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[1] These figures are based on sodium carbonate ($Na_2 CO_3$) 99 per cent pure and sodium sulphate ($Na_2 SO_4$) 95 per cent pure.

DYE INDUSTRY

The estimated annual consumption of sodium sulphate (Glauber's salt) by the dye works is from 1,300 to 1,500 tons per year. The dyers prefer the natural Glauber's salt to by-product salt cake, as it is free from nitrates and nitrites which readily oxidize the dyes.

MEDICINAL INDUSTRY

Glauber's salt is employed for medicinal purposes as an aperient. It is also used to some extent in stock foods and for veterinary purposes.

NICKEL REFINERIES

Sodium acid sulphate in the form of nitre cake is used in large quantities in the refining of nickel, between 3,000 and 4,000 tons being required annually. It is hardly probable that the natural anhydrous material from western Canada will be able to replace the cheaper nitre cake in this industry, unless the physical and chemical properties of the former prove to be greatly superior.

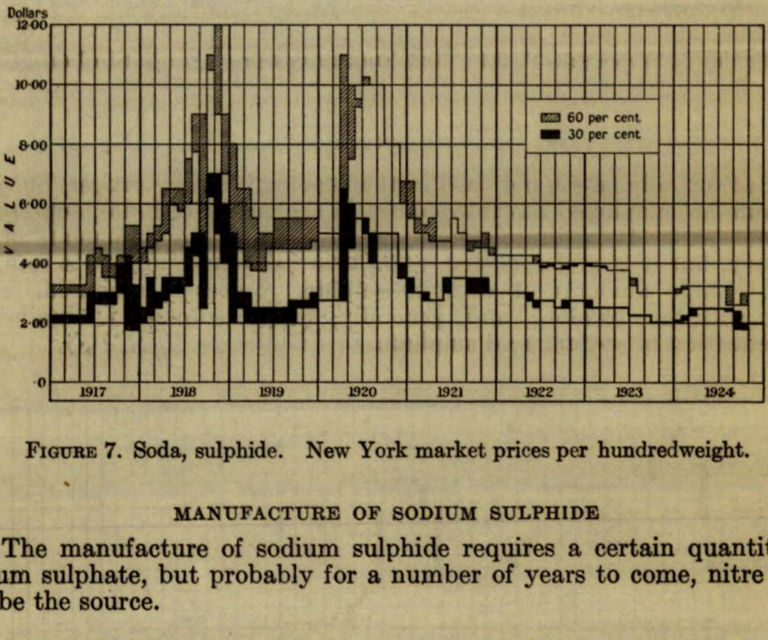

FIGURE 7. Soda, sulphide. New York market prices per hundredweight.

MANUFACTURE OF SODIUM SULPHIDE

The manufacture of sodium sulphide requires a certain quantity of sodium sulphate, but probably for a number of years to come, nitre cake will be the source.

Sources of Present Supply and Canadian Consumption

Up to the present time practically all of the salt cake and Glauber's salt consumed in Canada has been supplied from the by-product material resulting from the manufacture of hydrochloric acid. The greater part of the supply has been imported from the United States, with smaller quantities from the United Kingdom, Japan, Germany, and the Netherlands. The Glauber's salt used is manufactured from by-product salt cake.

A small tonnage of crude Glauber's salt and dried anhydrous sulphate has been obtained for the past few years directly from the deposits in western Canada.

TABLE IV

Canadian Consumption[1] of Anhydrous Sodium Sulphate (Salt Cake)

Calendar Year	Production in Canada						Imports			Total	
	Natural			Artificial							
	Tons	Value	Per cent[2]	Tons	Value	Per cent[2]	Tons	Value	Per cent[2]	Tons	Value
1919......	......	....	......	4,153	$ 73,240	14·8	23,952	$343,007	85·2	28,105	$ 416,247
1920......	630	$ 17,237	1·3	5,524	111,983	11·2	42,974	958,628	87·5	49,128	1,087,848
1921......	512	17,067	1·7	2,418	54,804	7·9	27,654	690,311	90·4	30,584	762,141
1922......	340	10,880	0·8	2,583	59,804	6·1	39,472	830,515	93·1	42,395	901,199
1923......	523	9,139	1·6	2,376	57,621	7·0	30,967	684,604	91·4	33,866	741,364
1924......	118	1,179	0·4	2,088	42,402	5·4	36,022	673,322	94·2	38,228	716,903

[1] Compiled from statistics furnished by Dominion Bureau of Statistics.
[2] Per cent of total consumption.

TABLE V

Canadian Consumption[1] of Hydrated Sodium Sulphate (Glauber's Salt)

Calendar Year	Production in Canada						Imports			Total	
	Natural			By-product							
	Tons	Value	Per cent[2]	Tons	Value	Per cent[2]	Tons	Value	Per cent[2]	Tons	Value
1919......	......	....	......	1,417	$ 45,731	79·3	369	$ 9,763	20·7	1,786	$ 55,494
1920......	181	$ 2,259	8·1	1,781	50,336	79·3	283	8,364	12·6	2,245	60,959
1921......	112	1,824	7·5	1,239	42,719	83·1	140	4,521	9·4	1,491	49,064
1922......	164	1,100	7·3	1,905	54,899	85·0	173	5,554	7·7	2,242	61,553
1923......	210	1,050	6·9	2,315	61,446	76·0	521	11,542	17·1	3,046	74,038
1924......	965	4,825	29·0	1,458	36,602	43·8	906	14,684	27·2	3,329	56,111

[1] Compiled from statistics furnished by Dominion Bureau of Statistics.
[2] Per cent of total consumption.

Tables IV and V show the consumption of salt cake and Glauber's salt in Canada. Since in neither case are there any exports, the total consumption is considered to be the Canadian production plus the imports.

Canadian Situation

Since salt cake, normally, is a by-product from the manufacture of hydrochloric acid, the amount produced is attendant on the market available for hydrochloric acid. If the market for the acid is strong and prices are good, the producers may have a large stock of salt cake on hand and can afford to sell it at a low price. If, however, the market for hydrochloric acid is weak, less salt cake is produced and the price of salt cake will rise correspondingly. Conditions have also arisen whereby the demand for salt cake and the price have been such that it has proved profitable to the manufacturers to produce salt cake to meet the requirements, leaving in this case the hydrochloric acid as the by-product. It can thus be seen that the factors governing the production and price of salt cake are varied and that the price does not depend on the demand for the material alone.

It is true that hydrochloric acid can be produced electrolytically, but although this method will probably become increasingly popular, it will be many years before the present methods which produce salt cake as a by-product will be obsolete.

In considering, therefore, the development of any natural deposit of sodium sulphate the strong competition of the by-product material for many years to come will have to be taken into consideration.

Another point which must be considered is the fact that the Canadian deposits of sodium sulphate are situated in western Canada, whereas, at present, the larger markets in Canada are in the east. This is a serious handicap to the product from the western deposits since freight rates of $10.00 or more per ton have to be added to the cost at plant before the material can be landed at the markets. The foreign material imported from the United States has considerably lower freight rates since there are numerous plants producing by-product salt cake in the New England states, as well as in Cleveland, Philadelphia, and elsewhere.

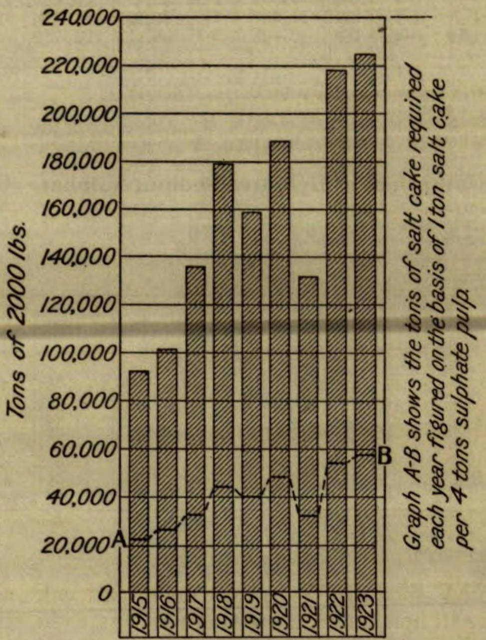

FIGURE 8. Production of sulphate pulp in Canada.

The cheaper ocean freight rates also allow the English and European salt cake to be landed at Three Rivers and others of the more eastern markets at a very low cost, so that as long as the excess production from the English plants cannot be absorbed by the European market this material will continue to compete with the material produced in western Canada.

Moreover, the Canadian deposits are in the form of Glauber's salt and since this carries 56 per cent water of crystallization, it is necessary to convert it into the anhydrous salt cake before marketing, in order to save freight charges. This treatment adds to the cost of production. While great steps have been made in developing economic methods of drying Glauber's salt, it has not been definitely proven that a satisfactory and economical process has been discovered.

Conclusions

As before stated, the pulp and paper industry consumes by far the largest proportion of the material used in Canada, and, until other uses are developed, the natural salt cake industry in Canada will be dependent to a large extent on the success of the sulphate pulp industry. The greater part of the sulphate pulp produced in Canada is exported to the United States, in fact over 50 per cent of the United States imports of this material are supplied by Canada. Statistics covering imports of sulphate pulp into the United States are of interest in this connexion.

Imports of Sulphate Pulp into United States

—	Month June, 1924	Month June, 1923	Year ending June 30, 1924	Year ending June 30, 1923
From Canada.............................tons	8,788	11,300	133,448	138,283
From Sweden......................... "	6,578	9,272	88,214	103,044
From Finland......................... "	999	1,138	10,243	18,720
From Norway......................... "	150	147	10,186	8,686
From other countries.................. "	19	....	2,295	760
Total............................ "	16,534	21,857	244,386	269,493

From this table it can be seen that Canada's most serious competitor is Sweden and although the amount of sulphate pulp exported from Canada to the United States shows a slight decline, that from Sweden showed even a greater drop. With the stabilization of Europe, the surplus production of sulphate pulp in the Scandinavian countries should be absorbed more readily by the European market and one may then reasonably look for an increased demand in the United States market for Canadian pulp. Such an increased demand will in turn reflect on the salt cake market, with a possible rise in price.

The Canadian natural sodium sulphate has many technical advantages in its favour, since it contains no free sulphuric acid or iron, and is not liable to caking in the cars. In consequence it is in every way suitable for the manufacture of high-grade products. If proper methods of recovery are adopted, producers should be able to guarantee a uniform product of a high degree of purity.

TABLE

Canadian Imports—

Twelve months ending March 31	United Kingdom			United States		
	Cwt.	Value	Average	Cwt.	Value	Average
Fiscal Year						Salt Cake.
1915	89,542	$ 40,659	$0 45	287,764	$126,604	$0 44
1916	151,005	73,893	0 49	190,610	87,663	0 46
1917	33,089	23,771	0 72	431,231	216,832	0 50
1918	227,138	159,895	0 70	475,798	449,134	0 94
1919	328,908	216,068	0 66	347,270	410,378	1 18
1920	24,788	40,609	0 64	514,413	369,033	0 72
1921	6,302	7,730	1 23	843,021	1,019,445	1 21
1922	100	134	1 33	588,380	707,065	1 21
1923	114,757	109,231	0 95	563,644	578,048	1 03
1924	112,311	124,397	1 11	483,675	543,607	1 12
						Glauber's Salt
1915	6,103	$2,363	$0 39	552	$ 329	$0 60
1916	5,072	2,226	0 44	2,454	5,678	2 31
1917	278	1,301	4 69	5,705	8,478	1 49
1918	73	249	0 34	8,006	15,272	1 91
1919	879	682	0 78	4,633	9,398	2 03
1920	2,519	2,078	0 82	4,583	6,793	1 48
1921	4,197	5,166	1 23	1,018	2,507	2 46
1922	1,364	1,894	1 39	2,055	3,684	1 79
1923	949	982	1 03	2,003	4,438	2 22
1924	452	950	2 10	3,337	4,252	1 27
						Total Imports—Salt Cake
1915	95,645	$ 43,022	$0 45	288,316	$126,933	$0 44
1916	156,077	76,119	0 49	193,064	93,341	0 48
1917	33,367	25,072	0 75	436,936	225,310	0 52
1918	227,211	160,144	0 70	483,804	464,406	0 96
1919	329,786	216,750	0 66	351,913	419,776	1 19
1920	27,307	42,687	1 56	518,996	375,826	0 72
1921	10,499	12,896	1 23	844,039	1,021,952	1 21
1922	1,464	2,028	1 39	590,435	710,749	1 20
1923	115,706	110,213	0 95	565,647	582,486	1 03
1924	112,763	125 847	1 12	487,012	547,859	1 12

VI

Sodium Sulphate

Other Countries			Total			
Cwt.	Value	Average	Cwt.	Value	Average	
					Cwt.	Ton
(Free)						
....	....	....	377,306	$167,263	$0 44	$ 8 87
....	....	....	341,615	161,556	0 47	9 46
....	....	....	464,320	240,603	0 52	10 36
....	....	....	702,936	609,029	0 87	17 33
....	....	....	676,178	626,446	0 93	18 53
....	....	....	539,201	409,642	0 76	15 19
a. 11,200	$16,000	$1 43	860,523	1,043,175	1 21	24 24
....	....	....	588,480	707,199	1 20	24 03
b. 1,694	870	0 51	680,095	688,149	1 01	20 23
{ *b.* 6,555	3,626	0 55	638,646	711,741	1 11	22 28
{ *c.* 36,105	39,611	1 10				
(Dutiable)						
....	....	....	6,655	$ 2,692	$0 40	$ 8 09
....	....	....	7,526	7,904	1 05	21 01
....	....	....	5,983	9,779	1 63	32 69
....	....	....	8,079	15,521	1 92	38 43
....	....	....	5,512	10,080	1 83	36 57
....	....	....	7,102	8,871	1 25	24 98
....	....	....	5,215	7,673	1 47	29 43
....	....	....	3,419	5,578	1 63	32 63
b. 943	$ 895	$0 95	3,895	6,315	1 62	32 42
b. 9,774	7,152	0 73	13,563	12,354	0 91	18 22
and Glauber's Salt.						
....	....	....	383,961	$169,955	$0 44	$ 8 80
....	....	....	349,141	169,460	0 49	9 80
....	....	....	470,303	250,382	0 53	11 60
....	....	....	711,015	624,550	0 88	17 60
....	....	....	681,690	636,526	0 93	19 60
....	....	....	546,303	418,513	0 77	15 40
11,200	$16,000	$1 43	865,738	1,050,848	1 21	24 20
....	....	....	591,899	712,777	1 20	24 00
2,637	1,765	0 67	683,990	694,464	1 02	20 40
52,434	50,389	0 96	652,209	724,095	1 11	22 20

a. From Japan.
b. From Germany.
c. From Netherlands.

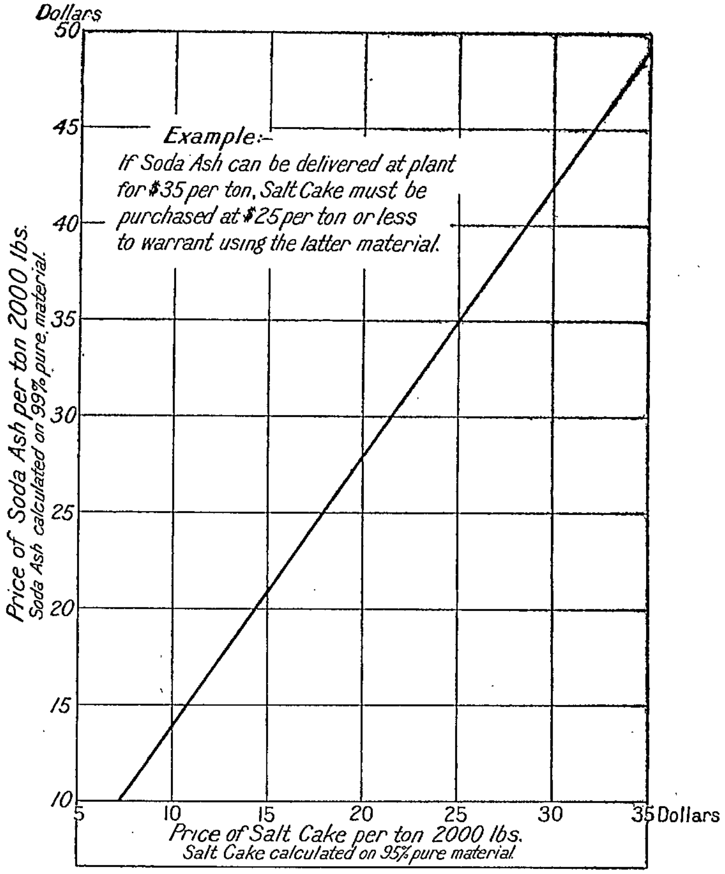

FIGURE 9. Chart showing prices at which salt cake and soda ash must be purchased for equal values of sodium oxide.

CHAPTER III

GENERAL OCCURRENCES OF NATURAL SODIUM SULPHATE

Sodium sulphate is found in nature both as the decahydrate (mirabilite) and in the anhydrous state as thenardite. It also occurs in combination with other salts such as glauberite in which it is associated with calcium sulphate, and bloedite in which it is associated with magnesium sulphate. It is also a common constituent of many mineral waters as well as sea-water, and many of the saline or so-called "alkali" lakes throughout the world show varying proportions of sodium sulphate.

For a proper economic study of the deposits of sodium sulphate of western Canada and in order to properly gauge their relative value a knowledge of the more important world occurrences is necessary. Brief descriptions of a number of deposits occurring elsewhere, which either have already been operated or which give promise of being of economic importance in years to come, are therefore given.[1]

UNITED STATES

Arizona

Verde Valley. An extensive deposit of thenardite, which outcrops along the side of Copper canyon in the Rio Verde region, is being worked by the Western Chemicals Inc. of Los Angeles, California.

According to Blake[2] the deposit covers a considerable area and is probably 50 feet or more in thickness so that the quantity available will run into millions of tons.

The thenardite carries about 10 per cent of sodium chloride and varying amounts of insoluble material which must be removed to obtain a commercial product.

The company operating this deposit has a plant in operation which is essentially as follows[3]:—

> A primary crusher is arranged so that it can be moved into the deposit as the first cut proceeds. This plan of operation, incidentally, will assist in making a survey of the extent of the mineral, of which several million tons is indicated by present exposures. The initial reduction is to about ¾ inch, the product then passing to a belt conveyer, by which it is carried to a storage bin, and thence to a fine crusher for reduction to about ⅕ inch. The washing plant consists of a four unit conveyer operating in troughs, up which the material passes, counter-current to a supply of liquor that is kept saturated in sulphate but undersaturated in chloride. This liquor is removed as concentration is reached; and a by-product, Glauber's salt, is produced by fractional crystallization. The mother-liquor passes to evaporating ponds, the crude salt from which may eventually find a market. The consumption of water in the washing plant amounts to about 1,000 gallons per hour.

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[1] For more detailed descriptions of such deposits the reader is referred to the following publications:—
The Manufacture of Hydrochloric Acid and Salt Cake, by Alexander Charles Cumming.
(This is Vol. V in the series entitled "The Manufacture of Acids and Alkalis" by George Lunge, and is published by Guerney and Jackson, London, 1923.)
Sodium Sulphate: Its Sources and Uses, by Roger C. Wells.
(This pamphlet is Bulletin 717 of the United States Geological Survey, Department of Interior, and is published by the Government Printing Office, Washington, 1923.)
Geology of the Non-Metallic Mineral Deposits, by Amadeus W. Grabau.
(This is Vol. I entitled "Principles of Salt Deposition," published by McGraw-Hill Book Company, New York, 1920.)

[2] Blake, W. P., Am. Jour. Sci. 3rd Series, Vol. 39, p. 43, 1890.

[3] Chemical and Metallurgical Engineering Magazine, Vol. 30, No. 15, p. 588, April 14, 1924.

The sulphate crystals from the washers are drained by passage over a perforated conveyer and pass to an 8 by 50-foot rotary, oil-burning drier, equipped with baffles and exhaust fan. The dried product, which analyses about 98 per cent pure, is elevated to storage bins, from which it is drawn to motor trucks for conveyance to the railroad at Clarkdale.

California

Soda Lake. A deposit of sodium sulphate in the form of Glauber's salt, which in dry seasons dehydrates to a white powder, occurs in tp. 31 S., R. 19 E., and tp. 31 S., R. 20 E., Carrizo plain, San Luis Obispo county, California. The deposit has been estimated by Arnold and Johnson[1] to include an area of nearly 3,000 acres. Transportation to the nearest railway station, McKittrick, on a branch line of the Southern Pacific railway, 16 miles distant, entails a haul over the Temblor range, on a road that is winding with steep grades.

According to Gale[2], the surface of the deposit remains dry during the greater part of the time. Its surface normally presents a broad, flat plain of white crystalline salts, ranging from a thin sheet about the margins to a deposit a few inches thick in the deeper parts. It is possible that there are patches of greater depths throughout the deposit.

When visited by the writer in October, 1922, the lake evidently had been dry for a considerable time since the surface of the whole deposit was covered with the dehydrated salts to a depth of over half an inch. Beneath the crystal a greenish-grey mud very similar in appearance to the underlying mud of the Canadian deposits was encountered. A number of crystals were collected from this mud by Gale which were determined by Schaller[3] to be bloedite.

Gale[4] estimated the probable available sodium sulphate (crude salts) in this deposit, to be over a million short tons.

The deposit has been worked for a number of years and shipments of dried salts have been made, some being shipped to Canada. From one carload shipped to Canada a representative sample was obtained which analysed as follows:—[5]

	Per cent.
Insoluble in water (clay and sand particles)	0·91
Soluble in water	
Lime (CaO)	0·34
Magnesia (MgO)	1·00
Soda (Na_2O)	38·72
Sodium chloride (NaCl)	5·95
Sulphur trioxide (SO_3)	50·83
Moisture	2·65
Total	100·40

A combination possible from the above analysis may be calculated as 88·71 per cent anhydrous sodium sulphate.

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[1] Arnold, Ralph, and Johnson, H. R., Sodium Sulphate in Soda Lake, Carrizo Plain, San Luis Obispo County, Cal. Bull. U.S. Geol. Survey No. 380, 1909, pp. 369–371.

[2] Gale, H. S., Sodium Sulphate in the Carrizo Plain, San Luis Obispo County, Cal., U.S. Geol. Surv. Bull. 540, pp. 428–433, 1914.

[3] Schaller, W. T., Bloedite Crystals, preliminary note; Jour. Washington Acad. Sci., Vol. 3, No. 3, Feb. 1913, pp. 75 and 76.

[4] Gale, H. S., op. cit. p. 433.

[5] Sample and analysis of material shipped from McKittrick, Cal., to Dominion Glass Co., Redcliffe factory, Redcliffe, Alberta. Analysis by J. T. Donald & Co., Montreal, Feb. 3, 1921.

Searles Lake. Searles lake, or marsh, is in the northwestern part of San Bernardino county, California, and in its central part a vast deposit of mixed salts occurs over an area of 11 to 12 square miles with an average depth of 70 feet. It is one of the most interesting saline deposits and has been fully described by Gale.[1]

The salts occur both in brines and in the solid state, and the chemical composition of both have been determined by numerous analyses. According to Gale[2] in the average hypothetical composition of the anhydrous residue of six samples of brine, collected from different parts of the deposit, there was 19·22 per cent of sodium sulphate (Na_2SO_4) present. Gale also cites the analyses of samples from well "SE. 8" in this deposit, in which the percentage of sodium sulphate at different depths is as follows:—

Feet	Per cent of sodium sulphate
0 to 18	7·6
18 " 25	30·5
25 " 30	28·1
30 " 35	17·1
35 " 50	22·3
50 " 65	10·6
65 " 79	7·3

When the property was visited by the writer in October 1922, the American Trona Corporation was working a part of the deposit for the recovery of borax and potash. The process employed entailed the preliminary separation of the sodium sulphate and the sodium carbonate but no endeavour was being made to recover either of the salts.

Nevada

Wabuska. Russell[3] cites an occurrence of sodium sulphate in Mason valley, Lyon county, about 1 mile north of Wabuska, a station on the Southern Pacific railway. The water from a group of hot springs has collected in a number of small basins from which it has evaporated forming a deposit of considerable extent. He gives a section of this deposit as follows:—

White, hard crust of sulphate of soda, with common salt, some calcium carbonate, etc	inches	1–2
Soft, mealy or clayey deposit, etc	inches	2–7
Clear transparent crystals of sodium sulphate, with some earthy impurities, resting on saline clay	feet	6–8

A government lease has recently been granted to the California-Nevada Sodium Sulphate Co. to operate this deposit. According to the Chemical and Metallurgical Engineering Magazine[4] small shipments from the top crust have already been made.

At present the crust of the deposit is being removed, dried and broken, for shipment in bulk at the rate of about two cars per week, to Louisiana, Wisconsin, Minnesota and Canada. A typical analysis of this material is as follows: Na_2SO_4, 98·19 per cent; Na_2CO_3, 0·13 per cent; NaCl, 0·23 per cent; insoluble and dirt, 0·52 per cent; moisture, 0·23 per cent; undetermined, 0·7 per cent; loss at 110° C., 16 per cent.

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[1] Gale, H. S., Salines in the Owens, Searles and Panamint Basins, Southeastern California, U.S. Geol. Surv. Bull. 580, 1915.

[2] Gale, H. S., op. cit., p. 277.

[3] Russell, I. C., Geological History of Lake Lahontan. U.S. Geol. Surv. Mon. 11, p. 48, 1885.

[4] Chemical and Metallurgical Engineering Magazine, Vol. 32, No. 1, p. 4, Jan. 5, 1925.

The method proposed for the production of high-grade crystals, to be put in operation as soon as water is available from nearby wells, is simple and ingenious. Small-scale production has demonstrated the practicability of the plan; the surface of the dry lake is first flooded with water, dissolving the salts, which recrystallize. This phase of the operation results in the formation of from 2 to 3 feet of crude sulphate The deposit is then reflooded with water to a depth of about 3 inches In about 15 days the water has been evaporated and a crop of high-grade crystals of sulphate is formed These are removed and the recrystallization process is repeated Water is obtained at a depth of from 60 to 80 feet.

The harvested crystals, which contain no magnesium, are dried in the sun for about 15 days, then crushed by passage through rolls. A typical analysis of the recrystallized product is as follows: Na_2SO_4, 99·59 per cent; moisture at 110°C., 0·09 per cent; impurities, 0·32 per cent. The depth of crude crystalline material below the top crust is estimated to average about 8 feet.

Ragtown Soda Lakes. Two soda lakes, known locally as the Ragtown ponds, near Fallon, Churchill county, although worked for their "soda" content are known to contain appreciable quantities of sodium sulphate. Russell[1] has estimated the larger of the two ponds to contain in the neighbourhood of 340,000 tons of sodium sulphate.

New Mexico

Dona Ana County[2]. A deposit of sodium sulphate lies 25 miles by road, west of Valmont, a station on the main line of the El Paso and Southwestern railway, 10 miles south of Alamogordo, New Mexico.

The sodium sulphate occurs in the lowest part of the White Sand plains in the Tularosa basin. The plains are composed mostly of gypsum and the soil underneath is highly impregnated with sodium salts. Considerable gypsum is mixed with the sodium sulphate in the deposit, but wherever pits are dug the brine which fills them is practically saturated with sodium sulphate, and crystals of Glauber's salt form readily when the brine cools.

Experimental work on the production of anhydrous sodium sulphate was undertaken on this deposit in 1919. The road to the railway is fairly level so that transportation by wagons or auto trucks is feasible.

Texas

Ward County. Wells[3] mentions a lake about 11 miles from the railroad at Manahans, Ward county, said to be underlain by at least one and possibly two thin beds of crystallized salts, which appear to be chiefly Glauber's salt.

The lake is stated to cover an area of 160 acres. The first layer of salts, from 3 to 6 feet thick, occurs at a depth of 1 to 3 feet below the surface of the lake. A second bed has been noted 30 feet lower, under red clay.

Utah

Great Salt Lake. Sodium sulphate occurs on the south shore of Great Salt lake in deposits said to be from 5 to 7 feet thick, about half of which is sand. Attempts have been made to operate these deposits from time to time and small tonnages of salt cake have been produced.

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[1] Russell, I. C., Geological History of Lake Lahontan. U.S. Geol. Surv. Mon. 11, p. 80, 1885.

[2] For more detailed descriptions see:—
Phelan, W. C. "Salt Resources of the United States," Bull. 669, pp. 150–152, U.S. Geol. Surv., 1919.
Wells, R. C. "Sodium Sulphate, Its Sources and Uses, Bull. 717, pp. 24–26, U.S. Geol. Surv., 1923.

[3] Wells, R. C., op. cit., p. 27.

Jones[1] gives an analysis of the sodium sulphate produced from these deposits by the Midwest Dye and Chemical Co. at their plant about 2 miles southwest of the Garfield smelter, as follows:—

	Per cent.
Sulphur trioxide (SO_3)	68·87
Chlorine (Cl)	3·64
Magnesium (Mg)	0·24
Calcium (Ca)	0·36
Potassium (K)	0·15
Sodium (Na)	31·37
Total	99·63

The following account of the method of recovery is given by Jones[2]:—

> The overburden is easily removed, exposing the sodium sulphate, which is hard and crusty, and contains about 50 per cent sand. The deposit itself is from 5 to 7 feet thick. After removing the sand overburden, live steam is injected into the deposit by means of an open-end pipe. The heat causes the salt to go into solution very rapidly, and practically all of the sand settles to the bottom of the deposit. When sufficient solution is accumulated it is pumped into a small storage-tank, where additional settling takes place. This solution is then decanted and stored in shallow evaporating ponds. As the solution cools, crystals of Glauber's salt form.

The brines of Great Salt lake also contain appreciable proportions of sodium sulphate which separate out and sink when the temperature nears the freezing-point. Small quantities have been occasionally washed up on the shore and have been harvested.

Wyoming[3]

In many parts of Wyoming there are numerous deposits of different depths containing various percentages of sodium sulphate. In many respects these deposits are very similar to the deposits in western Canada. Some of them have been worked for the recovery of sodium sulphate. A few of the largest of these deposits will be briefly mentioned.

Downey Lakes, Albany County. The Downey lakes, three in number, are situated in secs. 15, 21, 22, tp. 13 N., R. 75 W., 22 miles southwest of Laramie. Only the two lower lakes contain permanent crystal beds which vary in depth from a few inches to 10 feet. Jones[4] states that there are approximately 4,000,000 tons of crude salts (sodium and magnesium sulphates) present in these deposits, and that tests carried out at the University of Wyoming in 1920, indicated a sodium sulphate content in excess of 95 per cent in the calcined product. The deposits have been operated in past years.

Union Pacific Lakes, Albany County. The Union Pacific Lakes, situated 13 miles to the southwest of Laramie contain crystal beds up to 40 feet in thickness. In addition to four large lakes which cover an area of 60

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[1] Jones, Chester H. "Sodium Salts Mineral Industry," pp. 634–635, 1920.

[2] Op. cit.

[3] For fuller descriptions of the Wyoming deposits the reader is referred to the following publications:—
Wells, R. C., op. cit. Ladoo, R. B. "Non-Metallic Minerals." Occurrence, Exploitation and Utilization. McGraw-Hill Book Co., 1925, pp. 571 and 572.
Schultz, A. R. "Deposits of Sodium Salts in Wyoming," Bull. 430, U.S. Geol. Surv., pp. 570–589, 1910.
Grabau, A. W. Geology of the Non-Metallic Mineral Deposits, Vol. 1, Principles of Salt Deposition, pp. 222–225, 1920.
Jones, C. H. Mineral Industry, 1920, p. 634.
Knight, W. C. and Slosson, E. E. Alkali lakes and Deposits, Bull. Wyoming Exper. Sta., No. 49, 1901.

[4] Jones, C. H., Mineral Industry, 1920, p. 634.

acres there are many other smaller depressions. The deposits were worked as far back as 1885 and the partly air-dried salts were refined at the Laramie Chemical works. According to Wells[1] some of the material from these deposits was utilized for glass-making, but the deposits have not been worked since 1892.

Sodium, Natrona County. In sec. 26, tp. 35 N., R. 78 W., 8 miles northeast of Casper, there is a series of four deposits containing sodium sulphate. According to Wells[2] these deposits are now being worked by the Gill Soda Company at Sodium. The quantity of salts available is estimated at more than 250,000 tons. Schultz[3] states that pits have been sunk to a depth of 12 to 20 feet, but the entire thickness has not been determined.

Sweetwater Valley, Natrona County. Schultz[4] states that the alkali deposits of the Independence group, occur in two old river channels north of the present Sweetwater river. The channels are about 3 miles apart and are separated by a marked divide. The lakes in Series I, or the Dupont lakes, occupy the southern channel, and those in Series II, or the Berthaton lakes, the northern channel. There are a large number of lakes that cover more than 900 acres. The beds range from a thin film to 40 feet in thickness. As far back as 1892 attempts were made to operate these deposits.

There are also numerous other occurrences of sodium sulphate in Wyoming, the detailed descriptions of which can be found in the publications referred to at the beginning of this section.

EUROPE

Russia. Sodium sulphate occurs in the form of mirabilite in some of the saline lakes in provinces around the west shore of the Caspian sea. Production from these deposits has been reported.

Spain. Crude sodium sulphate associated with calcium and magnesium sulphate occurs at Cerezo de Rio Tiron, province of Burgos. It is transported by motor truck to Mirande de Ebro in the same province where it is subjected to a purifying process that yields an anhydrous product, 97 per cent sodium sulphate, for use in local glass factories.

Roumania. Lacu Sarat, some 10 to 12 miles south of Braila, on the west shore of the Danube, is reported to deposit Glauber's salt in cold weather.

Italy[5]. Sodium sulphate is reported as being produced from mines in the territory of Montedoro, province of Girgenti.

ASIA

In the neighbourhood of Minnissinsk, in that part of the Yeniseisk region lying to the south of the Trans-Siberian railway and situated on the steppes on both sides of the Yenisei river are a number of lakes which are

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[1] Wells, R. C. Op. cit. Ladoo, R. B. "Non-Metallic Minerals," Occurrence and Utilization. McGraw-Hill Book Co., 1925, pp. 571 and 572.

[2] Wells, R. C. Op. cit.

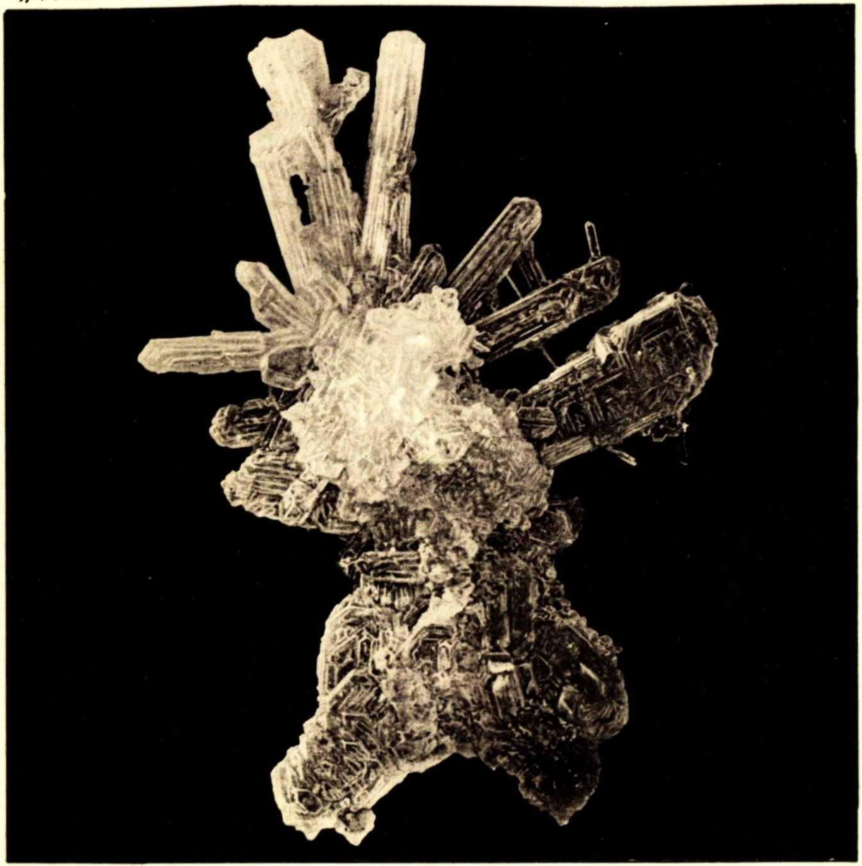
[3] Schultz, A. R. Op. cit.

[4] Schultz, A. R. Op. cit.

[5] Wells, R. C. Op. cit.

PLATE I

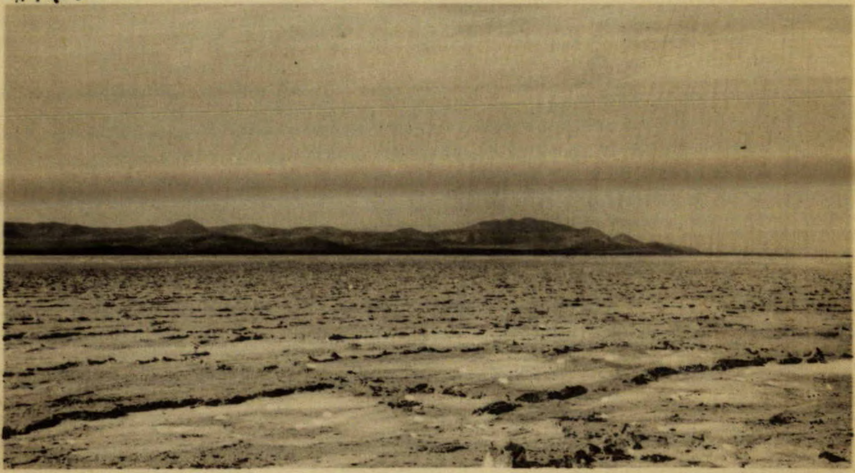
A-1680



Group of mirabilite crystals from Snakehole lake, Sask. From tip to tip, 22 inches.

negative on file Mineral Resources Division

#1681



A. Sodium sulphate deposit in the Carrizo plain, San Luis Obispo county, California, U.S.

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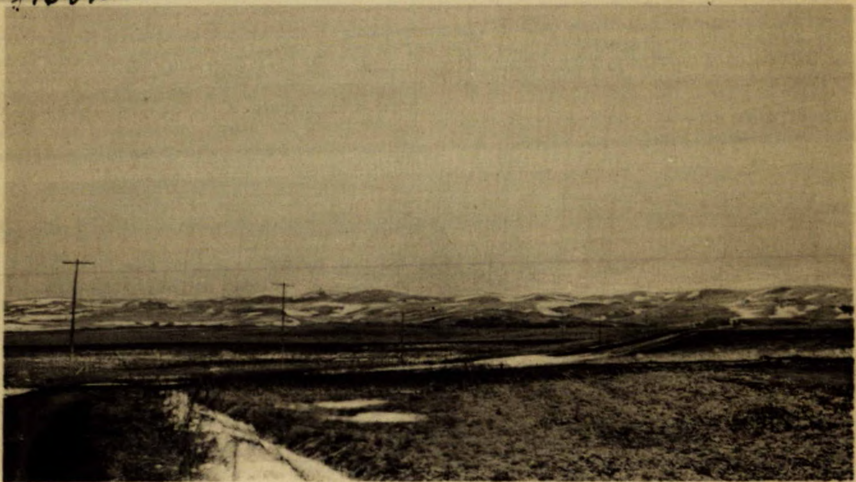

B. General view showing the escarpment of the Missouri coteau, east of Dunkirk, Sask.

underlain by permanent beds of Glauber's salt. Among the more important of these lakes may be mentioned lakes Altai and Domoshakovo.

Lake Altai, according to Ludwig[1], has a diameter of over 1,000 yards. There is a solid deposit of salts about 10 inches thick underlain by mud, underneath which other salts and mud layers occur. The anhydrous material from this deposit runs over 95 per cent sodium sulphate with small proportions of sodium chloride, calcium sulphate and magnesium sulphate. Lake Domoshakovo, about 500 yards long by 250 yards wide, is very similar to lake Altai and has a crystal bed from 20 to 30 inches in thickness.

These deposits are very similar in mode of occurrence to those of western Canada.

Kara Bugas gulf (Black Gulf), on the east side of the Caspian sea, is a large body of water partly cut off from the Caspian sea, and thus conditions are favourable for the concentration and deposition of various salts. A deposition of Glauber's salt takes place in the gulf each winter and does not completely redissolve in the spring. In consequence a permanent deposit of Glauber's salt has been formed.

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[1] Ludwig, F., Chemical Examination of some Mineral Lakes on the East Siberian Steppes. Zeitschr. parkt. Geologie, Vol. XI, 1903.

CHAPTER IV

MINERALOGY

Sodium sulphate occurs in nature as such in *Thenardite* and with combined water as *Mirabilite.* These are the two forms in which it is found in the largest quantities in western Canada, mirabilite forming by far the greater part of the deposits.

It is found in all degrees of purity, from some of the surface or intermittent crystals which closely approximate the theoretical composition of mirabilite, to the massive deposit which contains either combined or mixed salts, and insoluble impurities.

The main characteristics of the two more important minerals of sodium sulphate are given in Table VII[1].

Sodium sulphate also occurs in nature in combination with other minerals, and although none of them have been discovered so far in Canada in sufficient quantities to make them of economic importance, they are of interest as possible forms in which it may be found.

Bloedite. Hydrated double sulphate of sodium and magnesium, $Na_2SO_4 \cdot MgSO_4 \cdot 4H_2O$. Composition: sodium sulphate (Na_2SO_4), 42·5 per cent; magnesium sulphate ($MgSO_4$), 36·0 per cent; water (H_2O), 21·5 per cent. The mineral occurs at the Basque deposits, west of Ashcroft, B.C.

Aphthitalite. A double sulphate of sodium and potassium $(NaK)_2SO_4$. Composition: sodium sulphate (Na_2SO_4), generally 21 to 38 per cent; potassium sulphate (K_2SO_4), 62 to 78 per cent.

Glauberite. Anhydrous sodium-calcium sulphate, $Na_2SO_4 \cdot CaSO_4$. Composition: sodium sulphate (Na_2SO_4), 51·7 per cent; calcium sulphate ($CaSO_4$), 48·9 per cent.

Hanksite. A triple salt with chemical formula of $9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCl$. Composition: sodium sulphate (Na_2SO_4), 81·7 per cent; sodium carbonate (Na_2CO_3), 13·5 per cent; potassium chloride (KCl), 4·8 per cent.

Sulphohalite. A sodium sulphate, chloride and fluoride, $2Na_2SO_4 \cdot NaCl \cdot NaF$. Composition: sodium sulphate (Na_2SO_4), 73·9 per cent; sodium chloride (NaCl), 15·2 per cent; sodium fluoride (NaF), 10·9 per cent.

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[1] For more detailed mineralogy the reader is referred to the following:—

Dana's Mineralogy, Sixth Edition.

Wells, R. C. U.S. Geol. Surv. Bull. 717. Sodium Sulphate: Its Sources and Uses. Washington Govt. Printing Office, 1923.

Ladoo, Rayomd B. Non-Metallic Minerals, pp. 558-564. McGraw-Hill Book Co. Inc., New York. 1925.

Loeweite. A hydrous sulphate of sodium and magnesium, $2Na_2SO_4 \cdot 2MgSO_4 \cdot 5H_2O$. Composition: sodium sulphate (Na_2SO_4), 46·3 per cent; magnesium sulphate ($MgSO_4$), 39·1 per cent; water (H_2O), 14·7 per cent.

Mendozite. A hydrous sulphate of sodium and aluminium, $Na_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$. Composition: sodium sulphate (Na_2SO_4), 15·5 per cent; aluminium sulphate ($Al_2(SO_4)_3$), 37·3 per cent; water (H_2O), 47·2 per cent.

Tamarugite. A hydrous sulphate of sodium and aluminium, $Na_2SO_4 \cdot Al_2(SO_4)_3 \cdot 12H_2O$. Composition: sodium sulphate (Na_2SO_4), 20·3 per cent; aluminium sulphate ($Al_2(SO_4)_3$, 48·9 per cent; water (H_2O), 30·8 per cent.

Ferronatrite. A hydrous sulphate of sodium and iron, $3Na_2SO_4 \cdot Fe_2(SO_4)_3 \cdot 6H_2O$. Composition: sodium sulphate (Na_2SO_4), 45·6 per cent; ferric sulphate ($Fe_2(SO_4)_3$), 42·8 per cent; water (H_2O), 11·6 per cent.

In addition to the above-mentioned minerals there are a few associated minerals which are found in the deposits of western Canada, and which are of interest.

Natron. A hydrous sodium carbonate, $Na_2CO_3 \cdot 10H_2O$. Composition: carbon dioxide (CO_2), 15·4 per cent; soda (Na_2O), 21·7 per cent; water (H_2O), 62·9 per cent. The mineral occurs in extensive deposits in central British Columbia; and is probably present in small quantities associated with the hydrous sulphates on the western plains, when immersed in saturated solutions.

Trona. A hydrous compound of sodium carbonate and sodium bicarbonate, $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$. Composition: sodium carbonate (Na_2CO_3), 46·90 per cent; sodium bicarbonate ($NaHCO_3$), 37·17 per cent; water (H_2O), 15·93 per cent.

Halite. Common salt or sodium chloride, NaCl. Composition: chlorine (Cl), 60·6 per cent; sodium (Na), 39·4 per cent. This is the salt of commerce and small quantities are found in practically all the western deposits.

Gypsum. A hydrous calcium sulphate, $CaSO_4 \cdot 2H_2O$. Composition: sulphur trioxide (SO_3), 46·6 per cent; lime (CaO), 32·5 per cent; water (H_2O), 20·9 per cent. Gypsum crystals are common in the muds associated with the sulphate deposits and in the morainic deposits of the western plains as well as in the Cretaceous shales.

Epsomite. Hydrous magnesium sulphate, $MgSO_4 \cdot 7H_2O$. Composition: sulphur trioxide (SO_3), 32·5 per cent; magnesia (MgO), 16·3 per cent; water (H_2O), 51·2 per cent. The mineral is commonly known as Epsom salts and occurs in varying percentages associated with the sodium salts in the deposits of western Canada.

TABLE VII

Characteristics of Mirabilite and Thenardite

Name	Chemical formula	Theoretical composition
Mirabilite, Glauber's salt........................	$Na_2SO_4 \cdot 10H_2O$......	Na_2SO_4 = 44·1 % H_2O = 55·9 % or Na_2O = 19·3 % SO_3 = 24·8 % H_2O = 55·9 %

Crystal form	Hardness Sp. Gr.	Colour	Lustre	Taste
Monocline. Often long, needle-like crystals, with development of many faces in a long prismatic form.	H = 1·5–2 Sp. Gr. = 1·481	White, transparent to opaque.	Vitreous	Cool, then feebly saline and bitter.

Remarks

Hydrous sodium sulphate. Very soluble in water, and its solubility increases rapidly with a rise in temperature. At 0°C, 100 parts of water dissolve 5·02 parts of Na_2SO_4, while at 33°C, the temperature at which the solubility is highest, the same quantity of water will dissolve 50 parts Na_2SO_4. Loses its water on exposure to dry air and falls to powder. This is the common form in which sodium sulphate occurs in western Canada, where it is found in bedded deposits, as efflorescences and in saturated brines. Goes into solution in water of crystallization on heating above 33°C.

Thenardite......................................	Na_2SO_4............	Na_2O = 43·68 % SO_3 = 56·32 %

Orthorhombic. Pointed pyramids combined into crusts, with surface rough and striated.	H = 2·5. Sp. Gr. = 2·68.	White, grey or brownish, colour being due to included impurities. Transparent to translucent.	Vitreous.......	Faintly saline.

Remarks

Anhydrous sodium sulphate. Very soluble in water. When exposed to the air, it absorbs water and becomes opaque. The massive form of the mineral is occasionally found in the deposits of western Canada, where it has probably been deposited from saturated solutions above temperature of 33°C. It is also found, in dry seasons, on the surface of the deposits in the form of a dry powder as a result of the dehydration of crystallized mirabilite.

CHAPTER V

PHYSICAL AND CHEMICAL PROPERTIES

HISTORICAL[1]

Sodium sulphate was first prepared and described by Glauber in 1658. Its method of preparation then was by the decomposition of common salt by sulphuric acid. He gave to it the name of "sal mirabile," strongly recommending it as a medicine for external and internal use. Later, it was called after its discoverer, "Sal Mirabile Glauberi." The crystallized salt, containing 10 molecules of water of hydration, is, even yet, called Glauber's salt. Kunkle, however, in his Laboratorium Chymicum (1716), asserts that sodium sulphate in the hydrous form had been known as an arcanum to the Electoral house of Saxony a century before Glauber made his discovery.

Anhydrous sodium sulphate, Na_2SO_4 ($Na_2O = 56 \cdot 3\%$, $SO_3 = 43 \cdot 7\%$), was first observed by J. L. Casasica in 1826. It was later identified in the scoria on Mount Vesuvius after the eruption of 1855.

SOLUBILITY OF SODIUM SULPHATE

Table VIII (after Cumming) shows the solubility of sodium sulphate and its hydrates.

These figures are perhaps more readily visualized by studying Figure 10, where the solubility is plotted graphically. An interesting point, well shown by this diagram, is the decreased solubility of the anhydrous salt with increase in temperature. Although the heptahydrate ($Na_2SO_4 \cdot 7H_2O$) is unstable at all temperatures, its solubility has been measured by Loewel.

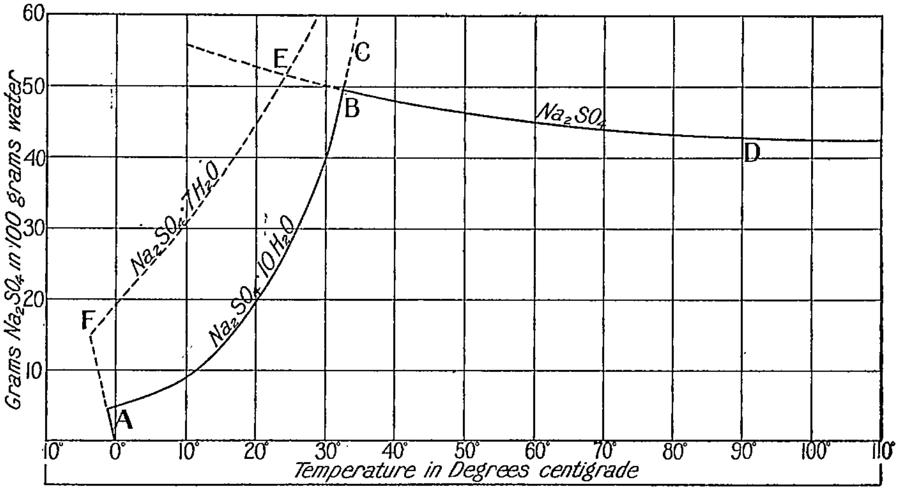

FIGURE 10. Solubility of sodium sulphate in water.

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[1] Cf. Cumming, A. C. Hydrochloric Acid and Salt Cake. Vol. V, of Manufacture of Acids and Alkalis. Lunge and Cumming. p. 23.

TABLE VIII

Solubility of Sodium Sulphate in Water

Temp. °C.	Salt separated at the bottom	Grms. Na_2SO_4 dissolved in 100 grms. water	Observer
0	$Na_2SO_4, 10H_2O$	5·0	Loewel.
10	" "	9·0	"
15	" "	13·2	"
20	" "	19·4	"
25	" "	28·0	"
30	" "	40·0	"
34	" "	55·0	"
Fusion point 34	" "	78·89	Tilden and Shenstone.
−3·55	Ice+$Na_2SO_4, 7H_2O$	14·5	De Coppet.
0	$Na_2SO_4, 7H_2O$	19·6	Loewel.
10	" "	30·5	"
20	" "	44·7	"
26	" "	55·0	"
18	Na_2SO_4	53·3	"
20	"	52·8	"
24·4	$Na_2SO_4, 7H_2O$	51·8	"
25	Na_2SO_4	51·5	"
30	"	50·4	"
32·38	$Na_2SO_4, 10H_2O$	....	Richards and Wells.
32·5	" "	49·6	Interpolated from Gay-Lussacs' results.
35	Na_2SO_4 rhombic crystals	49·4	" " "
40	" "	48·2	" " "
50	" "	46·8	" " "
60	" "	45·5	" " "
70	" "	44·5	" " "
80	" "	43·7	" " "
90	" "	42·9	" " "
100	" "	42·7	" " "
101·9	" "	42·2	Berkeley (at 751 mm. pressure).
120	" "	41·9	Tilden and Shenstone.
140	" "	42·0	" "
160	" "	42·9	" "
180	" "	44·2	" "
230	" "	46·4	" "
150	" "	42·2	Etard.
190	" "	42·7	"
240	" "	42·9	"
320	" "	21·7	"

Crystals of this salt rapidly become changed in air to a mixture of the anhydrous salt and the decahydrate. Seidell[1] found that the solubility of sodium sulphate decreased as increasing proportions of sodium chloride were added to the solution, until when 35 grammes of sodium chloride per 100 grammes of water had been added, the sodium sulphate was practically insoluble.

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[1] American Chemical Journal, Vol. 28, (1902) p. 52.

According to Cumming[1] sodium sulphate is not appreciably soluble in absolute alcohol at ordinary temperatures, and only slightly more so in alcohol which has been acidulated with sulphuric acid. Thus absolute alcohol will precipitate sodium sulphate from a cold saturated solution. In dilute alcohol, however, it is more soluble; the saturated solution, according to Schiff[2], contains at 15° C:—

Alcohol of Specific Gravity	Per cent C_2H_6O by weight	Per cent of $Na_2SO_4 \cdot 10H_2O$
1·000 (water)	0	25·6
0·976	10	14·35
0·972	20	5·6
0·939	40	1·3

Sodium sulphate is soluble in glycerine and also in hydrochloric acid; in the latter case there is a strong evolution of heat. In strong acetic acid it is less soluble. In solutions of potassium sulphate, magnesium sulphate, potassium chloride and other strong saline solutions, it is more readily soluble than in pure water, the increased solubility being probably due to the formation of more easily soluble complex salts.

VARIOUS CHARACTERISTICS OF SODIUM SULPHATE

BEHAVIOUR OF SODIUM SULPHATE IN WATER

Sodium sulphate, at ordinary temperatures, crystallizes from water with 10 molecules of water of crystallization, forming the decahydrate (Glauber's salt), $Na_2SO_4 \cdot 10H_2O$.

Findlay[3], in discussing the behaviour of sodium sulphate in water, says in part:—

> On determining the solubility of this salt in water, it is found that the solubility increases as the temperature rises, the values of the solubility being represented graphically by the curve AC (Figure 10).
>
> On continuing the investigation at higher temperatures, it was found that the solubility no longer increased, but decreased with rise in temperature. At the same time it was observed that the solid phase was now different from that in contact with the solution at temperatures below about 33°; for whereas in the latter case the solid phase was sodium sulphate decahydrate, at temperatures above 33° the solid phase was the anhydrous salt. The course of the solubility curve of anhydrous sodium sulphate is shown by BC (Figure 10).
>
> As is evident from the figure, the solubility curve which is obtained when anhydrous sodium sulphate is present as the solid phase, cuts the curve representing the solubility of the decahydrate, at a temperature of about 33°.

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[1] Cumming, A. C. Hydrochloric Acid and Salt Cake, p. 28. Guerney and Jackson, London, 1923.

[2] Ann. Chem. Pharm. CXVIII, p. 365.

[3] Findlay, Alexander, The Phase Rule and Its Applications, Longmans, Green & Co., London, 1923, pp. 107–109.

If a solution of sodium sulphate which has been saturated at a temperature of about 34° be cooled down to a temperature below 17°, while care is taken that the solution is protected against access of particles of Glauber's salt, crystals of a second hydrate of sodium sulphate, having the composition of $Na_2SO_4 \cdot 7H_2O$, separate out. On determining the composition of the solutions in equilibrium with this hydrate at different temperatures, the values represented by the curve FE were obtained.

Since, as has already been stated, each solid substance has its own solubility curve, there are three separate curves to be considered in the case of sodium sulphate and water. Where two curves cut, the solution must be saturated with respect to two solid phases; at the point B, therefore, the point of intersection of the solubility curve of anhydrous sodium sulphate with that of the decahydrate, the solution must be saturated with respect to these two solid substances. But a system of two components existing in four phases, anhydrous salt—hydrated salt—solution—vapour, is invariant; and this invariability will remain even if only three phases are present, provided that one of the factors, pressure, temperature, or concentration of components retains a constant value. This is the case when solubilities are determined in open vessels; the pressure is then equal to atmospheric pressure. Under these circumstances, then, the system, anhydrous sodium sulphate—decahydrate—solution, will possess no degree of freedom, and can exist, therefore, only at one definite temperature and when the solution has a certain definite composition. The temperature of this point s 32·383° or, in round figures, 32·4°.

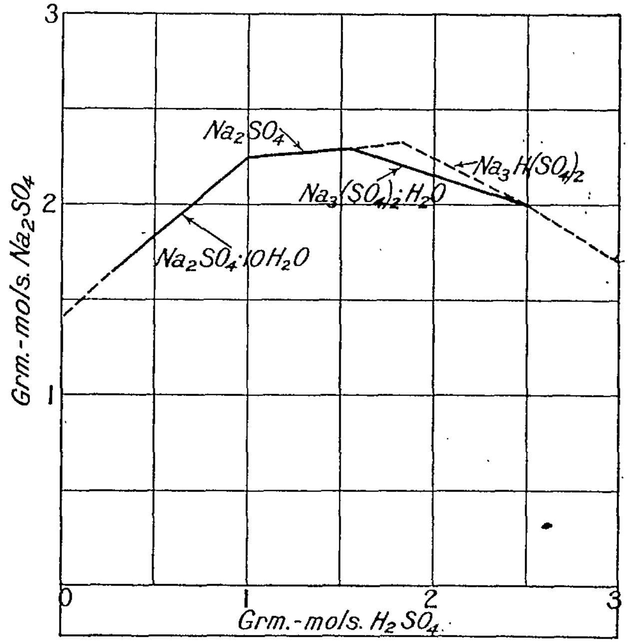

FIGURE 11. Solubility of Na_2SO_4 with increasing proportions of H_2SO_4 per 100 grammes of solution.

According to Mellor[1] a solution of sodium sulphate and sulphuric acid deposits double salts the composition of which is determined by the temperature, the concentration, and the relative proportion of acid and salt in the solution. If the number of molecules of normal sulphate,

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[1] Mellor, J. W. A Comprehensive Treatise on Inorganic and Theoretical Chemistry: Vol. II, p. 677. Longmans, Green & Co., London, 1922.

Na_2SO_4 and of H_2SO_4, in equilibrium with a solid phase or phases at 25°, be plotted, a curve will be obtained with breaks as shown in Figure 11 (after Mellor). This shows the limiting concentration for the passage from the decahydrate, $Na_2SO_4 \cdot 10H_2O$, to the anhydrous sulphate Na_2SO_4, thence to the anhydrous trisodium hydrodisulphate, $Na_3H(SO_4)_2$, or the monohydrated trisodium hydrodisulphate, $Na_3H(SO_4)_2 \cdot H_2O$. With a greater increase in the concentration of the acid, a break appears corresponding with the formation of monohydrated sodium hydrosulphate, $NaHSO_4 \cdot H_2O$; then the anhydrous hydrosulphate, $NaHSO_4$, appears and the curve joins on to that shown in Figure 12.

P. Pascal and M. Ero made a detailed study of the ternary system, Na_2SO_4-H_2SO_4-H_2O, and determined the solid phases and their regions of stability. The results which they obtained are graphically shown in Figure 13.

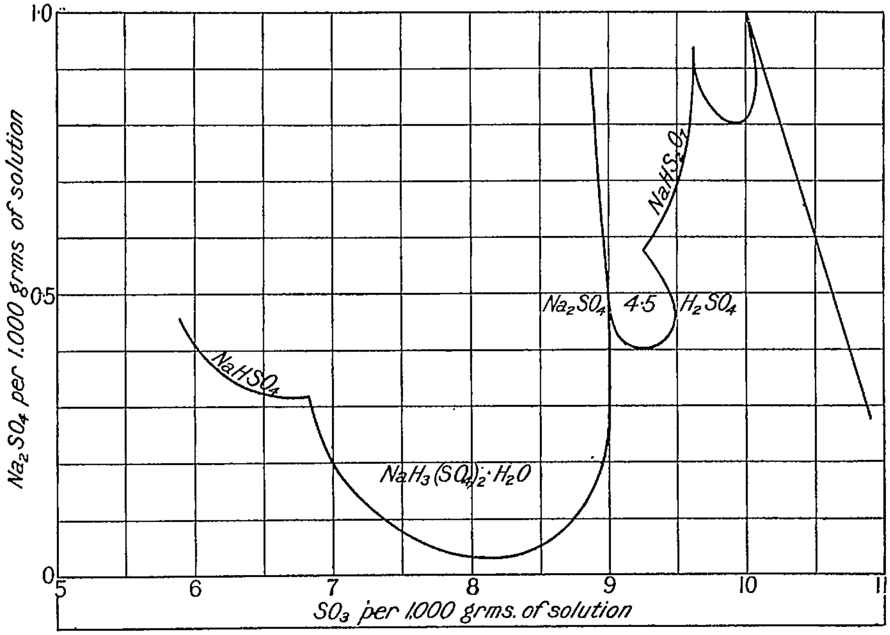

FIGURE 12. Solubility curve of sodium sulphate, Na_2SO_4, in mixtures of SO_3—H_2O, at 25° C. (after Mellor).

The three component system, Na_2SO_4-$NaCl$-H_2O, has been studied by many investigators, notably by W. Myerhoffer, A. P. Saunders, J. H. Van't Hoff, A. W. Browne, A. Seidell and W. O. Robinson. The general results they obtained are shown in Figure 14 (after Mellor). This shows a part of the triangular diagram with H_2O, Na_2SO_4 and $NaCl$ each at an apex. The curve AB shows the solution in equilibrium with the solid phase $Na_2SO_4 \cdot 10H_2O$; BC, with the solid anhydrous phase Na_2SO_4; and CD with the solid phase NaCl. From this it can be seen that there is no sign of a double salt.

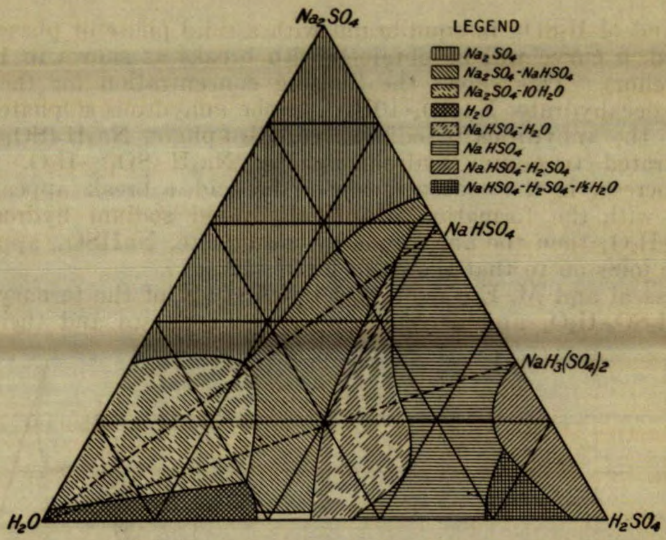

FIGURE 13. Regions of stability of the solid phases in the ternary system H_2SO_4—Na_2SO_4—H_2O. (P. Pascal and M. Ero).

Myerhoffer and Saunders found that the temperature at which the change from the decahydrate $Na_2SO_4 \cdot 10H_2O$ to anhydrous sodium sulphate Na_2SO_4 takes place is reduced from 32·8° to 17·9° C, when the liquid is saturated with respect to NaCl.

If crystallization occurs in an aqueous solution below the temperature of 32·383° C, crystals of the decahydrate $Na_2SO_4 \cdot 10H_2O$ are formed.

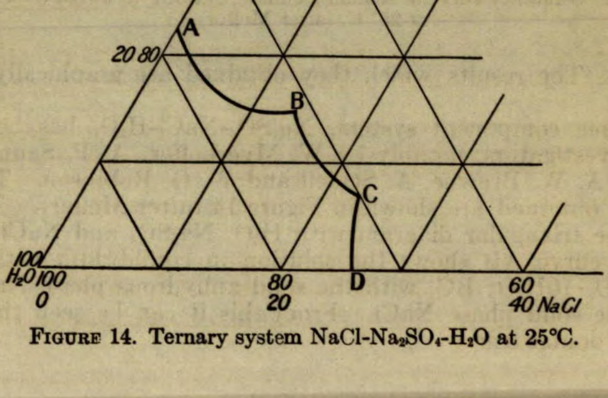

FIGURE 14. Ternary system NaCl-Na_2SO_4-H_2O at 25°C.

A supersaturated solution is readily obtained by simply lowering the temperature of a warm solution of sodium sulphate in half its weight in water, keeping the vessel covered. However, the supersaturated state is easily upset, and crystallization may be started by introducing a minute fragment of Glauber's salt. If, however, the solution is cooled below –15° there is no need of adding the fragment of Glauber's salt, as crystallization occurs spontaneously.

The *vapour pressure* of the decahydrated salt at 20° is 27·8 mm. The *fusion temperature* of the same salt is 32·383°, the same as the transition temperature.

The *specific gravities* of solutions of sodium sulphate at different degrees of concentration at 15° and 19° C are given in the following tables (after Cumming):—

TABLE IX

Specific Gravity of the Solutions of Sodium Sulphate at different Degrees of Concentration at 15°C., according to Gerlach

Per cent	Na_2SO_4	Na_2SO_4, $10H_2O$	Per cent	Na_2SO_4	Na_2SO_4, $10H_2O$
1	1·0091	1·004	16	....	1·064
2	1·0182	1·008	17	....	1·069
3	1·0274	1·013	18	....	1·073
4	1·0365	1·016	19	....	1·077
5	1·0475	1·020	20	....	1·082
6	1·0550	1·024	21	....	1·086
7	1·0644	1·028	22	....	1·090
8	1·0737	1·032	23	....	1·094
9	1·0832	1·036	24	....	1·098
10	1·0927	1·040	25	....	1·103
11	1·1025	1·044	26	....	1·107
12	....	1·047	27	....	1·111
13	....	1·052	28	....	1·116
14	....	1·056	29	....	1·120
15	....	1·060	30	....	1·125

At 19°C., according to Schiff,[1]

Specific Gravity	Per cent Na_2SO_4, $10H_2O$	Per cent Na_2SO_4	Specific Gravity	Per cent Na_2SO_4, $10H_2O$	Per cent Na_2SO_4
1·0040	1	0·441	1·0642	16	7·056
1·0079	2	0·882	1·0683	17	7·497
1·0118	3	1·323	1·0725	18	7·938
1·0158	4	1·764	1·0766	19	8·379
1·0198	5	2·205	1·0807	20	8·820
1·0238	6	2·640	1·0849	21	9·261
1·0278	7	3·087	1·0890	22	9·702
1·0318	8	3·528	1·0931	23	10·143
1·0358	9	3·969	1·0973	24	10·584
1·0398	10	4·410	1·1015	25	11·025
1·0439	11	4·851	1·1057	26	11·466
1·0479	12	5·292	1·1100	27	11·907
1·0520	13	5·733	1·1142	28	12·348
1·0560	14	6·174	1·1184	29	12·789
1·0601	15	6·615	1·1226	30	13·230

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[1] Ann. Chem. Pharm., CX, p. 70.

According to Mellor[1] the *diffusion coefficient* of 1·4 N solution of sodium sulphate in cold water at 10° is 0·66 sq. cm. per day. The *specific heat of solutions* of sodium sulphate falls from 0·997 (12°–15°) for 1·9 per cent solution, to 0·781 (24°–100°) for 30·3 per cent solution. According to G. Jager, the *thermal conductivity* of a 10 per cent solution of sodium sulphate is 99·8 where water is 100.

Boiling-point. A solution containing 9·5 grammes of sodium sulphate per 100 grammes of water, boils at 100·5°, while one with 46 grammes of salt per 100 grammes water boils at 103·7° C. A saturated solution when boiled becomes covered with a crust of the anhydrous salt (Na_2SO_4).

CHEMICAL REACTIONS

At a temperature above 500° C sodium sulphate is reduced by hydrogen, forming a mixture of sodium sulphate, sodium hydroxide and sulphuric acid.

The anhydrous salt, when heated alone, does not readily decompose, even at high temperatures.

When sodium sulphate is intimately mixed with carbon, in the proportion required by the equation $Na_2SO_4 + 4C = Na_2S + 4CO$, and heated, no reaction takes place until a temperature of 950° C is reached, after which the reduction is rapid and uniform, and the rate of reaction increases rapidly as the temperature is raised.

If silica is added to sodium sulphate and heated to a high temperature no reaction takes place until carbon is added, when sodium silicate is formed. This reaction is taken advantage of in the manufacture of glass and allows the use of sodium sulphate in place of sodium carbonate. However, care must be taken not to add more carbon than required for the reaction, as otherwise sodium sulphide will be formed and the glass coloured yellow.

Carbon monoxide reacts with sodium sulphate to form sodium sulphide and carbon dioxide. Sulphur dioxide does not act on the sulphate at red heat, but sulphur at the same temperature forms sodium sulphide and sulphur dioxide.

If a current of hydrochloric acid gas is passed over sodium sulphate at red heat, it is entirely converted into sodium chloride, sulphuric acid being liberated.

No decomposition takes place when sodium sulphate is fused with calcium carbonate.

Sodium sulphate and alumina do not react even on prolonged heating to redness, but, in the presence of water and carbon, sodium aluminate is formed.

METHODS EMPLOYED IN ANALYSES OF SAMPLES OF SODIUM SULPHATE

Natural sodium sulphate gives, generally, an alkaline or neutral reaction. Foreign constituents are in most cases composed of insoluble material such as sand, clay, marl, organic matter, etc., and solubles such

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[1] Mellor, J. W., A Comprehensive Treatise on Inorganic and Theoretical Chemistry, Vol. II, Longmans, Green & Co., London, p. 669.

as magnesium sulphate ($MgSO_4$), sodium chloride ($NaCl$), sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$) and calcium sulphate.

A description of the methods employed in making the analyses given in this report follows.

Insoluble Matter

Three grammes of substance is weighed, dissolved in 100 c.c. distilled water, boiled and filtered and the insoluble residue dried and weighed. The percentage of insoluble is then calculated and reported as insoluble in water. The filtrate is made up to 300 c.c.

Sodium Chloride

The quantity of sodium chloride is determined by taking 50 c.c. of the above filtrate, adding a few drops of yellow potassium chromate, and titrating with deci-normal silver nitrate solution, till the precipitate takes just a perceptible pink shade. Each cubic centimetre of the silver solution will indicate 0·146 per cent of NaCl, but when potassium chromate has been employed as the indicator, 0·2 c.c. must be deducted from the silver nitrate solution used for the quantity required to produce the coloration. Instead of the ordinary N–10 silver solution it is sometimes found more convenient to employ a solution containing 2·905 grammes silver nitrate per litre, which indicates 0·001 milligram of sodium chloride per cubic centimetre. In case the salt gives a strong alkaline reaction, it should first be neutralized with sulphuric acid.

Lime

In determining lime 50 c.c. of the filtrate is pipetted off, made acid with hydrochloric acid in order to decompose any carbonates present, brought to boiling, and ammonia water added in slight excess. The lime is then precipitated as calcium oxalate by the addition of ammonium oxalate and determined in the usual way by titration with potassium permanganate.

Magnesia

Magnesia is determined by precipitating it in the filtrate from the calcium oxalate, by the addition of the usual phosphate mixture. It is then calculated as the sulphate or the chloride as the case may be.

Ferric Oxide and Alumina

Ferric oxide and alumina very rarely occur in any appreciable quantities in the soluble portion of natural Glauber's salt. When present, they are precipitated by adding ammonia water before precipitating the lime as oxalate. Alumina and ferric oxide are weighed together, and the iron is estimated separately by fusing with potassium bisulphate, the melt dissolved in water and the iron determined by reducing with stannous chloride and titrating with potassium permanganate.

A considerable quantity of iron and alumina will always be present in the insoluble matter.

Carbonate and Bicarbonate

Carbonate and bicarbonate are determined by titrating 50 c.c. of the solution with N–20 hydrochloric acid, using phenolphthalein as the indicator for the carbonate, and methyl orange for the bicarbonate. The results obtained are calculated as sodium carbonate and sodium bicarbonate.

Sulphuric Acid

In this determination 50 c.c. is pipetted off, made acid by adding hydrochloric acid, heated to boiling and precipitated with 10 per cent solution of barium chloride added drop by drop. The solution is allowed to settle, is filtered and the precipitate weighed as barium sulphate.

Analyses of Brine

The methods for analyses of brines are very much the same as for the solid salt in estimating lime, magnesia, chlorine, sulphuric acid and carbonates. In natural springs the bicarbonate is calculated as the calcium salt, in which form it is generally conceded to be present.

The specific gravity is taken, and the temperature observed. An amount of brine is pipetted off corresponding to a quantity of solids convenient for analyses and the different constituents determined and calculated either in parts per million or per thousand.

Bromine and Iodine

Bromides may occur in natural salts and springs. They are tested for by acidifying the brine with hydrochloric and adding a little chlorine water and shaking up with chloroform. The presence of bromine is indicated by a yellow colour. *Iodine* under similar treatment will yield a purple colour.

CHAPTER VI

USES OF SODIUM SULPHATE

In the chemical manufactories, sodium sulphate finds an extensive application and the demand is increasing. Since by far the greater part of the Canadian consumption is imported, it is of importance to analyse the different uses with a view to finding whether material from Canada can be utilized.

Sodium sulphate is used extensively in the pulp and paper, glass, dye, and textile industries and to a smaller extent for medicinal and tanning purposes.

PULP AND PAPER INDUSTRY

In Canada sodium sulphate in the form of salt cake finds its largest use in the pulp and paper industry. The sulphate pulp process, in which method salt cake is employed as one of the raw materials, is a modification of the soda process and has only come into extensive use in Canada within the last 20 years. The fibre obtained by the sulphate process has gained considerable favour on account of its great strength and flexibility. Paper produced from this fibre is known to the trade as kraft paper and mills using the sulphate process are sometimes called kraft mills.

Although all the mills employing this process in Canada at the present time use woods of the coniferous type, it is also possible to use esparto, straw and other similar fibrous materials.

Outline of Sulphate Pulp Process

The term 'sodium sulphate,' as applied to this process, is really a misnomer since sodium sulphate as such is not employed in the cooking of the batch but is first changed to sodium sulphide, and therefore the process really should be known as the 'sulphide process.' The different operations in this process are clearly shown in Figure 15. The order of the operations is clockwise around the diagram, according to the figures given in the centre. In commencing with No. 1, the chips of wood or other material to be cooked are placed in the digester together with the white liquor and also a certain amount of black liquor brought back from the diffuser in order to dilute the white liquor to the required strength. Steam is added under pressure and the batch is cooked or digested for a certain length of time. The arrows in the diagram indicate the direction of the different products obtained. When the cooking is completed, the batch is transferred to the second operation where the pulp is completely washed and recovered. The black liquor, containing the spent alkalis and the organic substances extracted from the wood, is transferred to the evaporator departments where it is concentrated sufficiently to allow it to be dried in the rotary furnace. From the rotary furnace it comes out in lumps known as black ash. This black ash contains sometimes as high as 50 per cent combustible matter, derived from the organic matter of the wood. The remainder of the material is the inorganic chemicals from the cooking.

To the black ash, sodium sulphate (salt cake) is added in the proper proportion to renew the alkali and the mixture is then fired in the smelting furnace where the organic material and gases are driven off. A certain proportion of the salt cake is carried off in the flue dust and where this loss is considerable it is recovered in suitable apparatus and re-charged into the smelting furnace. Some operators prefer to add the salt cake in solution to the black liquor entering the rotary furnace, but a more common practice is the one described. In this smelting furnace the sodium sulphate is practically all changed to sodium sulphide so that when the furnace is tapped and the molten mass is discharged into the dissolving-tanks the melt contains varying proportions of sodium carbonate, sodium sulphide, and a little sodium sulphate.

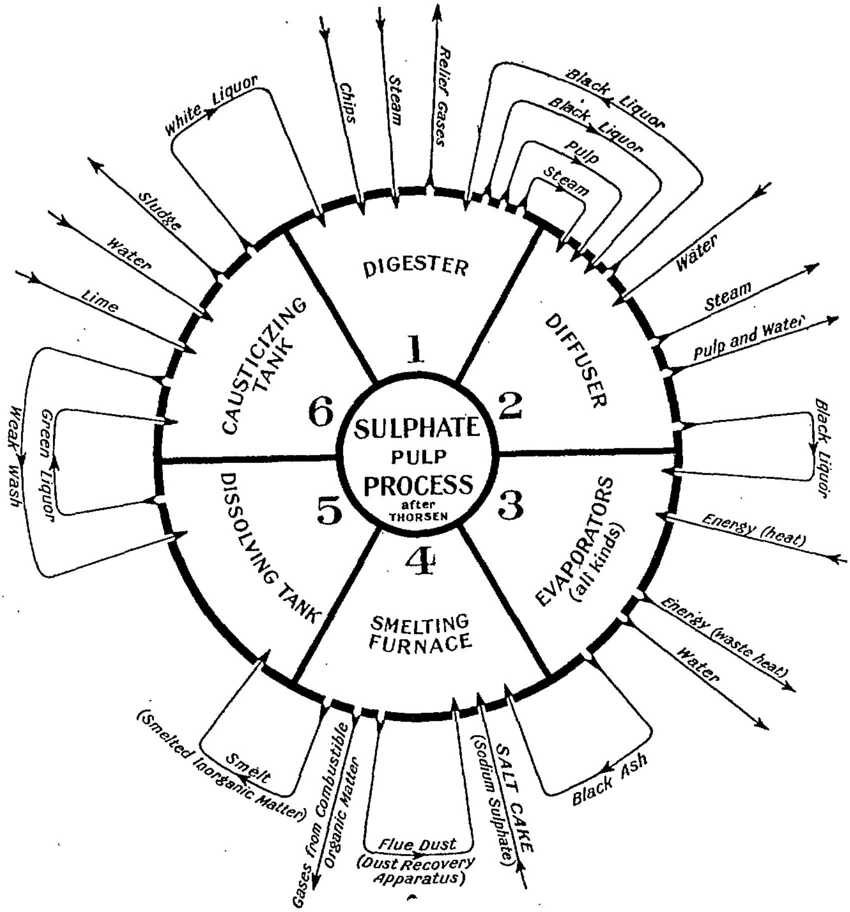

FIGURE 15. Diagram showing sulphate pulp process. (After Thorsen.)

Weak wash water from the causticizing tanks is used to dissolve the melt. From the dissolving tanks the dissolved alkalis, called the green liquor, is transferred by siphons to the causticizing tanks. Since sodium carbonate, as such, plays no part in the digesting of the wood, it has to be changed into caustic soda. This is done by adding lime to the causticizing tanks in sufficient quantity to neutralize the sodium carbonate. The resultant liquor obtained from the causticizing tanks is known as white liquor and as such is ready for use in the digesters, thus completing the cycle of operations.

REQUIREMENTS OF SODIUM SULPHATE FOR THE PULP AND PAPER INDUSTRY

The requirements of the paper manufacturers call for a salt cake running as high in sodium sulphate as possible. The salt cake of commerce is material produced as a by-product in the manufacture of hydrochloric acid, a typical analysis of which runs as follows:—

	Per cent
Moisture	0·24
Silica	0·19
Iron oxide	0·45
Alumina	trace
Sodium chloride	2·15
Free sulphuric acid	1·95
Sodium sulphate (calc.)	95·01

Less than one per cent of sodium chloride is advisable, and not more than 0·5 per cent of iron since the presence of iron causes trouble in causticizing the liquor. Calcium and magnesium sulphates would probably not prove detrimental to the product and it is thought that the magnesium salt would make a paper a little more flexible though perhaps a little heavier. It must be understood, however, that the more impurities there are present the smaller will be the amounts of available sodium sulphate. The material as obtained from the deposits of western Canada contains no free sulphuric acid such as is found in the by-product material produced. It is also iron-free and should therefore prove entirely suitable for use in the pulp and paper industry.

THE GLASS INDUSTRY

One of the most extensive uses of sodium sulphate is as a source of "alkali" in glass manufacture. In the production of sheet and plate glass of all kinds the alkali required in the 'batch' is frequently introduced in the form of salt cake. Since commercial salt cake is a relatively crude product, its extensive use in the glass industry has been due to the fact that it is generally obtainable at a greatly cheaper rate per unit of Na_2O than soda ash.[1]

In its use in glass-making it has certain disadvantages as compared with soda ash. Probably the chief one is that silica alone cannot decompose the salt cake and therefore some reducing agent has to be added. The reducing agent generally employed is some form of carbon such as charcoal, coke or powdered anthracite coal. The disadvantage of using such reducing agent is that highly skilled labour is required to tend the furnace tanks when salt cake is used, since the use of a slightly incorrect quantity of

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[1] See Figure 9, Chapter II.

carbon is quite liable to lead to the loss of the whole batch. Another objectionable feature is that it is not easy to remove all traces of sulphur compounds from the glass made by this process and it is only by the most careful attention that high quality glass can be produced. With the use of the ordinary by-product salt cake further troubles are liable to be encountered due to the deleterious impurities that many of the commercial by-product salt cakes contain. It frequently carries small quantities of free sulphuric acid as well as undecomposed sodium chloride, and in most cases an appreciable quantity of iron. Commercial by-product salt cake when powdered and exposed to air absorbs a certain quantity of moisture from the air, with the result that part of it is converted into Glauber's salt, thus tending to compact the material into hard masses which have to be reground before use. In fact, it has been known to become so hard both in the cars in which it was shipped from the works as well as in the stock piles that it has required dynamiting to break it up. It is also an exceedingly difficult material to grind at all fine.

On the other hand, there appear to be a number of advantages when salt cake is substituted for soda ash under certain conditions. With the use of salt cake a higher temperature is required in the tank and in consequence a greater proportion of silica sand can be employed, thus reducing the cost of the batch. Frink[1] found that glass made with salt cake, the furnace conditions being the same, is harder, has a higher softening-point, greater strength, and is less viscous at 845°C. than that containing soda ash, although analyses showed that their composition was practically the same.

Gelstharp and Parkinson[2] found that sodium sulphate must be present in order to successfully produce glasses containing more than 8 per cent of lime.

Very little sodium sulphate has been used for glass manufacture in Canada and until sheet and plate glass of all kinds are produced in this country it is not likely to come into extensive use. The possibility of substituting sodium sulphate for soda ash in the Canadian glass-plants, which manufacture bottles, etc., will largely depend on the relative price of sodium sulphate and soda ash based on their respective Na_2O content.

The amount of sodium sulphate added to the batch varies greatly in different practice. Some manufacturers of glass bottles and other containers use comparatively small amounts of salt cake, in some cases only about 40 pounds per ton of product. Window and plate glass manufacturers require that from 20 per cent to 25 per cent of the batch be sodium sulphate.

REQUIREMENTS AND SPECIFICATIONS OF SALT CAKE FOR GLASS MANUFACTURE

Opinions differ greatly as to the specifications required for a good salt cake for use in glass manufacture. Rosenhain[3] states that:—

> A good salt cake, however, should contain at least 97 per cent of anhydrous sodium sulphate, and not more than 1·0 per cent of either sodium chloride or sulphuric acid.

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[1] Transactions American Ceramic Society, Vol. XI, 1909, p. 311.

[2] Transactions American Ceramic Society, Vol. XVI, 1914, p. 115.

[3] Rosenhain, Walter. Glass Manufacture, 2nd Ed. Constable & Company, Ltd., London, 1919.

While pure sodium sulphate is readily soluble in water, ordinary salt cake always leaves an insoluble residue, consisting frequently of minute particles of clay or other material derived from the lining of the furnace in which it was prepared, or from the tools with which it was handled; and these impurities are liable to become deleterious to the glass if present in any quantity. The insoluble residue should not exceed 0·5 per cent in amount, and in the best salt cake is generally under 0·2 per cent.

Like the other impurities in the batch, the iron and aluminium oxide content of the sodium sulphate should be as low as possible and should in no case exceed 0·4 per cent. It is generally specified that the magnesium sulphate present should be less than 0·2 per cent, though why this very low limit is set for the magnesium sulphate in the salt cake is hard to understand when one glass company on this continent, whose reputation for quality of glass stands unexcelled, has for years been using a lime carrying an average of 6 per cent of magnesia, and at times going as high as 13 per cent.

Moisture in the salt cake is undesirable since it tends to cause trouble in the glass-tank due to the turning of the water into steam, and in some cases causes dangerous explosions. Even if the generation of the steam does not cause danger it is liable to carry an excess of the finely divided sulphate up the stack causing a loss of an appreciable amount of the salt cake available in the melt. An excess of moisture in by-product salt cake also causes trouble where the material has to be ground before mixing with the batch.

It can, therefore, be seen that it is difficult to set hard and fast specifications for salt cake for use in glass manufacture since impurities which one manufacturer may claim to be deleterious, another manufacturer may claim to be essential to successful operation. It should be borne in mind, however, that the salt cake is employed in glass-making to supply "alkali" (Na_2O) to the batch and therefore any impurities, while they may not affect the quality of the glass in themselves, reduce the amount of available Na_2O content in the salt cake.

NICKEL REFINING

In refining nickel matte by the Orford process sodium sulphate is employed in the form of nitre cake.

The process consists in fusing the matte containing the sulphides of iron, copper and nickel with sodium sulphide or with sodium sulphate and coal (which mixture produces sodium sulphide on fusion) in a cupola furnace and tapping into pots. The greater part of the nickel sulphide and small percentages of the iron and copper form a matte which sinks to the bottom of the pot and can be readily separated.

The process is being continually improved upon but it is the basis of the process employed by the International Nickel Co. at their refinery at Port Colborne, Ont.

The following quotation from the patent specifications of the U.S. patent No. 802012 granted to Ambrose Monell, gives the outline of the process in so far as it deals with sodium sulphate:—

> Instead of smelting the compound matte, as heretofore, in a cupola-furnace and running the product continuously into moulds, I so smelt the matte that when melted it will remain in a molten state subject to the high temperature of a furnace for a considerable period of time, during which I find that the copper and iron sulphides will be thoroughly dissolved by the sodium sulphide, and in one melting a good separation can be effected,

and by two such treatments results are obtained equal or superior to the results of the four or five meltings which have been employed heretofore. For this purpose I employ as the smelting-furnace an open-hearth reverberating furnace lined with magnesite brick, as I find that silica-lined furnaces are quickly destroyed by fluxing with the sodium sulphide. Into such furnaces I introduce a charge of nickel-copper-iron matte, either solid or molten together with coke and *sodium sulphate, the latter being preferably present in the proportion of sixty per cent of the weight of the matte,* and the coke in the proportion of fifteen per cent of the matte. *The sulphate is preferably added in the form of commercial nitre-cake.* Where, for example, a fifty-ton charge of matte is treated containing, say, forty-five per cent of nickel sulphide and thirty-five per cent of copper sulphide, it is melted in the furnace and retained subject to the heat for some time—say, four to five hours after fusion has occurred—during which time it is preferably "poled"—that is to say, treated by immersing beneath its surface poles of green wood, which evolve hydrocarbon gases and vapors, and thus aid in the reduction of the sulphate and produce an agitation of the material, which facilitates and renders more thorough the solution of the sulphides to be removed. Nearly complete solution of the copper and iron sulphides in the sodium sulphide reduced from the nitre-cake is thus effected, and the molten charge may be tapped from the furnace and allowed to separate in moulds.

The possibility of utilizing the sodium sulphate of western Canada for this purpose depends entirely on the price of the material as compared with nitre cake.

TEXTILE DYEING

In the dyeing of textiles such as wools and cottons, sodium sulphate is used in certain of the dye-baths. The use of the sodium sulphate in the dye-bath according to Matthews[1] may exert an influence in several different ways:—

(*a*) In mechanically retarding the interaction between the colour-acid and the fibre.
(*b*) In chemically retarding the liberation of the colour-acid from the dye-salt.
(*c*) In affecting the solubility of the dyestuff in the solution.

In dyeing of wool or cotton with acid colours the dye-bath usually contains an amount of Glauber's salt equivalent to about 20 per cent of the weight of the material being dyed. The dye-bath is kept just near the boiling-point.

In practice it is found that the use of sodium sulphate in the dye-bath tends to give a more level and better distribution of the dye stuff on the fibre being dyed.

Glauber's salt is the form of sodium sulphate generally used in textile dyeing. The use of this form has probably been due to the fact that, as a general rule, commercial Glauber's salt can be obtained in a greater degree of purity and of more uniform grade than the ordinary by-product salt cake. However, there does not appear to be any reason why the anhydrous sodium sulphate, such as can be prepared from the deposits of western Canada, could not be used in this industry.

TANNING INDUSTRY

Sodium sulphate is not used in the tanning industry proper but large amounts are employed advantageously in the curing of hides. For this purpose it is employed in a similar manner to common salt.

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[1] Matthews, J. M. Application of Dyestuffs, New York, John Wiley & Sons, 1920, p. 185.

PAINT AND VARNISH INDUSTRY

Sodium sulphate finds a limited use in the manufacture of mineral and lake pigments. For this use it is employed in both the hydrated and anhydrous forms. Since iron spoils the shade of the colours it is necessary to employ materials which are iron free. In this connexion the sodium sulphate obtained from the deposits in western Canada should prove entirely suitable since they contain practically no iron.

Ultramarines

In the manufacture of ultramarines, sodium sulphate is used to neutralize part of the silicic acid of the kaolin and to form some quantity of sodium sulphur compounds. According to Bersch[1] the following mixture can be successfully used:—

	Parts by weight	Per cent of batch
Anhydrous kaolin	100	38·9
Anhydrous Glauber's salt	42	16·3
Anhydrous soda	42	16·3
Sulphur	60	23·4
Coal	13	5·1
		100·0

In the manufacture of ultramarine, the raw materials are intimately mixed, and then calcined in a reducing atmosphere. The coal causes a reduction of part of the sodium sulphate to sodium sulphide, which, since sulphur is present in the original charge, unites with a further quantity of that element. The sodium sulphur compounds thus produced unite with the sodium and aluminium silicates to form a green compound, which when suitably washed and ground to a fine powder is sold as green ultramarine. The blue ultramarine of commerce is obtained by subjecting the green ultramarine for a short time to a moderate red heat, with free access of air, either with or without finely powdered sulphur.

Soluble Prussian Blue

In the preparation of soluble Prussian Blue, sodium sulphate is employed to precipitate the pigment which is insoluble in the salt solution.

ELECTRO-CHEMISTRY AND ELECTRO-PLATING

In the electro-chemical industries sodium sulphate is employed in a number of cases as one of the salts dissolved in the baths. In electroplating the addition of sodium sulphate to the bath tends to increase the conductivity. The purity of the salt for this use has to be high, since iron or other metallic compounds tend to affect the product being recovered or deposited.

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[1] Bersch, Josef. The Manufacture of Mineral and Lake Pigments, translated from the second revised edition by Arthur C. Wright, London, Scott, Greenwood and Son, 1901, p. 209.

MEDICINAL[1]

For medicinal use sodium sulphate in the form of Glauber's salt is widely employed. It is a hydragogue purgative and cholagogue, and has been found to be useful in cases of gall stones and of liver disease. When administered in small and repeated doses it is especially well adapted to cases of constipation associated with gout and nepatic dyspepsia.

In acute cases no drug is known which acts so rapidly, painlessly, or so effectually. The drug is generally administered in solution together with syrup of ginger, peppermint water, etc., in order to partly disguise the bitter taste. It is also used in the effervescent granule form. For the preparation of this form 50 parts of sodium sulphate crystals are used together with 50 parts sodium bicarbonate powder, 27 parts of tartaric acid powder and 18 parts of citric acid powder. The mixture is then granulated.

B.P. Glauber's salt is officially required to contain about 99·9 per cent of pure crystallized sodium sulphate. The more common impurities found in Glauber's salt are arsenic, copper, lead, iron, calcium, magnesium, ammonium, sodium acid sulphate, potassium, carbonates, chlorides, and excess of water.[2]

Veterinary Use

Sodium sulphate in the form of Glauber's salt, is extensively employed as a purgative for cattle, horses, and sheep. Concentrated solutions are said to draw water from the blood vessels, thus causing greater fluidity. It is also one of the principal ingredients of Carlsbad salt, used extensively as a laxative.

CHEMICAL INDUSTRIES

Sodium sulphate is employed in the chemical industry in the preparation of other sodium salts, such as sodium carbonate, sodium sulphide, sodium silicate, sodium hypochlorite, sodium thiosulphate, sodium acetate and several other sodium salts from the corresponding calcium salts. As the process of the manufacture of these various salts will be dealt with at greater length in Chapter IX, they will not be further enlarged on here.

In addition to the uses already mentioned, sodium sulphate is employed in limited quantity in a number of other industries or processes. Thus, it is used to a small extent in explosives manufacture. It is also occasionally employed as a fungicide, and as an adulterant in some baking powders.

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[1] See Squire's Companion to the British Pharmacopœia, 19th ed., 1916.

[2] For details of tests, and limits allowed, of these impurities in B.P. Glauber's salt the reader is referred to Squires Companion to the British Pharmacopœia, 19th ed. 1916, pp. 1306–1307.

CHAPTER VII

TECHNOLOGY OF NATURAL SODIUM SULPHATE

Sodium sulphate as it occurs in the deposits of western Canada is in the hydrous form of crude Glauber's salt, or in solution as a brine. Since very little of the material can be marketed in either of these forms, it will be necessary in most cases to subject the material to some purifying and dehydrating treatment before a marketable product is obtained.

RECOVERY OF SODIUM SULPHATE FROM DEPOSITS

The sodium sulphate may be recovered either as a brine or as crude Glauber's salt. The form in which the salts are recovered is dependent largely on several factors. Climatic conditions are such that the recovery in either form can be accomplished only at certain seasons. Thus, in the spring and early summer the deposits are generally brine-covered, the brine increasing in salt content as the season progresses. During this period little or no harvest crystal is present and consequently, unless an attempt is made to excavate the permanent bed, no crystal is available. During the latter part of the summer and in the winter months, harvest or intermittent crystal is formed, the brine in most years completely disappearing, so that crystal can be gathered. The process for purifying and dehydrating the salts also has a direct bearing on the form in which the salts are taken from the deposits, since if the process includes artificial evaporation, it may be possible to feed the saturated brine directly to the evaporators and thus eliminate the extra cost of having to put the crystals into solution. It can thus be seen that local conditions will to a large extent govern the form in which the material is recovered.

Recovery as a Brine

If the salts are to be recovered as brine from the deposits, Baumé readings of the brine should be taken daily in order to determine when it is of sufficient saturation. In using such brine it must be remembered that in most of the deposits the brine will carry a higher percentage of those salts which are more readily soluble than the sodium sulphate, such as magnesium sulphate, and that any product obtained from the evaporation of this brine will consequently also contain more of these impurities than if made from the crystal.

The brine may, if necessary, be concentrated in open vats along the shore, or if saturated may be pumped directly into storage tanks. Care would have to be taken in installing a pumping system for such brine, and arrangements made so that all pipe lines and pumps could be thoroughly drained when not in use, as a sudden drop in temperature, if the brine were saturated, would be liable to crystallize it solid throughout the whole pumping system.

Recovery as Crude Glauber's Salt

The more feasible method to recover the sodium sulphate seems to be in crystal form as crude Glauber's salt. In the late summer the brine on the deposits becomes sufficiently saturated so that a slight drop in temperature will cause the salts in solution to crystallize and the continued deposition of these salts will, in a very short time, build up a bed of clean crystals, the thickness of which will vary from a few inches up to two feet, dependent on the amount of salts available in the brine and the size of the lake basin. The crystals known as the intermittent or harvest crystals are generally very pure when first deposited, and can be readily gathered when all the brine has disappeared.

The crystal of the intermittent bed may be gathered when first deposited or it may be allowed to gain a certain degree of hardness or compactness. If the material is to be shipped as Glauber's salt, and a clean product is required, it is advisable to gather the crystal when it first starts to form and the brine still protects it from contamination. At one deposit, where the brine over the surface of the whole lake is usually from three to four feet deep during the early summer months, the following method is adopted. About the middle of August, when the crystal first starts to form, large scows are floated on the brine and the harvesters wade beside the scows and load them with the loosely compacted crystals either by long-handled shovels or by lifting large masses of the crystals out of the brine by hand. The scows are then taken to a small dock, where the material, after sufficient draining to remove most of the entrapped brine, is filled into bags ready for hauling to the nearest railway for shipment. The method is slow and is only to be recommended where small tonnages are required and a pure material is desired for direct shipment without further treatment.

Where large tonnages are to be harvested, it is more convenient to allow the intermittent crystal to become sufficiently compacted to enable it to bear the weight of wagons and teams. The crystal is then loosened up to a depth of a few inches by ploughs, gathered into piles by horse scrapers and then hauled to stock piles on the shore. Where the conditions warrant it it might be feasible to install a dragline scraper to gather the crystal.

Whatever method of harvesting the crystal is employed, it must be remembered that, unless the crystal is to be recovered from the permanent bed, the harvesting season is confined to only a few months each yera and therefore it will be necessary in that time to gather into stock piles sufficient crystal to keep the refining plant operating the whole year.

In most of the deposits examined, the amount of intermittent crystal formed each year is sufficient to supply the yearly demands of any normal plant; so that it is probable that for a number of years at least it will not be necessary to harvest any crystal from the permanent bed. Even if the whole of the intermittent crystal were harvested in any one year, and the thin deposit of mud on top of the permanent bed removed, sufficient of the top layers of the permanent bed would go into solution the following spring to supply a crop of intermittent crystal in the fall. The formation of a yearly crop of intermittent crystal is of great value to the operators of these deposits, since it furnishes an easily gathered material of a considerably higher degree of purity than could be excavated from the permanent bed.

Shipment as Glauber's Salt

There is a possibility that a small market can be obtained for the crude salts. If the crude salts are to be shipped by rail it is preferable to bag the material since if placed in the cars in bulk, unless the salts have been thoroughly drained of the entrapped brine, it is probable that by the time it had reached its destination the whole carload would have become one solid mass due to the mechanically held brine crystallizing and cementing the rest of the crystals. Although this also takes place to a small extent in the bags, they permit of the material being readily removed from the car with the least possible expense. When shipping the natural salts as taken from the deposit, only the purest material should be selected, and great care should be taken to prevent contamination. It is probable that only the very purest of crystals will be shipped direct from the deposit, and by far the greater part will have to be treated to produce a marketable product.

REFINING OF THE CRUDE MATERIAL

The salts as excavated from the deposits contain approximately 56 per cent water of crystallization. They may contain also varying small proportions of other salts such as magnesium sulphate, sodium chloride, etc., as well as included insoluble material. These impurities in most cases have to be removed. It is therefore necessary to subject the salts or brine to some process in order to remove the water of crystallization as well as the impurities.

The insoluble impurities in the salts can readily be removed by putting the salts into solution and allowing the mud or sand to settle, after which the clear brine can be decanted off to the dehydrating plant. By using care in harvesting the crystal from the intermittent bed it is possible to select material which contains only small quantities of other salts; in deposits where magnesium sulphate is present in considerable quantities this salt tends to crystallize out last and occurs as a layer on top of the sodium sulphate, which can readily be removed before excavating the sodium sulphate. In some places, therefore, the salts as recovered from the deposits are of a high degree of purity and require only to have the water of crystallization removed.

The largest market for sodium sulphate is in the form of the anhydrous salt and, therefore, in most cases it will be necessary to remove the water of crystallization before a product suitable for the market is obtained.

A number of methods have been suggested for the dehydration of these crude salts, some of which have already been operated on a commercial scale with considerable success. However, the final product has to compete in the open market with the cheap by-product material from the manufacture of hydrochloric acid, and in most cases the deposits are considerably farther from the markets than the by-product material. Therefore, any process for the dehydration of these salts, to be operated successfully, will have to be cheap, simple in operation, continuous in output, and give a product of uniform grade in all ways superior to the by-product material.

Air-drying

As is well known, Glauber's salt, when exposed to the air at ordinary temperatures, loses its water of crystallization. If a pile of salts taken from these deposits, however, is stored on the shore exposed to the weather, even for several years, only the surface to a depth of a few inches will lose its water of crystallization, since once the surface has become dehydrated, the dehydrated material seems to form a protective coating. On the other hand, if the material is spread out over a large area in a thin layer and protected from the rain, the dry air and wind will in time remove the greater part of the water of crystallization and the remainder of the water can quickly be driven off by artificial heat.

The following method of drying has already been practised at one of the deposits in Saskatchewan. A building was erected about 10 feet high by 12 feet wide by 100 feet long. In this shed the hydrous salts were exposed to the air on trays with cotton bottoms which allowed the air to circulate freely through the material. The trays were arranged in rows one above the other, about 2 inches apart. The trays when filled were pushed along, one following the other, until the shed was filled. The sides of the shed were built in sections, which opened from the top and lay back on the ground. This allowed the air to circulate freely above and below the thin layer of exposed crystals on the trays. About two weeks were required to lower the moisture content from approximately 56 per cent to 15 per cent. The material was then removed to another building where it was placed on shallow tin trays in a rack above a small stove, and the last traces of water were easily removed in from one to two days without danger of the material going into solution in its own water of crystallization.

About 5 tons of the dried material was obtained by this method in 2 weeks. In order, then, to have an output of 5 tons per day, 14 sheds of the size stated above would be required. This would entail a considerable initial outlay and the cost of maintenance and labour would be considerable.

The process is dependent on the dry air and the fact that the normal temperature of the atmosphere in the vicinity of these deposits is generally below 33°C (91·4 F.)above which temperature the salts go into solution in their own water of crystallization. Being subject to climatic conditions, the rate of dehydration is variable and a uniform rate of output could not be depended upon The rate of output could be controlled, however, and a uniform product obtained, if the drying were carried out in an enclosed shed or tunnel in which the humidity and temperature of the atmosphere could be regulated.

The process can be used only where the original salts are very pure since none of the impurities are removed in dehydration. The product from this process is light and powdery.

Evaporating Processes Using Artificial Heat

Many attempts have been made to remove economically the chemically combined water from Glauber's salt by the application of heat. The fact that the salts go into solution in their own water of crystallization at temperatures above 33°C. complicates the problem of dehydration. If an attempt be made to expel the water by heating the crystals, the whole mass of crystals goes into solution just as soon as the temperature is raised above 33°C. and then it is an evaporation problem that has to be handled instead of one of drying.

One of the chief difficulties encountered in any process of evaporation has been the fact that the solubility of sodium sulphate decreases once the temperature of 33°C. has been exceeded. (See Figure 10). Above this temperature the anhydrous salt thenardite starts separating out and this fact has led many to attempt to recover the anhydrous salt in this way. The presence also of any impurities such as other salts in the brine affects the transition temperature lowering it according to the amount of such impurities present. It can thus be seen that the exact behaviour of sodium sulphate when other salts are present is of the greatest importance and would have a direct bearing on the results obtained by any dehydration process.

Of the processes experimented with, employing artificial heat as the means of dehydrating sodium sulphate, some have given promise of being commercially successful, whereas others have had to be abandoned in the earlier stages. Many experiments have been already made, but there still remains much research work to be done on this problem.

A few of the many processes of evaporation tried out for the dehydrating of Glauber's salt will be briefly mentioned. Although all of these processes will undoubtedly produce anhydrous sodium sulphate in one form or another, the commercial possibilities of many of them still remain problematical. Some of the processes have never passed beyond the laboratory stage, others have been experimented with in small semi-commercial units, and to the writer's knowledge only two have been tried in commercial plants.

Direct Evaporation of the Water

It was thought at first that driving off the water from Glauber's salt was simply a matter of heating in open pans. Experiments, however, showed that when the crystals are heated in this way they very quickly go into solution in their own water of crystallization. It was also found that when all the water had been expelled, the dried salt caked so solidly in the bottom of the pans, that it had to be loosened with picks, thus greatly increasing the cost. Such a product would also have to be ground before it would be in a condition suitable for some of the industries, and the cost of fuel for the evaporation would be considerable.

Rotary driers have been suggested for drying purposes, but whether these would work on material which goes into solution in its own water of crystallization has not been demonstrated. The possibility of using rotary driers through which dry air at a temperature below the critical temperature of the salts is allowed to pass has been considered, but no experiments have been carried out along this line. In this case it would be a question of the moisture-absorbing power of air in combination with evaporation, and one would have to take into consideration the capacity of the air for carrying off moisture and the amount of heat it can give up for evaporation. Air has a definite moisture-carrying capacity which increases rapidly as the temperature increases.

Part Evaporation of the Water of Crystallization

Another method that has been suggested for the recovery of anhydrous sodium sulphate, and one which has been studied to a small extent on a laboratory scale, is to place the crystals into solution in the water of crystallization by the application of heat at some controlled temperature above 33° C and to collect the percentage of sodium sulphate which is precipitated in the anhydrous form and dry it by some suitable means. Experiments made in Mines Branch laboratories showed that percentages of sodium sulphate varying from about 33 per cent at 60° C to nearly 44 per cent at 100° C could be recovered in this manner. The material thus obtained was in a finely crystalline form rather than a powdered form. The mechanical difficulties of such a process, however, still remain to be solved.

Vacuum Pan Evaporation

The success that has attended the evaporation of many and varied kinds of solutions in vacuum pans, early turned the attention of investigators to this process as a possible means of recovery of anhydrous sodium sulphate from the brine. Such evaporators have been successfully employed in the recovery of sodium chloride from brines, and it was thought that sodium sulphate could readily be recovered in the same manner. Numerous experiments were tried in small-scale plants, but great difficulties were encountered from the beginning. Some of these were due to the design of the evaporator, whereas others were due to the peculiar characteristics of sodium sulphate. It is not the purpose in this report to go into the detail of the principles of vacuum evaporators, as these are discussed at length in all standard text books, as well as in technical magazines.[1]

The fact that the solubility of sodium sulphate in water increases rapidly until around 33° C and then decreases the higher the temperature, was one of the main difficulties met with, as it caused the rapid clogging of the whole system, until a method was found to overcome the difficulty. Another trouble met with was the difficulty of removing sufficient of the entrapped brine carried down into the salt basket with the anhydrous crystals to prevent their caking solidly in the basket on cooling and to leave them still hot enough to enable the salts to dry the last remaining traces of moisture out by their own heat when removed from the basket to the stock piles.

It was only after experiments, lasting from six months to a year, had been made by the Swenson Evaporator Company of Harvey, Ill., at their experimental plant at Ann Arbor, Michigan, that they considered they had obtained sufficient data to enable them to erect a commercial unit with reasonable prospects of success. Accordingly, a plant was erected at Hopewell, Virginia, embodying all the ideas to overcome the many difficulties encountered.

The material worked on was a sodium sulphate brine obtained from the vast waste piles of nitre cake left from extensive munition factories in the neighbourhood. After some months' endeavour, this plant was put into operation and is claimed to be operating successfully. However, this plant is operating on a material of very low initial cost in a district where high-grade fuel is obtainable at a low price. Whether such a process employing a similar evaporator would be successful in western Canada,

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[1] Brief descriptions with diagrams of various types of evaporators are given in The Salt Deposits of Canada and The Salt Industry, Mines Branch, Dept. of Mines, Ottawa, Report No. 325, 1915.

where the cost of coal is high and where other salts are frequently present in small quantities, has to be demonstrated. Great progress has, however, been made in the application of vacuum evaporation to the recovery of sodium sulphate.

Evaporation in Space

Another process of evaporation which has proved successful in a number of industries and which has been attempted in the dehydration of sodium sulphate is the spray process or, as it is sometimes known, "evaporation in space." The process consists in spraying the brine through a fine nozzle or aperture and allowing the atomized brine to fall through a rising current of dry, hot air; the solids fall to the bottom of the chamber as a dry powder and the water vapour passes off at the top with the air.

Probably the best known application of evaporation in space is in the manufacture of powdered milk. The milk at a definite temperature is sprayed through a fine aperture in a small disk into a large chamber in close proximity to a current of hot air. The milk in the form of a dry powder almost immediately starts to settle to the bottom of the chamber, from which it is collected and parcelled for marketing.

The process has been applied with apparent success to the preparation of dry anhydrous sodium sulphate by the Bishopric and Lent Co. at Frederick lake, Saskatchewan. In this plant the sodium sulphate brine is sprayed through a number of specially constructed nozzles at the top of a circular tower and allowed to fall against a rising current of hot air injected near the bottom. The dried salts are drawn off at the bottom of the tower.

The product obtained is very light and fluffy in texture, running only 30 pounds per cubic foot, but the method lends itself to close control, and it is claimed that a variety of products can be produced.

Chemical Processes

It has long been known that the presence of other salts in the sodium sulphate brine alters the behaviour of the brine under certain conditions. This has led a number of investigators to attempt to utilize this fact to recover the sodium sulphate in the anhydrous form by the addition of some other salt and thus do away with the expense of having to evaporate the large quantity of water present.

The addition of some such salt as sodium chloride or magnesium chloride to a saturated brine containing sodium sulphate changes the equilibrium of the salts, causing the precipitation of the sodium sulphate in the anhydrous form.

Pechiney, as early as 1878, obtained a patent on a process based on this reaction, and applied it successfully to his Giraud plant in southern France. Lunge[1] on visiting these works found the process carried out as follows:—

> Since the dehydration of Glauber's salt by fire is a very awkward operation, whether the fire acts from below or from above, Pechiney utilizes the greater attraction for water possessed by the above "mixed salts" (50 per cent Epsom salts—50 per cent sodium chloride) at a temperature of 80°. Glauber's salt changes into anhydrous sodium sulphate

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[1] Cumming, A. C. (and Lunge), Hydrochloric Acid and Salt Cake. Vol. V. Mfg. of Acids and Alkalis. Gurney & Jackson, London 1923, pp. 193-194.

far below this temperature. The Glauber's salt is mixed with 45 per cent of its weight of the "mixed salts," the whole is heated to 80°, and is "whizzed" in a centrifugal machine, in which the anhydrous Na_2SO_4 remains behind. The temperature of the magma must never sink below 33°; it is washed in the warm water, which leaves the Na_2SO_4 with only 4 per cent water and almost free from magnesium salt.

In 1923 a Canadian patent on similar lines was granted to Handcock and Ide (Pat. No. 216621), in which they proposed to recover anhydrous sodium sulphate from solution of the crystals by the addition of common salt. The following excerpt from the patent specification gives an outline of the process:—

> The crude crystals of hydrated sodium sulphate containing water of crystallization together with any surplus moisture or brine which might possibly adhere to the surface or be contained in pockets in the crystals, are heated by means of steam or any source of heat which might be found suitable or economical to a temperature of 33 degrees C. or any temperature between 33 degrees C. and the boiling point of the solution. At any temperature within the range just mentioned, the crude hydrated sulphate melts and an equilibrium condition can be established in which about 37 per cent of the total sodium sulphate present is precipitated from the solution in the form of anhydrous sulphate together with small amounts of impurities as above named. The percentage of anhydrous sodium sulphate precipitated will vary in accordance with the total amount of water in the crude salt taken, and will vary also with the temperature maintained during this stage of the process.
>
> The important feature of the present invention is the introduction of a change in the equilibrium of the system producing the precipitation of all or any of the sodium sulphate remaining in the solution, depending on the chemical control of the process.
>
> The agent to bring about this change is sodium chloride, any grade of which may be used as, for example, natural crude rock salt, crude sodium chloride in any form, refined sodium chloride or mixtures of sodium chloride and sodium sulphate or of sodium chloride and magnesium sulphate.
>
> The sodium chloride either pure or any admixture with other salts as just specified is added to the crude hydrated sodium sulphate either before or during the application of heat. The sodium chloride passes into solution in the liquid with the result that the remaining dissolved sodium sulphate (plus small amounts of impurities) is precipitated or part of it, depending on the proportion of sodium chloride used, or, in other words, the precipitation of the sodium sulphate from the solution as an anhydrous sodium sulphate varies directly as to the amount of the sodium chloride added. For example: at a temperature of 35 degrees C. from a solution of sodium sulphate containing 47·94 grammes per 100 grammes of water, the entire sodium sulphate would be precipitated by the addition of 35·63 grammes of sodium chloride. Smaller amounts of the precipitant would precipitate correspondingly smaller amounts of sodium sulphate.
>
> The impurities (such as magnesium sulphate, etc.), which are not mechanically carried down with the precipitated salt, remain in the solution with the sodium chloride. The solid matter, i.e., anhydrous sodium sulphate, is now separated from the solution by means of a rotary filter, filter press, or by any suitable filtering apparatus or device. The sodium chloride solution is evaporated by solar evaporation or by any other suitable method and the sodium chloride may be recovered and used again in the process.
>
> The "salt cake" or anhydrous sodium sulphate recovered by filtration containing about 10 per cent moisture is carried by means of mechanical conveyors, for example, to a direct heat rotary drier or any other suitable drying apparatus. When dry it is ready for shipment.

This process necessitates the recovery of the sodium chloride from the extracted brine by some suitable means of evaporation in order to return it again to the system. It would be only in exceptional cases, where the sodium chloride could be obtained at a very low cost, that one could afford to discard the brine without recovering the salt from it.

FUEL SUPPLY

Whatever process is adopted finally for dehydrating sodium sulphate will entail the use of some class of fuel. It is therefore of importance to gain some idea of the cost of coal and where it can most conveniently be obtained. Table X shows the cost per ton of the different grades at the mines for the past three years.

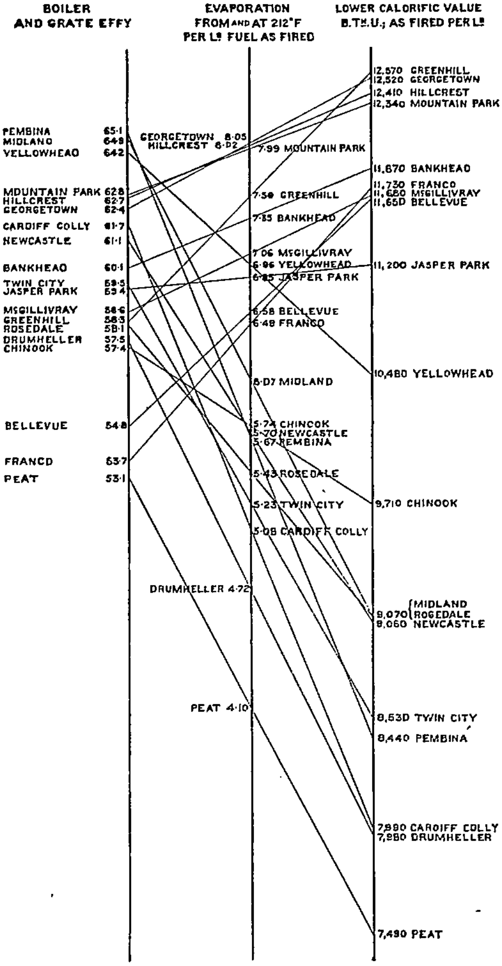

FIGURE 16. Chart showing the relation between the evaporation and calorific value per pound of fuel and the thermal efficiency of the boiler and grate. (After J. Blizard and E. S. Malloch).

The above chart[1], Figure 16, gives the heating values of a number of these coals as determined in tests made in the Fuel Testing Division of the Mines Branch, Department of Mines at Ottawa.

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[1] Taken from p. 11, Bulletin No. 27, Mines Branch Rept. No. 496. Results of Forty-One Steaming Tests conducted at the Fuel Testing Station, Ottawa. Blizard and Malloch, 1920.

TABLE

Average Prices[1] of Western Canadian Coal at the Mine

District	Run-of-mine					
	1922		1923		1924	
	High	Low	High	Low	High	Low
	$ cts.	$ cts.	$ cts.	$ cts.	$ cts.	$ cts.
Saskatchewan	2 35	2 10	2 26	2 04	2 19	1 99
Alberta—						
Anthracite—						
Banff	3 13	3 13	8 50	5 08	....	....
Bituminous—						
Brazeau	5 30	4 64	5 25	4 00	3 00	3 00
Canmore	5 25	4 33	6 50	4 91	5 75	4 82
Crowsnest Pass	5 43	5 08	5 51	4 16	5 13	4 09
Jasper Park	5 10	4 60	4 85	4 85	5 50	4 60
Mountain Park	5 33	4 05	5 42	4 00	4 92	3 75
Yellowhead Pass	3 85	3 20	(a)	(a)	....	....
Average (bituminous),	4 90	4 23	5 50	4 23	5 00	4 03
Sub-bituminous—						
Calgary	(b)	(b)	3 00	3 00	3 00	3 00
High River	....	....	3 63	3 23	3 47	3 47
Pincher Creek	....	....	3 62	3 46	3 71	3 09
Saunders	....	....	5 19	5 06	5 00	4 41
Yellowhead Pass	(c)	(c)	3 41	2 89	3 48	2 99
Average (sub-bituminous)	(b)	(b)	3 86	3 43	3 67	3 22
Lignite—						
Aldersyde	4 70	3 67	4 20	3 85	4 80	3 65
Battle River	2 76	2 44	2 80	2 23	2 78	2 62
Big Valley	3 60	3 19	3 17	2 97	3 36	3 12
Bow Island	3 80	3 40	3 60	3 25	3 15	2 95
Brooks	4 40	3 91	3 83	3 50	3 60	3 50
Camrose	3 16	2 29	2 83	2 14	2 66	2 17
Carbon	3 54	3 53	3 87	3 44	3 92	3 42
Cardiff	2 12	2 00	2 50	1 70	2 50	1 58
Clover Bar	2 58	1 76	2 66	2 25	2 50	2 02
Drumheller	4 13	3 76	4 00	3 38	3 50	3 00
Edmonton	2 86	2 81	2 00	2 00	3 50	2 75
Gleichen	(b)	(b)	3 90	3 30	3 37	3 25
Hanna	2 88	2 48	2 61	2 40	2 68	2 62
High River	3 92	3 62	(a)	(a)	....	....
Lacombe	2 69	2 47	2 73	2 67	2 68	2 63
Lethbridge	4 25	3 93	3 94	3 25	4 08	4 03
Magrath	4 00	2 50	4 00	4 00	4 00	4 00
Medicine Hat	2 81	2 72	2 75	2 59	3 10	2 70
Milk River	4 50	4 43	4 00	3 90	3 97	3 83
Namao	3 38	3 25	3 25	3 25	2 75	2 60
Peace River	(b)	(b)	2 75	2 75	3 25	2 08
Pembina	4 09	3 83	4 09	3 83	2 75	2 00
Pincher Creek	3 38	3 00	(a)	(a)	....	....
Rosedale	(b)	(b)	3 45	3 26	3 57	3 50
Strathcona	(b)	(b)	3 16	3 16	2 24	2 07
Taber	4 12	3 95	3 88	3 75	3 90	3 68
Three Hills	3 42	3 25	3 19	3 12	3 25	2 78
Tofield	2 00	1 60	2 00	1 50	1 75	1 70
Trochu	2 83	2 73	3 34	2 93	2 89	2 75
Wabamun	2 50	1 35	3 00	2 00	2 50	2 25
Wayne	(b)	(b)	4 73	4 32	4 16	3 89
Average (lignite)	3 44	3 04	3 24	2 91	3 17	2 89
Average for Alberta	3 61	3 18	3 46	3 06	3 37	3 01
British Columbia—						
Crowsnest Pass	5 53	4 10	5 38	4 10	4 89	3 57
Inland	5 30	4 85	4 13	3 72	4 81	4 31
Island	....	....	....	....	4 75	4 75
Average for B. C.	5 36	4 63	4 45	3 81	4 81	4 23

(a) See Sub-bituminous. (b) Not separately shown in 1922. (c) See Bituminous.

[1] Compiled from figures furnished by Dominion Bureau of Statistics.

X

by Grades for each District and Province 1922-1924.

Screened						Slack					
1922		1923		1924		1922		1923		1924	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
$ cts.	$ cts.	$ cts.	$ cts.	$ cts.	$ cts.	$ cts.	$ cts.	$ cts.	$ cts.	$ cts.	$ cts.
2 73	2 34	2 72	2 37	2 54	2 24	1 35	0 63	0 96	0 63	1 25	0 72
9 55	2 00	9 55	9 55	....	....	1 33	1 33	2 84	2 84	......	......
6 85	6 00	....	....	4 68	4 68	2 88	1 56	....	......	......	......
8 25	3 81	8 25	3 81	8 25	3 81	5 00	4 93	5 25	3 72	3 72	3 60
7 20	6 61	7 14	6 50	6 66	6 49	5 06	4 73	5 08	4 13	4 78	3 93
....	....	....	....	....	....	....	....	....	......	......	......
6 00	5 15	....	....	4 38	3 71	4 25	4 25	....	......	......	......
5 02	3 93	(a)	(a)	....	....	1 40	0 96	(a)	(a)		......
6 28	5 19	7 36	5 96	6 04	5 23	3 19	2 57	5 12	4 03	4 52	3 85
(b)	(b)	....	....	4 50	4 50	(b)	(b)	....	......	......	......
....	....	....	....	5 00	5 00	....	....	....	......	......	......
....	....	5 00	4 50	4 37	3 87	....	....	1 38	1 00	1 00	1 00
....	....	7 07	6 54	6 33	5 28	....	....	2 90	2 10	3 00	1 70
(c)	(c)	5 04	3 99	5 32	3 88	(c)	(c)	1 23	1 04	1 32	1 10
(b)	(b)	5 76	5 01	5 16	4 27	(b)	(b)	1 83	1 38	1 48	116
....	....	4 75	4 50	4 62	4 12	2 00	0 75	1 50	1 50	1 67	1 67
2 80	2 50	....	....	2 75	2 26	....	....	1 13	1 13	1 30	1 39
4 67	4 00	3 94	3 30	4 00	3 33	0 38	0 38	0 50	0 38	1 37	1 12
3 95	3 69	3 93	3 48	3 58	3 00	1 67	1 50	2 50	2 50	1 12	1 12
....	....	4 25	4 00	4 00	4 00	1 50	1 12	2 00	2 00	....	......
3 75	2 78	3 71	2 41	3 80	2 88	0 62	0 47	0 77	0 45	0 63	0 49
4 08	2 67	4 70	2 50	4 12	3 38	1 08	0 80	1 15	0 51	0 59	0 44
3 17	2 58	2 55	1 65	3 50	2 63	0 50	0 50	0 50	0 50	0 63	0 50
4 28	2 43	4 09	2 12	4 23	2 32	0 92	0 44	0 90	0 46	0 87	0 44
5 21	3 88	5 03	3 19	4 86	3·35	0 77	0 31	0 85	0 40	0 86	0 47
3 94	3 15	5 15	2 10	4 35	3 00	1 05	0 81	0 85	0 50	0 85	0 40
(b)	(b)	5 00	5 00	5 00	3 33	(b)	(b)	....	......	......	......
3 09	2 51	3 21	2 56	3 12	2 63	0 95	0 48	0 64	0 54	1 25	0 75
5 00	5 00	(a)	(a)	....	....	....	....	(a)	(a)	......	......
2 88	2 50	2 81	2 63	3 43	2 89	1 37	1 12	1 00	1 00	1 00	1 00
5 04	3 79	5 12	3 76	5 48	4 08	0 96	0 57	0 86	0 46	1 06	0 74
4 50	4 50	4 33	4 33	4 00	4 00	....	....	....	......	......	......
4 00	3 43	3 87	2 62	4 08	3 33	1 00	1 00	1 00	......	......	......
4 80	4 60	4 75	4 06	4 50	4 50	....	....	0 75	0 75	0 75	0 75
4 50	2 00	3 75	3 75	4 00	1 00	0 50	0 20	0 50	0 30	0 75	0 50
(b)	(b)	4 00	4 00	4 00	4 00	(b)	(b)	....	1 00	......	......
4 60	4 20	4 60	4 20	4 25	1 00	1 05	1 05	1 05	1 05	0 65	0 40
4 75	4 50	(a)	(a)	....	....	1 80	0 88	(a)	(a)	......	......
(b)	(b)	5 06	3 93	5 00	3 80	(b)	(b)	0 50	0 30	0 60	0 48
(b)	(b)	3 20	2 50	3 21	3 03	(b)	(b)	1 00	0 95	0 40	0 40
4 28	3 61	4 59	3 64	4 33	3 28	1 10	0 60	0 87	0 62	1 25	0 72
3·92	3 59	4 28	3 50	4 12	2 82	0 89	0 80	0 58	0 57	0 67	0 63
3 27	1 92	3 17	2 67	3 33	2 83	1 00	1 00	1 62	1 25	1 33	1 33
3 66	2 81	4 15	3 10	3 84	3 50	....	....	2 00	2 00	0 90	0 35
4 75	1 50	4 40	1 75	2 67	1 29	1 50	0 20	1 00	0 35	0 76	0 52
(b)	(b)	5 25	4 12	4 67	4 16	(b)	(b)	1 02	0 51	0 96	0 63
4 11	3 33	4 25	3 20	4 09	3 19	0 98	0 64	0 91	0 62	0 94	0 66
4 33	3 48	4 49	3 46	4 28	3 39	1 27	0 90	1 20	0 87	1 14	0 87
6 33	5 80	6 33	5 93	6 19	5 55	4 81	3 75	4 63	3 88	4 91	3 75
6 75	5 17	6 60	5 33	6 10	5 15	3 82	3 29	4 31	3 69	3 56	3 43
7 42	6 19	7 02	6 30	7 63	5 79	4 27	3 80	3 84	3 58	4 04	3 47
6 97	5 72	6 73	5 83	6 88	5 53	4 24	3 64	4 12	3 67	4 12	3 52

(a) See Sub-bituminous. (b) Not separately shown in 1922. (c) See Bituminous.

CHAPTER VIII

MANUFACTURE OF BY-PRODUCT SALT CAKE AND GLAUBER'S SALT

Until recently, most of the salt cake used in commerce has been produced artificially either as a by-product from some other chemical process, or directly when the demand for the product has been sufficient to enable it to be prepared as the principal product.

Since the artificially prepared material will, it is expected, for many years to come, be a strong competitor of the material from the natural deposits, it is desirable that the processes of manufacture of the by-product material should be thoroughly understood by all those contemplating the production of the natural material. Brief descriptions of the several processes in commercial use at present will therefore be given.

MANUFACTURE OF BY-PRODUCT SALT CAKE

Commercial anhydrous sodium sulphate or "salt cake" as it is known to the trade is prepared in a number of different ways. Probably its first commercial production was as an intermediate product in the LeBlanc process for the production of soda ash. In fact a modification of this method still remains the chief process for the manufacture of salt cake and is known as the "salt cake process."

Salt Cake Process

Probably the most widely employed method for the preparation of salt cake is the "salt cake process" for the preparation of hydrochloric acid, in which process salt cake is recovered as a by-product. The process depends on the reaction of sulphuric acid on sodium chloride and is really the first step in the original LeBlanc process.

The decomposition occurs in two distinct stages depending on the temperatures:—

$$(1)\ NaCl+H_2SO_4=NaHSO_4+HCl.$$
$$(2)\ NaCl+NaHSO_4=Na_2SO_4+HCl.$$

The first of these reactions begins at ordinary temperatures whereas the second is only completed at a red heat. The exact temperatures employed in the several operations vary within small limits at different plants but it is apparent that the hottest place in the muffle furnace at the end of the operation must not exceed 800°C. which is the melting-point of ordinary salt cake.

Raw Materials.

The raw materials required in this process are sodium chloride (common salt) and sulphuric acid. The salt best adapted to this process is the "pan salt" or the coarse-grained salt resulting from the evaporation of sodium chloride brine in open pans. The sulphuric acid generally used for decomposing the salt is the common chamber-acid, with a specific gravity of from 1·7 to 1·72.

Method of Operation.

The salt is generally treated in batches of about half a ton, in a large hemispherical, direct-fired pan, set in suitable brickwork. To the salt an equal weight of sulphuric acid is added and the reaction shown in the first of the above equations takes place. The hydrochloric acid evolved in the decomposing-pan is drawn off through a flue in the dome of the brickwork covering the pan and is absorbed by water.

The hot mass is then raked into a muffle or reverberatory furnace and the reaction is completed at a higher temperature. The hydrochloric acid evolved in the muffle furnace is collected separately. When no more vapours are seen rising in the muffle furnace the batch is drawn out and usually left to cool in a closed box in order to avoid the nuisance of obnoxious gases.

The yield of salt cake by this process will vary in different plants, 115 pounds of salt cake per 100 pounds of original salt being an average recovery.

Hargreaves Process

A process known as the Hargreaves process for the manufacture of sodium sulphate achieved considerable success a number of years ago, especially in England and Europe. It is probable that this process would have in time become the general system for the manufacture of salt cake, had not the discovery of the ammonia-soda process about the time that the Hargreaves process was just becoming well established, dealt a serious blow to the LeBlanc process. On account of the large sums of money invested in the LeBlanc process-plants the manufacturers were compelled to lay the greatest stress on the recovery of the salt cake by the first step of this process, and the Hargreaves process suffered in consequence.

While there were 12 plants in Europe employing the Hargreaves process in the year 1891, by the year 1918 the seven of these plants that were situated in Great Britain and Ireland were all closed down.

The process is of interest, however, since it dispenses with the manufacture of sulphuric acid. Hargreaves process depends on the reaction of sulphur dioxide gas on sodium chloride in the presence of air and steam. Pure sulphur dioxide gas, of itself, does not decompose sodium chloride, but when steam and air are mixed with it, the salt is gradually decomposed and in time completely converted into sodium sulphate. The final reaction may be represented by the following equation:—

$$2NaCl+SO_2+O+H_2O=Na_2SO_4+2HCl.$$

Raw Materials.

The sodium chloride has to be specially prepared. Pan salt to which generally a little finely-ground rock salt has been added, is moistened and pressed into cakes or small bricks and dried. This gives the salt a sufficient degree of porosity when placed in the decomposition chamber, to make it completely permeable to the gases, as well as having sufficient strength to resist crushing under the weight of the charge.

The sulphur dioxide is obtained from pyrites burners, similar to those used in the manufacture of sulphuric acid. In this process, however, the burners are specially designed and built back to back in order that as little as possible of the heat generated in them should be wasted.

The steam, which is superheated and completely dried, is added to the sulphur dioxide gas either in the gas-space above the burning pyrites or else in the large pipe which carries the gas fron the burners to the cylinders.

Method of Operation.

The salt is placed in a series of vertical cast iron cylinders each holding approximately 50 tons. These cylinders, which are brick encased, are each provided with a fireplace, so that the whole cylinder can be externally heated. There are generally 10 in number, connected up in two rows of 5 each to form a "cylinder battery." The hot sulphur dioxide gases are led into the cylinders, which are kept at a temperature of 500° C, and passed over the salt from the top downwards.

The gases direct from the pyrites burner are never passed over the fresh salt, since the reaction would generate such a high heat that the salt would be fluxed. They are, therefore, first led into the cylinder in which most of the salt has been converted into the sulphate, afterwards passing through the other cylinders, so that by the time the gases reach the cylinder in which fresh salt has just been charged, most of the sulphur dioxide has been removed.

The complete conversion of the salt into sulphate in one of the cylinders takes approximately three weeks.

The hydrochloric acid produced by the process is drawn off from the last cylinder of the series together with other gases, and after being cooled is led directly into the hydrochloric condensing towers.

The yield of salt cake by this process will vary from 7,000 to 7,500 tons per year per battery.

Nitre Cake Process

In the manufacture of nitric acid by the action of sulphuric acid on sodium nitrate, a by-product is obtained which approximates closely the acid sodium sulphate ($NaHSO_4$) and is known to the trade as "nitre cake." Commercial nitre cake usually contains a varying percentage (7 to 35 per cent) of free acid. In normal times the market for nitre cake is comparatively small, and many attempts have been made to put it to some commercial use. Where plants for the production of nitric acid have been conveniently situated with respect to LeBlanc soda plants, large quantities of nitre cake have been utilized for the manufacture of soda ash by adding sufficient salt to satisfy the amount of "free acid" in the nitre cake and then adding the mixture to that normally charged to the sale cake pans.

During the war, large quantities of nitric acid were manufactured on this continent for use in explosives, and in consequence vast stock piles of nitre cake accumulated at these plants. In order to utilize this material, which in many cases was a waste product and could be purchased at very low costs, a number of plants started to manufacture it into normal sodium sulphate (salt cake) and hydrochloric acid by the action of salt (sodium chloride). The process depends on the following equation:—

$$NaHSO_4 + NaCl = Na_2SO_4 + HCl.$$

Method of Operation.

The nitre cake and salt are ground and intimately mixed in a circular, flat, enclosed oven provided with suitable stirring apparatus. The temperature of the oven is maintained at about 700° C. The operation of the furnace is so conducted that the stirring-arms constantly move the material from the centre to the periphery, where it is discharged as the normal sulphate. The hydrochloric acid derived from this process is generally of high purity and very concentrated.

One furnace will turn out 7 tons of salt cake in 24 hours and the yield of salt cake is slightly over a ton per ton of nitre cake used.

As a By-product from the Manufacture of Sodium Dichromate

In the manufacture of sodium dichromate, sodium sulphate is recovered as a by-product. The sulphate so produced has obtained considerable favour among some of the pulp mill operators, since it is recovered in the form of the anhydrous crystals and in consequence does not cake into solid masses when in storage.

Method of Operation.

The operation consists in treating chrome iron ore in a reverberatory furnace with soda and lime in the presence of air, thus:—

$$2FeCr_2O_4 + 4Na_2CO_3 + 4CaO + 7O = Fe_2O_3 + 4CaCO_3 + 4Na_2CrO_4$$

In practice, the chrome ore is finely ground and mixed with the powdered quicklime and less than the theoretical amount of sodium carbonate required.

The fused mass from the furnace is dissolved in water together with the remainder of the sodium carbonate. The solution is concentrated and run into lead-lined vessels when sufficient sulphuric acid is added to turn the chromate into the dichromate. The sodium sulphate formed is thrown down in this solution in the anhydrous form and removed by centrifuges, after which it is washed until it contains less than 1 per cent of Cr_2O_3 (chromic oxide).

The sulphate obtained by this process is sometimes known to the trade as "chrome cake" or "chrome salt cake."

Other Processes

A number of other processes for the manufacture of salt cake from various raw materials have been patented and tried out from time to time. Some of these have proven successful under certain local conditions in the districts where they have been tried, but none of them have obtained the widespread application of the four processes already mentioned.[1]

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[1] A number of these processes are referred to in Cummings "Hydrochloric Acid and Salt Cake."

PROPERTIES OF COMMERCIAL SODIUM SULPHATE

Commercial sodium sulphate known to the trade as "salt cake," is a more or less finely granulated material, frequently containing larger masses of melted substance. The colour will vary from yellowish to greenish white but in some cases is pure white. A dirty grey colour indicates impurities due to incomplete decomposition of the sodium chloride. Generally speaking, the finer the grain of the salt cake, the higher the grade.

The following chemical analysis[1] gives an idea of the average composition of commercial salt cake:—

	Per cent
Moisture	0·24
Silica	0·19
Iron oxide	0·45
Alumina	trace
Sodium chloride	2·15
Free sulphuric acid	1·95
Sodium sulphate (calculated)	95·02
	100·00

MANUFACTURE OF PURE ANHYDROUS SODIUM SULPHATE

By far the largest part of the anhydrous sodium sulphate recovered by the methods already described is used in the industries in the crude state. Occasionally, however, anhydrous salt of a high degree of purity is required, and this is prepared from the impure salt cake.

The process by which the pure anhydrous salt is recovered is based on the fact that a solution of sodium sulphate deposits anhydrous crystals if evaporated at any temperature above 32·4° C. The impure salt cake is dissolved at a temperature around 35° C, which is slightly above the temperature of maximum solubility, and small quantities of both lime and bleaching powder are added while the mixture is constantly stirred. The impurities contained in the original salt cake, as well as the small proportion of anhydrous salt which has been thrown down, are allowed to settle and the clear liquor is drawn off to evaporating pans.

As the evaporation proceeds, anhydrous crystals of sodium sulphate are thrown down, and removed from the pan by a rake and allowed to drain. The last particles of moisture are removed from the crystals by heating.

MANUFACTURE OF NITRE CAKE

The residue obtained as a by-product in the manufacture of nitric acid is a mixture of sodium hydrogen sulphate and sodium sulphate and is known to the trade as "nitre cake."

The process of manufacture of "nitre cake" is of interest, since this material is employed in a number of industries in a similar manner to salt cake.

Raw Materials.

The raw materials required for the manufacture of nitre cake are nitrate of soda ($NaNO_3$), obtained mostly from the extensive nitrate deposits of Chili, and sulphuric acid.

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[1] Analysis kindly furnished by Dr. McLean of J. T. Donald & Company, Ltd., of Montreal, Que.

Sodium nitrate is obtained chiefly from the crude deposits in Chili. The crude material, known as "caliche" containing around 20 per cent sodium nitrate, is suitably treated and a product is marketed containing around 95 per cent to 96 per cent nitrate content and not more than 2 per cent NaCl. The sulphuric acid employed depends on the strength of the nitric acid to be produced. Normally two grades of nitric acid are made: in one, acid with average strength of 90 per cent is recovered; and in the other, acid of 80 per cent average strength is made. For the production of the stronger acid, sulphuric acid with from 90 to 94 per cent H_2SO_4 content is required, whereas for the 80 per cent grade, sulphuric acid of about 78 per cent H_2SO_4 content (Glover acid) is satisfactory.

Method of Operation of Process.

The process for the manufacture of nitric acid and the recovery of nitre cake depends on the following reaction:—

$$2NaNO_3+H_2SO_4=Na_2SO_4+2HNO_3$$

In commercial practice, however, it is not found advisable to work with the proportions of raw materials required for the above equation since the high temperature needed to complete the reaction would mean the loss of some of the nitric acid produced due to decomposition, as well as other serious disadvantages; it is therefore endeavoured to proportion the raw materials so that they approximate closely the following equation:—

$$NaNO_3+H_2SO_4=NaHSO_4+HNO_3$$

This permits the operation to be carried on at a considerably lower temperature, so that the residue remains sufficiently fluid to permit of its being easily handled. The residue, "nitre cake", is therefore a mixture of sodium acid sulphate and the compound $Na_2SO_4 \cdot NaHSO_4$.

The operation is carried on in cast iron retorts under a vacuum and when the reaction is completed the molten residue is tapped from the bottom of the retorts and either allowed to solidify in moulds or else granulated by an air blast.

Composition of Nitre Cake.

Commercial nitre cake carries varying percentages of free acid usually around 30 per cent. It is marketed in lump powder, or granulated form. Although in many industries it is not possible to employ nitre cake as a substitute for sodium sulphate, there are, however, a number of processes in which it can be used in place of salt cake and therefore it should in certain instances be seriously considered as a competitor of the normal sulphate.

MANUFACTURE OF GLAUBER'S SALT

The manufacture of Glauber's salt ($Na_2SO_4 \cdot 10\,H_2O$) is accomplished by dissolving crude salt cake in water and recrystallizing below a temperature of 30°C.

In practice the salt cake is dissolved in water, bleaching powder and lime are added, and the resulting precipitate is allowed to settle. The depth of the crystallizing pans determines the size of the crystal produced.

CHAPTER IX

ALLIED PRODUCTS

In the preceding chapter mention has been made that sodium sulphate forms the basic material from which many of the other sodium compounds are derived. Salt cake has already been largely employed for this purpose, and it is possible that the product from the natural deposits may in time be similarly employed. It is therefore necessary that operators of the western deposits be familiar with the processes for the preparation of these several sodium compounds in order that they may be enabled in time to extend the market for the material they produce.

Brief outlines of the various processes involved in the preparation of a number of these sodium compounds are here given. For more and complete details the reader is referred to the numerous detailed accounts to be found in all the standard textbooks and works on the alkali industry.

SODIUM CARBONATE

The manufacture of sodium carbonate (soda ash) by the LeBlanc process has already been mentioned as being the process from which the present vast alkali industry had its start. The first step in the process produces sodium sulphate and is really the "salt cake process" already described. Sodium sulphate will therefore be considered one of the raw products of the process.

The process consists in melting together proper proportions of salt cake, coal or coke and limestone, in a reverberatory furnace, in which the sulphate is reduced to the sulphide, which in turn reacts with the calcium carbonate to form sodium carbonate. The reactions involved may be expressed by the following equations:—

$$Na_2SO_4 + 2C = Na_2S + 2CO_2 \text{ (CO is also formed).}$$
$$Na_2S + CaCO_3 = Na_2CO_3 + CaS.$$

In reality the process is not so simple as the reactions indicate and the material has to be passed through several operations to obtain the finished product.

From the furnaces, the fused mass called "black ash" is removed and allowed to cool after which it is lixiviated in order to dissolve out the soluble salts. The tank liquors are allowed to stand for a time to permit suspended matter to settle, after which it is evaporated in suitable evaporators, and the resultant crystals are collected and calcined to produce the soda ash.

The proportions of raw materials used in this process vary at different plants but an average would be 100 pounds salt cake, 80 to 90 pounds limestone, and 30 to 45 pounds of coal.

Sodium carbonate, or soda ash, is used for many different purposes, the principal ones being the manufacture of glass; the making of certain kinds of soap; and the purification of oils, etc.

SODIUM SULPHIDE

Until recently by far the larger part of the sodium sulphide produced was prepared by melting sodium sulphate with coal in large reverberatory furnaces and afterwards lixiviating the solid mass with water. The resulting clear solution was allowed to crystallize out, and the salt is put on the market in the form of the deliquescent crystals ($Na_2S \cdot 9H_2O$) containing around 30 per cent Na_2S. A more concentrated form is sometimes prepared by partly dehydrating the crystals to a product containing 60 to 65 per cent Na_2S.

Extensive research work has recently been carried out on this substance by Mr. Horace Freeman in conjunction with the Research Council of Canada, with the result that a process has been perfected and placed in operation at Shawinigan Falls, Que., whereby the charge is melted in an electric furnace and a good grade product of considerably higher Na_2S content has been produced.

In a private communication Mr. Freeman gives the following notes on his process:—

> When sodium sulphate is heated with coal in a reverberatory or rotary furnace, reduction is never complete. It is found that the mass in the furnace, when it contains from 50 to 60 per cent of sulphide, changes from a semi-liquid condition to an infusible coke. This is due to the infusibility of sodium sulphide, and it effectively prevents contact between the particles of carbon and the sulphate, and for this reason the reduction does not go to completion. The mass is drawn from the furnace, cooled, crushed, dissolved, the solution filtered and crystallized. The crystals containing 30 per cent approximately of sulphide, are evaporated to a 60 per cent sulphide content in caustic pots, and the product, which is really a hydrate of sodium sulphide, is cooled in slabs or solid drums.
>
> When the electric furnace is used for this process, it is found that the resistivity greatly increases as reduction proceeds, and the only result is conversion of the infusible sulphide to vapour, which it does without passing through the liquid stage.
>
> For these reasons, the electric furnace has not been applied hitherto.
>
> In my process, I have overcome the infusibility of the sodium sulphide by adding to the charge some other sulphide, which will form a fluid mixture with the sodium sulphide. This other sulphide may be lead sulphide, in which case it has to be removed from the product, or it may be potassium sulphide, which may be left in the product. In practice I am using potassium sulphide. A small quantity added to the furnace charge keeps the charge fluid throughout, and so reduction proceeds to completion. The product from the furnace, according to the purity of the materials employed, is from 85 to 90 per cent Na_2S. This is crushed and the lumps, freed from dust, are packed in steel drums. The clean lumps are not subject to combustion and the product is anhydrous monosulphide.
>
> In this new process, the electric tapping furnace is proving itself especially effective. The contamination of the furnace product by the brick lining, as in the fuel-fired furnace, has been entirely overcome, and the wet purification process is not necessary. By hydrating the product which we obtain from our furnace, we obtain the 60 per cent, which is of greater purity than that hitherto sold.

Sodium sulphide is used on a large scale in the manufacture of "sulphur" dyes and also in the tanning industry for removing hair from hides.

SODIUM SILICATE

In the production of sodium silicate soda ash is generally employed as the source of sodium. Sodium sulphate may, however, replace the sodium carbonate, and has been used to a considerable extent in Germany, since the unit cost of the sodium sulphate is cheaper than that of the carbonate.

According to Sterne,[1] however, the silicate produced from sulphate contains the product of various other reactions to such an extent that a purification is required and the advantage of the lower unit cost is lost. The addition of coal which is added to reduce the sulphate further complicates the reaction.

There are two processes in commercial use for the manufacture of sodium silicate, namely, the "Dry or Fusion Process" and the "Wet or Solution Process."

The Dry or Fusion Process.

This process for the manufacture of sodium silicate is the oldest known. It consists of fusing silica sand with sodium carbonate (or sodium sulphate) in a silicate furnace very similar to the ordinary glass tank furnace. The silica and soda are mixed before entering the furnace in the approximate proportion of 1 sodium oxide (Na_2O) to 3·25 silica. From the furnace it is tapped either into special moulds or else directly into the dissolving tank. Variations in the grade of silicate placed on the market are produced by varying the ratio of sodium oxide to silica in the charge.

The Wet or Solution Process.

This process which enjoys a greater use in Europe than on this continent consists of dissolving silica in the form of diatomaceous earth in caustic soda under a pressure of 7 to 8 atmospheres, and then evaporating the resulting solution to the desired consistency.

Practically all the sodium silicate used in America is marketed in the form of solution. It is used in the manufacture of soap and as an adhesive in the manufacture of corrugated boxes, approximately 85 per cent being consumed by these two industries. It is also employed in the manufacture of various kinds of paper and fibre boards and as a size for paper. Its use as an egg preservative is well known and new uses are being constantly developed.

SODIUM HYPOCHLORITE

While most of the hypochlorite ($NaOCl$) produced is prepared electrolytically, a small amount is still prepared by the double decomposition of calcium hypochlorite and sodium sulphate, in which the insoluble calcium sulphate is formed while the sodium hypochlorite remains in solution.

This material is employed for bleaching vegetable fibres such as cottons, linens, etc., and also as a bleach to whiten wood pulp and other cellulose products. It is sometimes used as a disinfectant for laundry use.

SODIUM THIOSULPHATE (SODIUM HYPOSULPHITE)

Sodium thiosulphate ($Na_2S_2O_3 \cdot 5H_2O$) popularly known as sodium hyposulphite or "hypo" is obtained in large quantities from the "tank waste" obtained in the manufacture of soda ash by the LeBlanc process.

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[1] Sterne, T. E., Paper on Soluble Glass, Its Manufacture, Property and Uses. Presented before Ottawa Branch E.I.C., Nov. 26, 1924.

The residues containing calcium carbonate or calcium sulphide or both are oxidized by blowing air through them until all the sulphide is converted into calcium sulphide and thiosulphate. Then sodium sulphate is added which forms the insoluble calcium salt ($CaSO_4$) and leaves sodium thiosulphate in solution. This may be evaporated and sodium thiosulphate obtained by crystallization.

Sodium thiosulphate is used extensively in photography as a fixer for negatives, and also in the metallurgy of silver. To a small extent it is used in certain kinds of dyeing as well as an antichlor in paper-making.

Whether any or all of these sodium compounds can be commercially manufactured from the sodium sulphate obtained from the deposits of western Canada depends on economic factors, such as size of market, cost of production, transportation facilities, and availability of other raw materials.

CHAPTER X

GENERAL TOPOGRAPHY OF THE WESTERN PLAINS

The Interior Plain of western Canada comprises the greater part of the provinces of Manitoba, Saskatchewan, and Alberta, and contains with the exception of the few small occurrences in central British Columbia, all the known deposits of sodium sulphate described in this report. The deposits lie for the most part in the southern parts of the provinces of Saskatchewan and Alberta, between the 49th parallel (which here constitutes the southern boundary of Canada) and the 54th parallel. The area, therefore, in which deposits of this nature have so far been found contains approximately 200,000 square miles.

GENERAL TOPOGRAPHY[1]

The area embraces a large territory of what appears at first to be comparatively level, gently rolling country, for the most part devoid of heavy timber. It is bounded on the east by the Laurentian plateau and on the west by the Cordilleran Mountain system.

The part, however, between the 54th and 49th parallels is composed of two well-defined topographic divisions, varying greatly in their topographic features, and separated by a prominent escarpment.

First Division (Manitoba Lowland)

This division, the lower in elevation, its average elevation being approximately 800 feet above the sea, takes in the greater part of the province of Manitoba and includes a large tract of level plain underlain by sediments deposited in the bed of the glacial lake Agassiz. In the southern part, few lakes are found, but in the northern part the lakes of the Winnipeg system cover a large part of the area. The western boundary of the division is the escarpment just mentioned and is known as the Manitoba escarpment. This escarpment (see Map No. 647) commences in the Pembina mountains near the International Boundary and extends in a northwesterly direction taking in the Riding, Duck, Porcupine, and Pasquia hills. It rises in places to a height of from 400 to 1,000 feet above the level of the Manitoba lowland, and although broken in places by wide valleys which open eastward into the level lowland, it is a prominent and well-marked topographic feature several miles in width.

Second Division (Alberta Upland)

The second division or Alberta upland is bounded on the east by the Manitoba escarpment and includes all the territory west to the Rocky mountains. The eastern part of the upland, embracing that part of Saskatchewan situated east of a line running approximately northwesterly

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[1] For more detailed description see Young, G. A., Geology and Economic Minerals of Canada, Geol. Surv., Canada, Econ. Geol. Ser.; No. 1 (1916).

through township 15, and the 3rd meridian, is less regular in its surface configuration than the Manitoba lowland and consists of gentle undulations, low hills, and occasional pronounced morainic ridges. It is a typical ground moraine topography. Going westward, there is a gradual change in the topography; the morainic hills and ridges become more pronounced and the country more of a terminal morainic district.

The general slope of the Alberta upland is to the northward or eastward from elevations of from 3,000 to 5,000 feet along the edges of the foothills of the Rockies on the west, to elevations of 1,200 to 1,500 feet or less along the eastern boundary.

In many places plateaux occur in this Alberta upland, some of which are of considerable extent and rise steeply hundreds of feet above the general level of the surrounding country.

BEDROCK DEPOSITS[1]

The formations exposed in the Interior Plains region, range in age from the rocks of the Palæozoic and Mesozoic up to the Cenozoic.

At the eastern boundary of the province of Manitoba and extending northwesterly, Precambrian rocks occur, upon which, to the southwestward is laid Palæozoic strata consisting mainly of dolomitic limestones and ranging in age from Ordovician to Devonian. These formations underlie the Manitoba lowland, and the northern part of the Alberta upland.

These deposits in turn are covered by heavy deposits of shales and sandstones mainly of Cretaceous age, though remnants of Tertiary deposits are to be found in the higher plateaux of the Alberta upland such as in the Cypress hills and Wood mountain.

Cretaceous strata underlie the larger part of the Alberta upland. These strata form the eastern slope of the Manitoba escarpment where the lowest member rests on Devonian beds and is composed chiefly of white and brown, false-bedded, quartzose sandstone, sandy shale and shales. These basal measures are succeeded by marine Colorado shales of the Benton formation, overlain by calcareous shale and occasional thin limestone beds of the Niobrara formation. The Colorado beds are in turn covered by the Montana shales of the Pierre formation. In southwestern Saskatchewan, the Pierre shales in one district have interbedded with them a bed of tuff whose materials were presumably transported from a great distance, for no other evidence of former volcanic activity has been found in the general region.

The Montana beds occur at the surface of the Alberta upland, wherever exposures are to be seen, over a broad area extending west for some 400 miles. In the southern part of Saskatchewan and Alberta these beds pass under younger rocks of Upper Cretaceous and Tertiary age, which form high plateaux such as Wood mountain and Cypress hills.

The Cretaceous and Tertiary succession varies in different parts of the Interior Plains region and for a more detailed description of the various local differences, the reader is referred to the many reports of the Geological Survey relating to the geology of the western provinces.

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[1] This section has been compiled largely from the work of G. A. Young, op. cit.

SUPERFICIAL DEPOSITS AND GLACIATION

During the Glacial epoch the western plains of Canada were covered by a continental glacier advancing from a centre situated somewhere west of Hudson bay. The ice-sheet, travelling in a southwesterly direction, carried boulders and other detrital material derived from the Laurentian plateau and scattered them over practically the whole of the western plains almost as far as the Alberta foothills, where it met the glacial ice flowing eastward from the mountains.

Evidence of the distance which some of the superficial material resting on the plains has been carried, was readily indicated by field analyses of a number of sand and gravel exposures in the vicinity of the alkali deposits which showed that over 50 per cent of the material was derived from the Precambrian, the nearest outcrops of which lie many miles to the northeast, and a large proportion of the balance came from the Palæozoic areas adjacent to the Precambrian. The softer rocks of the formations underlying the whole of the western plains have furnished excellent material for the action of the ice-sheet, in consequence of which the larger part of the fine detrital deposits are composed of till derived from the younger formations of the area. These fine, superficial deposits are frequently of local origin, and only rarely have they been transported from great distances. The material from the several formations has usually been thoroughly intermixed to form the local soils.

During the retreat of the ice-sheet terminal moraines composed of gravel and sand accumulated, especially in southwestern Saskatchewan and in southern Alberta. Subsequent erosion has modified these moraines to some extent and dissected the till which practically covers the whole area.

The Interior Plains region is, therefore, nearly continuously covered with glacial, lacustrine, and fluviatile deposits produced during the Glacial epoch. The cover varies in thickness from a few feet in some places to several hundred in others, and except along the steep slopes of the large rivers has practically hidden all bedrock.

EROSION AND DRAINAGE

The western plains originally consisted of a great thickness of nearly horizontal sedimentary strata. These have, however, been subjected to extensive erosion probably mostly during Pliocene time[1], with the result that the greater part of the Tertiary deposits were removed and the Cretaceous sediments were sculptured to very nearly their present contour.

The advance of the ice-sheet over the western plains caused the blocking of the northern drainage and the formation of temporary drainage channels to the south. Upon the retreat of the ice it is probable that most of the larger drainage channels were again opened up, but the vast amount of morainic material deposited over the western plains undoubtedly greatly 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. These areas, with scarcely any drainage, are of great importance, since it is within them that nearly all the largest deposits of sodium sulphate are to be found.

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[1] See Young, G. A. op. cit.

A study of the map (in pocket) shows that the areas in which the sulphate deposits have so far been found in the greatest number correspond with well-defined terminal morainic belts. Thus, in the area south of Moose Jaw the sodium sulphate deposits are to be found in undrained basins in the Missouri coteau which shows practically its best development in this part of the province. Again, in the district lying to the west of Swift Current the morainic area known as the Great Sand hills holds numerous sulphate deposits in its undrained depressions. To the north of the South Saskatchewan river, east from the 4th meridian, terminal morainic topography predominates and sulphate deposits also are numerous. Likewise to the east of Saskatoon the same conditions occur with accompanying alkali deposits.

It is probable that further and more detailed study of the superficial deposits of the western plains will reveal a far greater distribution of the sulphate deposits than is now known.

TRANSPORTATION FACILITIES

The Prairie Provinces of western Canada are well served with railways. Two large systems, the Canadian National railway and the Canadian Pacific railway have transcontinental lines running east and west, and these together with their branch lines form a network of railways which cover fairly completely the whole of the territory in which the sulphate deposits are known to occur. It is therefore seldom that the haul from any deposit to shipping-point would be greater than 20 miles.

Road allowances running north and south between each section, and running east and west along the township lines and the lines two miles distant therefrom are provided. The highways in many instances are well graded and except when heavy rains make them very soft they can usually be travelled with heavy loads. The gradients are seldom very steep except in the coulees.

It can be seen that the deposits are much more accessible than the average mineral deposit and the transportation of the material to the railway should in few cases prove difficult.

CHAPTER XI

ORIGIN OF CANADIAN SODIUM SULPHATE DEPOSITS

The origin of the deposits of sodium sulphate in western Canada is of considerable economic importance inasmuch as it has a direct bearing on whether the deposits as they exist at the present time are definite deposits, or whether they are still accumulating at an appreciable rate.

It is not the purpose of a report of this nature to enter into a detailed geological discussion of the origin of sodium sulphate deposits and, therefore, only the briefest outlines will be given, sufficient to correlate the data collected during the past four years.

The following notes are, therefore, more as suggestions for future investigators, and are not presented as definite or completely proven theories.

THEORIES ADVANCED FOR ORIGIN OF SIMILAR SULPHATE DEPOSITS ELSEWHERE

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[1] after making a study of the alkali lakes occurring 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. His argument for the spring theory is as follows:—

> It was first generally supposed that the soda arose simply by the evaporation of surface waters that had drained through the soil into the lakes and in this way had dissolved the soda salts. For many reasons this supposition was doubted, and is now proved to be incorrect. While it is true that soda deposits occur in basins with no visible outlet, there are also a great number of such basins with lakes or ponds in them which contain only alkali waters, or when dry, but a thin crust of the alkalis or alkaline earths. The true soda deposit on the other hand, though the basins in which they occur are of abnormal area, always contains exceedingly large quantities of salts peculiar to them, and these are pure and are not, as a rule, a mixture of sodium, magnesium, and calcium salts which would be present if they were the result of the evaporation of surface waters. Mr. Arthur L. Stone, of Laramie City, has found that the Union Pacific lakes near Laramie are fed by springs whose waters are highly charged with sodium sulphate. Finally at Rock Creek there are in one and the same basin, some lakes containing pure sulphate of magnesium, others which contain with the latter also large quantities of sulphate of sodium, and still others which contain no deposit whatever. For these reasons it seems very certain that all of the large deposits of soda in Wyoming arise from the evaporation of springs which feed the lakes, and which are highly charged with soda.

Knight[2] who made a further extensive examination of these same deposits, could not reconcile the data he gathered with the spring theory

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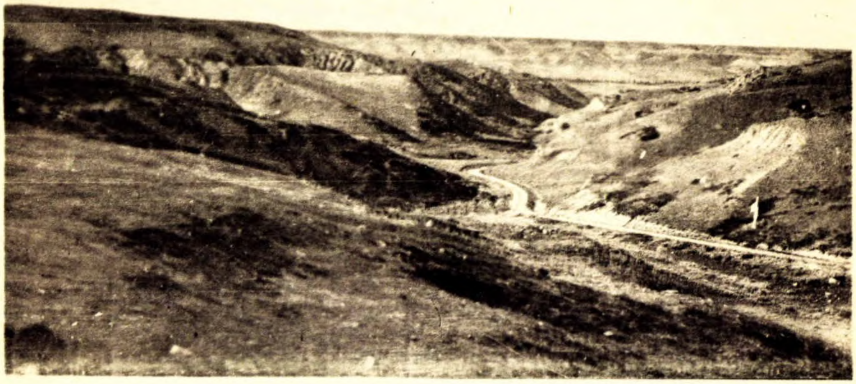
[1] Ricketts, L. C., Ann. Rept. Territorial Geologist, Wyoming, 1888.

[2] Knight, W. C., and E. E. Slosson, Alkali Lakes and Deposits, Bull. Wyo. Exper. Sta. No. 49, 1901, pp. 84-88.

#1684



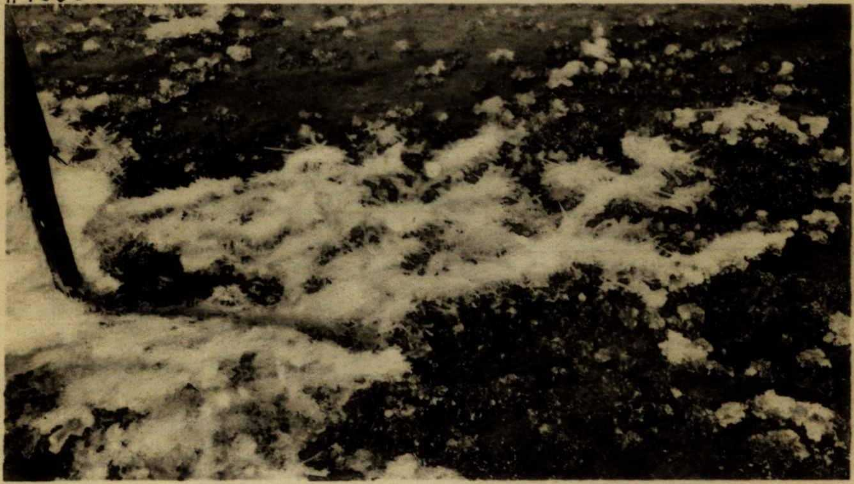
A. Coulee leading into Vincent Lake depression, Sask.

#1686

B. Granite erratic resting on Sandy plain, Ingebright, Sask.

A. Excavating crystal from Horseshoe Lake deposit, Sask., in winter months.

#1688



B. Crystals of mirabilite forming on surface of deposit, Frederick lake, Sask.

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. He summed up his evidence as follows:—

> Primarily the alkali has been produced by the decomposition of the various rocks containing these elements. These salts appear to have been formed extensively during the Mesozoic and Cenozoic eras, but in place of being stored in deposits were carried down with the sediments. Later, through the mountain-making agencies these formations were brought to the surface and through the influences of decomposition and erosion have been converted into soil. The salts have remained in the soils so formed, since there has not been sufficient water to leach them out. The decomposition of the rocks is still in progress and from this source and the storage already accumulated in the soils the deposits of alkali have been formed and are being increased.

Arnold and Johnson[1] consider that the sodium sulphate deposited in the lowest depressions of the Carrizo plain, San Luis Obispo county, Cal., 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 sulphate is thought to have been primarily derived from the decomposition of igneous rocks. Connate salts and older salt beds may, however, according to Grabau[2], produce a part of the salinity.

Wells[3] sums up his ideas as to the origin of the natural sodium sulphate deposits as follows:—

> The origin of sodium sulphate 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 sulphates are frequently observed. Rain water dissolves these coatings where it has access to them. This shows that basalts and lavas may furnish sodium sulphate to drainage systems. Moreover, granite and other igneous rocks are rarely free from pyrite and other sulphides. The sulphides on exposure are oxidized to sulphuric acid, which immediately dissolves some of the basic oxides, producing soluble sulphates.
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> Hardly any natural water can be found that is entirely free from sulphates. In most regions, however, such waters eventually escape to the ocean. In arid districts and the great closed basins, where rainfall is deficient and there is no outlet to the ocean, the soluble salts accumulate and may eventually form a deposit that is fairly dry for part of each year.
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> As an intermediate stage, even in waters that contain a relatively small proportion of sodium sulphate, mirabilite may be deposited in cold weather. The conditions that accompany this deposition generally involve some wind-blown sand, which may cover the precipitated sodium sulphate, or silt may effect the same result. In consequence of being more or less covered and on account of the high density of the saturated solution the salt is dissolved more slowly than it was precipitated and perhaps is not entirely redissolved in an entire season. Thus an accumulation is brought about. Subsequently, the water area shifts or the lake dries up, leaving the salt or salts deposited in the form of a hard layer or salt-incrusted sand.
>
> Some other possible methods of origin might be mentioned. For instance, the concentration and evaporation of many river waters, especially those of the Western States, which contain principally calcium bicarbonate, would cause a deposition of calcium carbonate and leave a solution rich in sodium sulphate, with smaller amounts of magnesium sulphate and sodium chloride.
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> Owing to the fact that soils consist largely of decomposed rock, sodium sulphate is a natural minor constituent of soils but one which is almost entirely removed by leaching

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[1] Arnold, Ralph and Johnson, H. R., Sodium Sulphate in Soda Lake, Carrizo Plain, San Luis Obispo County, Cal.; Bull. U.S. Geol. Surv. No. 380, 1909, p. 370.

[2] Grabau, A. W., Principles of Salt Deposition, Vol. I, McGraw-Hill Book Co., Inc., 1920, p. 222.

[3] Wells, Roger C., Sodium Sulphate: Its Sources and Uses. U.S. Geol. Surv. Bull. No. 717, 1923, pp. 17 and 18.

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.

It can thus be seen that opinions differ greatly as to the origin of sodium sulphate deposits. Even with respect to the same deposits there are wide differences in the theories of different investigators. It is highly improbable that one theory will be found which will be applicable to all sodium sulphate deposits, so that to each type of occurrence there will probably be ascribed that theory of origin which most nearly satisfies the observed data.

POSSIBLE SOURCES OF SODIUM FOR WESTERN CANADA DEPOSITS

With respect to the deposits of sodium sulphate in western Canada there are four possible sources from which the sodium found in the sodium sulphate may have been derived. These are briefly referred to in the following paragraphs.

UNDERLYING STRATA

The strata underlying the greater part of the western plains consist of fairly flat-lying sandstones and shales. The shales particularly, contain small proportions of alkalis. Whether the alkali present in these shales is in a form readily soluble is not known. Analyses of two shale outcrops from Saskatchewan show the percentage of alkalis present.

		Tilney[*]	Swift Current[1]
Moisture at 110°	Per cent	6·25	8·03
Loss on ignition	"	5·26	5·40
SiO_2	"	59·92	59·12
Fe_2O_3	"	8·16	13·42
Al_2O_3	"	11·60	6·30
CaO	"	1·68	2·13
MgO	"	0·50	trace
SO_3	"	2·00	1·61
Na_2O	"	1·24	1·41
K_2O	"	3·20	2·79
Totals	"	99·71	100·21

Interbedded with the shales, beds of volcanic ash have been recognized in some localities, notably in the area around Swift Current. It is also quite probable that material of this nature has a considerably wider distribution than is at present known. The ash, where it has been sampled and analysed, shows an appreciable percentage of the alkalis, running in some samples as high as 7 to 8 per cent sodium oxide. This alkali, however, is probably not present in a soluble form since it cannot be removed by ordinary leaching with water.

CONNATE WATERS IN UNDERLYING STRATA

When marine sediments are formed on the bottom of a sea, a certain amount of salts in solution in sea water are liable to be enclosed in such

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[*] F. MacNiven, Analyst.

deposits or later deposited as salts, and unless these salts are removed by leaching they may remain in the rock indefinitely. The entrapped sea water has come to be known by the name of connate water. That such waters are in sufficient quantities in some localities to be of great economic importance, has been clearly established, and as a possible source of the sodium of the western Canada deposits they have to be considered.

SPRINGS

It has been considered by many who have examined the sulphate deposits of western Canada, that they were being fed by springs which contained the salts formed in the deposits. The question naturally arises as to where the waters of the springs obtain their salts. According to the depth from which the spring has its source it might obtain salts from strata at a considerable distance from the point at which it rises to the surface or, on the other hand, it might be from the nearby surface drainage forced to the surface by hydrostatic pressure. A study of a number of these springs yielded some interesting data which will be referred to later.

SURFACE DEPOSITS OR GLACIAL DRIFT

The unconsolidated surface deposits which have been spread so extensively over practically all of the western plains consist, as has already been mentioned, of glacial drift made up largely from the pulverized underlying strata with smaller percentages of till brought from the Palæozoic and Precambrian formations lying to the northeast. It is thus largely calcareous clays, sands, etc. This material is well known all over the west for its remarkable stickiness and property of swelling after rains and for the slowness with which it gives up its moisture on drying. Another characteristic is that it shrinks considerably and cracks badly on drying. It is known locally as "gumbo." These peculiar physical properties of the gumbo soils of the west, according to Spence[1], are probably due to the presence in them of varying quantities of bentonite, a highly colloidal-like clay and which must have been derived either from bentonite beds or bentonitic sandstones or shales. This would suggest a wide-spread distribution of bentonitic sediments over the Prairie Provinces. Bentonite is known to contain varying percentages of the alkalis, as high as 4 per cent combined Na_2O and K_2O having been found in bentonite beds at depth.

POSSIBLE THEORY FOR ORIGIN OF WESTERN CANADA SODIUM SULPHATE DEPOSITS

The question arises as to which of the above sources is the most probable one in supplying the large deposits of sodium sulphate that are found in the Prairie Provinces. In this connexion the several possible sources will have to be examined in turn and all data which have any bearing on the question considered.

With respect to the underlying strata being the source of the salts, one has to consider the alkali being present in the strata in some soluble form which will lend itself readily to leaching by circulating waters. The under-

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[1] Spence, H. S. Bentonite, Mines Branch, Dept. of Mines, Rept. No. 626, p. 5.

lying beds are all stratified and hence were laid down in 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. There is, however, the possibility that the alkali was thus leached out but that drainage was in some way blocked. In due course, where the beds became land areas, the alkali would be deposited on evaporation as beds of salts interbedded with the other strata. The possibility of beds of salts of this nature being present in the underlying strata is really very slight due to the ready solubility of such salts, and in none of the numerous drill holes sunk for oil or gas in the western provinces has any trace of such beds been encountered. Where such drill holes have encountered brines they have invariably been chloride brines and not sulphate waters. Unless, therefore, the alkalis are present in these beds in some form not easily leached by ordinary circulating waters, it is improbable that these underlying strata are the source of the sodium sulphate for the western deposits.

The possibility of connate waters being the source of the salts for the surface deposits has to be considered. If the composition of the water of the sea which was present over the area in question at the time these underlying sediments were laid down, compared in any way with the composition of sea water at the present time (and from numerous analyses of salts derived from connate waters elsewhere, there is little reason to doubt this), then one would naturally expect the composition of the surface deposits to bear a striking similarity to salts derived from the evaporation of sea water. In that case one should find a large preponderance of sodium chloride in these deposits similar to the waters of Great Salt lake in Utah, the salts of which are thought by Grabau to be of connate origin.[1] That this is not the case in the deposits of western Canada has been clearly proven by the examination made, since with only one exception, sodium or magnesium sulphate is the predominant salt. In the one exception, namely Senlac lake, the salts in the waters are chiefly sodium chloride with sodium sulphate next in amount. It seems, therefore, hardly likely that connate waters furnish the salts for these deposits.

The numerous springs which are found around some of the deposits have been considered by many to be the source of the salts in the undrained basins of the prairies. The waters in these springs in nearly all cases carry small percentages of dissolved salts, principally sulphates, but with very few exceptions, was the percentage of the salts present sufficient to make the water unfit for drinking. A good example of this is the spring coming through the crystal bed in Muskiki lake. This spring for a number of years had been considered a true brine spring and the source of the salts in the deposit, but on putting a pipe down the spring orifice so as to prevent the waters coming in contact with the salts in the crystal bed, it was found that the waters of the spring were comparatively fresh and potable, and not a saturated brine as originally supposed. Similar water is obtained from an artesian well at the salt works on the lake shore, and is used for domestic purposes.

The temperature of all the springs or seepages examined was uniformly low, being around 4 to 7°C., which leads one to believe that they have their

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[1] See Grabau, A. W. Principles of Salt Deposition. Vol. I, 1920, McGraw-Hill Pub. Co., New York.

origin at no great depth.[1] One exception was found to this in a spring encountered in one of the holes in deposit No. 9 (Ingebright No. 1), in which a temporary flow of a strong brine with a temperature of 11°C. was struck. Whether this was the result of the spring water dissolving salts from the crystal bed through which it passed or whether it was naturally saturated with the salts was not determined.

The small percentage of salts found in all of these springs can readily be accounted for. In certain seasons of the year these deposits of alkali become dry and the surface of the material in the deposits readily becomes dehydrated and powdery. It has been noticed on windy days that this powdery material is subject to transportation by the wind for a considerable distance over the surrounding country. At one deposit, for example, it was observed after a heavy west wind lasting all day, that the country for a distance of from 1½ to 2 miles from the east shore of the lake was perfectly white due to the fine powdery salts being carried from the deposit and collecting on the vegetation . A rain of a few days later dissolved these salts and they were taken into the soil of the drainage basin, and it is reasonable to assume they would eventually find their way back into the deposits by the springs.

While springs may thus in a small way be supplying salts to the deposits it does not seem probable that they are the chief source from which the salts are derived.

From the observations made on the deposits during the last four years the most probable source of the salts seems to be from the leaching of the surface, or glacial deposits, by meteoric waters. Knight[2] in his study of the alkali lakes and deposits of Wyoming favoured this theory. He, however, assumed that the salts were produced by the decomposition of various rocks containing these elements during the Mesozoic and Cenozoic eras and that they remained as soluble salts even when carried down with the sediments.

In connexion with the Canadian deposits it did not seem conceivable that the salts in a soluble form could remain as such during the deposition of the Cretaceous sediments which were laid down in water, and through the subsequent formation into drift material by glacial action, without being leached out and carried away by drainage to the sea. It is, therefore, thought more probable that the alkalis were retained in a form not readily leachable, and that even in the material of the drift they still were present in the same condition and have only been released in a soluble form in comparatively recent times.

From the observations made of the deposits in western Canada the most probable source of the salts in these deposits seems to be from the alkali contained in the bentonite which is so widely distributed in the drift. It is not known definitely in what form the alkalis occur in the bentonite, but it is probable that they are present in the form of silicates in the original glass and as such are not readily leachable. Renick[3] explains in detail the possible means by which these alkalis may readily become

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[1] At the time the temperatures of these waters were taken, the atmospheric temperature ran between 17° to 20° C.

[2] Knight, W. C. and E. E. Slosson. Alkali Lakes and Deposits, Wyoming Experiment Stat., Bull. No. 49, 1901, p. 86.

[3] Renick, B. Coleman. Base Exchange in Ground Water by Silicates as illustrated in Montana. U.S. Geol. Surv. Water Supply Papor, 520-D, Washington, D.C., 1924.

available in the soluble form due to the base exchange of calcium or magnesium salts in meteoric waters releasing the alkalis. He gives the hypothetical reaction which might take place as follows:—

Na (or K) base-exchange silicate $+CaSO_4$ (or $MgSO_4$) =
(Ca (or Mg) base-exchange silicate$+Na_2SO_4$ (or K_2SO_4).

In an endeavour to test out this theory as to whether the alkali present in the bentonite could be readily released in this way, an experiment was made on some pure bentonite in which the alkali was definitely determined. Ten grammes of bentonite was agitated with 500 c.c. of distilled water to which 1 gramme of $CaSO_4 \cdot 2H_2O$ has been added. After agitation for 6 hours the mixture was allowed to stand and settle for 24 hours, after which the clear liquid was analysed. The original bentonite was found to contain 2·02 per cent Na_2O, while the clear liquid after agitation contained 1·59 per cent sodium oxide. This showed that a reaction of some sort had taken place, and since in the clear liquid there was also an equivalent loss of calcium oxide (CaO), it was presumed that the water containing calcium sulphate in solution had the power of releasing the alkalis and converting them into a soluble form. A similar test was made on bentonite with distilled water but without the addition of the calcium sulphate, and it was found that only a trace of the alkali had been removed from the bentonite.

The drift material of the western prairies is known to contain large quantities of calcium sulphate in the form of gypsum crystals widely distributed throughout its mass. This gypsum is probably formed by the action on limestone of sulphuric acid, formed by the decomposition of pyrite, which is known to be present in the shales. Surface waters dissolve certain amounts of this gypsum and this solution passing through the drift releases the alkali in the bentonite. The soluble salts of sodium thus formed are leached out and are concentrated as crystallized deposits in the undrained basins on the surface.

In the light, therefore, of the information gathered in this investigation it seems most probable that the source of the salts in the deposits of western Canada is from the unconsolidated drift material which covers practically the whole of the western plains. Circulating meteoric waters carrying calcium salts in solution by base exchange with the alkali silicates release the salts in the bentonite of the drift, in the form of soluble sulphates, etc., and these are in turn concentrated and deposited in the undrained lake basins in the surface deposits as found. The meteoric waters which carry the salts into the basins may be surface drainage, seepages, or springs.

It is probable that the greater part of the alkali in the unconsolidated drift material has already been leached out, so that the additions being made to the deposits at present are small compared to the rate of deposition in past years. For commercial purposes, therefore, these deposits should be considered as finite deposits, and when once worked out they are not likely to be replenished at an economic rate.

CHAPTER XII

CANADIAN OCCURRENCES OF SODIUM SULPHATE

The saline lakes occurring in western Canada have been known for many years. Bell[1] refers to a saline lake at the base of the escarpment (Dirt Hills) whose bed was covered with white salts, and another about 11 miles to the southeast. Bell[2] also mentions collecting specimens of the white efflorescent salt or "alkali" observed around many of the lakes and covering the dry beds of ponds in the region drained by the west branch of the Assiniboine, and found that they consisted principally of sulphate of sodium and magnesium together with chlorides of calcium and sodium.

Natural occurrences of soluble mineral salts are known in the provinces of Manitoba, Saskatchewan, Alberta, and British Columbia, either in the form of crystalline deposits or as brines. Some are of considerable extent and are probably of sufficient size to warrant commercial exploitation, provided economical methods of recovery can be developed and sufficient markets established.

GENERAL DESCRIPTION OF THE DEPOSITS

The occurrence of these salts may be broadly classed as

1. Solid salts and brines in undrained or partly drained basins.
2. Brines of flowing streams or springs.[3]

Those of the first class are very numerous in the Prairie Provinces and are generally similar in character, although the percentages of the different component salts vary in different localities. In many cases the term "alkali lake" has been appropriately applied to deposits of this nature, since in the early spring and often into late summer the deposits are covered with water and it is difficult to determine whether a bed of solid salts is present. The water accumulating from rain and melting snow in these undrained basins is often a foot or two in depth and carries a considerable quantity of the alkali salts in solution. In the late summer and especially in dry seasons these so-called lakes become deposits of crystallized salts closely resembling snow-covered basins.

Deposits of all degrees of concentration occur, from the "lake," the waters of which are only slightly alkaline and in which no crystal bed is present, to the heavily bedded deposit which is either completely dry or else has a covering of brine that is at or near the saturation point.

The deposits are all very similar in general character. They occur in depressions in the morainic drift with no apparent outlet. Usually the depression in which the salts are found in the crystallized form, is the lowest depression of a considerable area. In none of the deposits examined was bedrock encountered in place anywhere near the depression, the banks in all cases being composed of drift material, consisting of boulder clay,

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[1] Geol. Surv., Canada 1873-74, p. 79.

Geol. Surv., Canada 1878-79, p. 10C.

[3] Since most of the occurrences of this type are sodium chloride springs occurring in Manitoba which were dealt with in detail in Report No. 325, Mines Branch, Dept. of Mines, they will not be further referred to here.

sand or gravel. The slope of the banks varied in different lakes and even in different parts of the same deposit. In one deposit, for example, at the northern end there was a cutbank composed entirely of boulder clay, rising over 80 feet perpendicularly from the surface of the lake. At the other end of the same deposit the land had only a gentle rise.

Two types of crystal beds are found, one which is permanent, and another which is intermittent and which crystallizes or dissolves with varying conditions of temperature and moisture. A day's rain, for example, or a rise in temperature which increases the solubility of the salts, will quickly cover the surface of a deposit with a saturated brine due to the crystals in the intermittent bed going into solution. This brine will sometimes entirely disappear during one night if there is a fall in temperature. When first formed, the intermittent crystal consists of a mass of loosely compacted needle-shaped crystals of mirabilite which readily go into solution while the temperature of the atmosphere and brine is high, but with the approach of the cooler weather of the fall and winter, this bed becomes of greater thickness and solidifies into a hard compact mass. The material in the intermittent bed is generally very free from impurities when first deposited. Because this bed only forms under certain conditions in the fall and winter, and also because it is the material most readily recoverable it is known as "harvest crystal" or "harvest bed."

In the spring, when the melting snows and early rains occur, the whole or part of the top of the intermittent bed of crystal goes into solution and remains in the form of brine until evaporation produces saturation and crystal begins to form, when the cycle is again repeated. It is possible that each year a small part of the intermittent bed remains undissolved and becomes part of what is called the permanent bed. In the permanent bed the salts are generally found interbedded or mixed with small quantities of calcareous mud and organic material, and in only a few instances is the crude material from the permanent bed pure enough to be commercially marketable. In many cases the salt crystals contain mud stringers, so that the salts would have to be re-dissolved, and the impurities allowed to settle out of the solution before a pure product could be obtained.

The composition of the salts occurring in these basins consists chiefly of mixtures[1] of sodium and magnesium sulphate in varying proportions, with, generally, small quantities of sodium chloride, sodium carbonate, calcium sulphate and calcium carbonate. The sodium sulphate is the predominant salt in practically all the deposits with magnesium sulphate the next largest constituent.

THE BRINE

At certain seasons of the year brine is found on most of these deposits. The source of the water of the brine may be from spring rains, the melting snows, and from the numerous springs which are found in the neighbourhood of the deposits, as well as in the deposits themselves. The water of crystallization contained in the intermittent crystal also adds to the brine when the crystal goes into solution.

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[1] It is quite probable that some of the magnesium and sodium is present in small proportions as one of the more complex salts such as bloedite, loeweite, etc.; but these compounds were not definitely recognized as present in any of the deposits except in B.C.

The saline content of the brine is derived mainly from the solution of the intermittent crystal deposited during the previous autumn, and probably in some cases to a small extent from brine springs, where these are present, as in Deposit No. 9 (Ingebright No. 1).

When first formed the brine may be very dilute, but as the season progresses the brine gradually increases in its saline content, due to the natural evaporation and to the further dissolving of the crystal bed with which the brine comes in contact.

As the crystal dissolves, any mud which may have become entrapped when the crystal formed, drops to the bottom, so that in many cases there is a thin layer or film of mud left on top of the undissolved crystal. When crystallization again commences this clay forms a parting between the intermittent crystal and the permanent crystal. If, in the following year, only part of the intermittent crystal is taken into solution this parting of mud becomes part of the permanent crystal bed.

The depth of brine on different deposits varies greatly from year to year, according to local and climatic conditions. If a season is particularly wet, brine may remain on a deposit the year round; on the other hand, if the season is a particularly dry one, the brine may disappear early in the summer.

The solution of the crystal continues just as long as the incoming fresh water is greater than the amount of water lost due to solar evaporation. When equilibrium occurs no more crystal dissolves and as the evaporation increases the brine steadily becomes more concentrated until saturation is reached.

THE INTERMITTENT CRYSTAL

When the saturation point of the brine is reached, the salts commence to crystallize out. At this point the brine is very sensitive to sudden fluctuations of temperature. Thus, on a hot day the saturation point of the brine is raised and the salts more readily remain in solution. With the coming of cool nights, however, the brine is rapidly chilled and a sudden deposition of mirabilite takes place.

The first stage in the formation of the intermittent crystal as the cold air comes in contact with and cools the brine surface, is the sudden appearance of thin-bladed crystals of mirabilite on the surface of the brine. The surface tension of the brine is sufficient to float these crystals for a considerable time, but as they grow larger their weight overcomes the surface tension and they sink to the bottom.

The crystals increase in size rapidly as they fall through the brine, due partly to two or more crystals adhering together and partly to their causing the supersaturated brine to crystallize around them and build them up. As the weather becomes progressively cooler, less and less of the crystal dissolves each day and the crystal gradually becomes more compact until a solid bed of intermittent crystal is built up. The final stage of crystallization is reached when the weather remains cool enough throughout the whole day, so that the crystal remains and all the brine has disappeared.

When the crystal first starts to form it is generally very pure sodium sulphate. If, however, complete crystallization has taken place, all of the impurities in the brine, such as magnesium sulphate, sodium chloride, etc., also crystallize out and this, except in a few cases, is intimately mixed with the sodium sulphate crystals. Other impurities such as dust, are carried into the deposit by the wind and become embedded in the crystal.

THE PERMANENT CRYSTAL

In many of the deposits only part of the intermittent crystal bed has gone into solution with the spring rains, so that in time a bed of crystal more or less contaminated with mud has been gradually built up. This bed, known as the permanent crystal bed, is generally protected from solution by a thin layer of mud which covers it when the intermittent crystal partly dissolves and allows the entrapped mud to fall to the bottom.

The thickness of the hard permanent crystal bed varies greatly in different deposits and even in the same deposit. In some cases it is only a few feet in thickness, whereas in others it runs as much as 30 feet of solid crystal. An exceptional case was encountered in Deposit No. 9 (Ingebright No. 1) where a thickness of 139 feet of crystal was found in one part of the deposit.

In very few places was the permanent crystal encountered in a pure enough state to be suitable for commercial use without treatment. This crystal, however, is all available for commercial exploitation, since if by any chance, all the intermittent crystal were harvested from any deposit in any one year, by cleaning the top of the permanent bed, the top layer of the permanent crystal would go into solution in the spring and then supply sufficient material to form the next season's intermittent crop. In this way the permanent crystal would become available in a pure state as required.

In all the deposits examined a stoneless calcareous mud was encountered beneath the crystal bed. The mud immediately beneath the crystal was generally in the form of an ooze carrying about 50 per cent of sulphate crystals, below which it became more compact until finally the boulder clay was reached.

SPRINGS

Several types of springs were encountered associated with these deposits, the waters of most of them, however, being quite potable.

MARGINAL SPRINGS

Springs of this type are found around nearly every deposit. In most cases they are merely seepages and their temperature is low, showing that they do not come from any great depth. Analyses of a number of these springs are given elsewhere. They occur around the margin of the deposit and to all intents and purposes may be classed as freshwater springs.

FRESHWATER SPRINGS IN THE DEPOSITS

In a number of deposits springs were noticed coming up through the crystal bed, and for a long time these were thought to be brine springs, since any analysis made of them showed high percentages of salts. When, however, these springs were piped so that the rising water was not allowed to come in contact with the crystal bed, the water was found to be practically fresh and free from salts. The temperature in these springs also was very low, seldom higher than 7° C., and this also gave a clue as to whether a spring was a true brine spring or not, since springs with a high salt content, were generally quite high in temperature.

BRINE SPRINGS

A few springs which are probably true brine springs were noticed, notably the cone-building springs in the southern part of Deposit No. 9 (Ingebright No. 1).

During the summer it is hard to distinguish between the brine and freshwater springs, but when the cold weather arrives, the difference becomes very apparent, for mounds of crystal are soon formed around the orifices of the brine springs. These mounds are formed in the same manner as the intermittent crystal is formed, from the layer of brine over the surface of the deposit. The warm brine of the spring, when it reaches the surface is chilled by contact with the cold air, and mirabilite is deposited in a ring around the spring. On a cold night the crystallization is so rapid that it completely closes the outlet of the spring. The brine, however, is under hydrostatic pressure, which finally cracks open the top of the mound, and the brine gushes forth. After the sudden release of pressure, the brine slowly trickles down the sides of the cone, and, crystallizing, builds up the cone. The fissure is finally sealed up only to be broken open again by the increasing pressure. The process goes on until a cone of crystal (with a brine core) 10 feet or more in height, and having a diameter of over 20 feet at the base, is built up during the winter. The freshwater springs, on the other hand, have no such structures built up around their outlets. The cones dissolve away in the spring, together with the intermittent crystal.

In only three deposits were cone-building springs noticed.

METHODS AND APPARATUS EMPLOYED IN EXAMINING DEPOSITS

In surveying the deposits a small light transit was employed and measurements were made by stadia. The contours were determined by means of a hand level, and plotted directly on a plane table by stadia measurements.

The drilling was done by two power drills, built especially for the investigation, according to specifications, by the E. J. Longyear Company of Minneapolis, Minn.

During the first two years of the investigation (1921 and 1922) only one drill was employed. It consisted of a type BD diamond drill, together with a hoist, and a 2 by 3-inch Gould triplex pump, all operated by an 8-h.p. Cushman gasoline engine, the whole mounted on a platform. The platform was bolted to a steel frame on wheels, so that the whole outfit was easily moved from place to place. The entire weight was approximately 3,600 pounds. The drill was adapted to recover 1-inch and 2-inch cores.

A 200-foot steel cable attached to the hoist drum enabled the drill to be moved from place to place on the deposit by its own power. When moving from one deposit to another the drill was hauled behind a truck.

In place of using diamonds for the bits, pieces of hardened steel with chisel edges were placed in the bit, and these were found to give good results. On account of the friable nature of the material drilled, great care had to be taken in order to obtain satisfactory cores, since excessive vibration or too high a speed tended to break up the cores into individual crystals. A saw-toothed bit was tried, but it tore the crystals apart, instead of cutting them. High-speed tool steel, carbon steel and stellite were the materials used for the teeth and the best results were obtained with the stellite and high-speed tool steel.

At the commencement of the field season of 1923, the original drill was altered as a result of the experience gained during the previous years. A larger head was substituted, so that a 2-inch rod could be used and a 3-inch core obtained. This was a decided advantage, since it was found that with the 1- and 2-inch core barrels it was sometimes very difficult to obtain satisfactory solid cores. With the larger core barrel attached to the stronger rods, solid cores the full length of the barrel were commonly obtained. The engine was changed to a 10-h.p., and other minor changes made.

Difficulty had also been encountered in moving the drill from place to place on the deposits, due to the wheels of the drill sinking into the numerous mud holes which occur in the crystal, as well as their sinking through the soft material on the surface. The wheels were replaced by steel runners before the drill was taken onto a deposit, and this proved most satisfactory.

A second drilling outfit, a duplicate of the first after the alterations were made, was purchased and both drills gave complete satisfaction.

SAMPLING

The first few deposits examined were sampled every foot, but it was found on analysing the samples that the differences were so small that the data obtained were not commensurate with the amount of work entailed. It was therefore decided to sample every five feet separately. The samples from each hole were then combined by taking a proper proportion from each 5-foot sample and the composite sample for analysis obtained by quartering and drying at 105° C.

With the discovery, however, that some of the deposits were of considerable average depths (well over 5 feet), it was deemed expedient to sample and analyse each 5-foot separately, and consequently the greater number of the deposits examined in detail were treated in this manner.

The samples collected were broken up and spread out and allowed to partly dry after which they were quartered down to 1-pound samples. These were dried to constant weight at 105° C., after which they were crushed in an earthenware mortar to pass 10 mesh. They were then further quartered until a 4-ounce sample was obtained for analysis.

By drying all samples to constant weight, results comparable with one another were obtained. Any attempt to preserve the samples as obtained from the drill cores with the water of crystallization would have caused serious variations in the results, since even in the short time required in quartering the samples to convenient size, varying proportions of the water of crystallization would have been lost due to dehydration.

In each 5-foot sample *all* the material obtained as core was considered part of that sample. Thus, in many of the analyses the percentage of insoluble may seem rather high, but this can readily be understood when it is considered that the numerous mud seams which occur interbanded with the crystal are included with the 5-foot sample in which they are found. Of course any method of recovery of the crystal which involves putting the material in solution would not encounter any serious difficulty with the insoluble material, since this would settle out leaving the clean salt solution, but in order to gain a true knowledge of the several deposits it was thought best to sample the cores as they were actually recovered

In determining the true percentage of recoverable salts in each deposit it is, therefore, only necessary to recalculate the analysis on the basis of the soluble salts.

A complete chemical outfit for making preliminary analyses in the field was included in the equipment, and was found to be of great assistance.

Transportation of equipment and parties from one deposit to another was accomplished by touring cars and trucks.

DESCRIPTION OF DEPOSITS

In western Canada the occurrences of sodium sulphate vary in size from the small slough in which there is only a slight encrustation of salts on the surface of the mud, to the larger deposits in which the salts are present in thick-bedded deposits containing many millions of tons. It is manifestly impossible in a report of this nature to deal with each individual deposit, and only those deposits which have been examined in detail and drilled by the Mines Branch will be referred to at length. There are, therefore, a number of localities marked on the accompanying map which will not be described in the report. In many of these cases they are localities from which sodium sulphate has been reported and the extent of the deposits is not known. In other cases the deposits are small, but the material present was similar in all ways to other deposits examined. The general descriptions already given may be said to apply to all the deposits, and in the following descriptions only local differences will be referred to, in order to avoid repetition. In each case the deposit will be referred to by the number used in the field with its local name given in brackets.

Deposit No. 1—(Muskiki Lake Deposit)

LOCATION AND TRANSPORTATION

Muskiki lake is situated about one mile north of Dana, Saskatchewan, a station on the Winnipeg–Edmonton line of the Canadian National railway. The flag station of Maskakee Springs, on the Prince Albert branch of the same railway, is within a few hundred yards of the eastern shore of the lake.

The lake, which is about 7 square miles in area, is at present under a 21-year renewable lease to the Salts and Chemicals, Ltd., of Kitchener, Ontario.

The total tonnage of permanent crystal in the deposit is considerable, but the intermittent crystal will probably be the material utilized in commercial recovery for many years to come.

TOPOGRAPHY

Muskiki lake occupies the bottom of a circular undrained depression about 9 miles in diameter. The prairie surrounding the basin is quite flat and slopes gradually away from the rim of the depression towards the north, west, and south. To the east the country is level. The difference in elevation between the rim of the basin and the surface of the lake is approximately 200 feet. The sides of the depression slope gradually downwards to the edge of the lake and then form a steep bank 10 to 30 feet high around the deposit. At the extreme northwest end of the lake is an almost perpendicular bluff of boulder clay about 60 feet in height and extending for 2,000 feet along the shore.

The lake itself is divided by natural features into three sections. (See Map No. 648.)

1.—The Southern Section

This portion is about 4,000 feet wide and 1¾ mile long and extends from one mile north of Dana station northwards to a large island. The narrows on the eastern side of the island are only 300 feet in width and are completely blocked by a road which has been built from the mainland to the island. On the west side of the island, the narrows are about 500 feet wide and they form the only connexion between the southern section and the central part of the lake.

2.—The Central Section

This section, about 3 miles wide and 1¾ mile long, extends northwesterly from the island previously mentioned, to the narrows which separate it from the northwestern portion. The majority of the springs that occur in the bed are in this section.

3.—The Northwestern Section

This is the largest portion of the lake. It is about 2 miles long and 1½ mile wide and extends northwesterly from the narrows. It contains one small spring which is about 600 feet out from shore, just opposite the deep gully at the southern end of the boulder clay cliff running along the northwestern shore of the lake.

Muskiki lake was evidently formerly much larger than it is at present, since along the southwestern shore of the northwestern portion of the lake is the remains of what appears to be an ancient beach. This beach is approximately 15 feet above the present brine level.

The detailed investigation of this area was conducted during the winter months, so that the snow covering the ground made it impossible to study the character of the surface materials of the district. In a preliminary examination, however, during the previous summer, no bedrock outcrops were noticed anywhere in the drainage basin, and it is probable that glacial material mantles the whole district. Boulder clay predominates, with occasional sandy or gravelly areas. The depth of the glacial drift is unknown. Unfortunately, no record of the material drilled through in the artesian well at the plant was obtainable, so that although this well was sunk to a depth of 80 feet, no information is at hand as to whether the water-bearing stratum which was encountered is in the drift or in the shales beneath.

Springs

The springs occurring in Muskiki lake are quite numerous, but only eight were especially noticeable at the time of examination. Of these, seven were in the central section and one in the northwestern section. The one in the northwestern section was about 600 feet off the west shore. (See Map No. 648.) The flow from this spring was very small, but it was sufficient to keep an open space in the ice all winter. The temperature of the brine in the open space was 0° C., but this low temperature was probably due to the snow continually drifting into the water. No sample was taken, since no definite spring orifice could be found, the open space being merely a patch of slushy water three feet across, with soft mud beneath.

The springs in the central section of the lake are in the lake bed near the eastern shore. They are in three distinct groups and roughly in line. The smallest of these groups is located in the S.E. $\frac{1}{4}$, sec. 17, tp. 39, range 26, west 2nd meridian, 200 feet off shore opposite a narrow gully on the eastern shore. There does not appear to be any definite orifice to any of these springs, but merely a seepage up through the mud.

The major group of springs is located in the vicinity of Paint point in the eastern part of the central section. Paint point is a high, narrow point which juts out into the lake from the eastern shore for a distance of about 2,500 feet. The springs are situated on both the north and south sides of the point, at a distance of from 500 to 1,000 feet from the extremity.

The largest group is located on the north side of Paint point, 500 feet from the end. This group of springs, known as the Muskiki springs and from which the lake derives its name, have their orifices in the lake bed 80 to 150 feet from shore. (See Plate XII A.) The spring water, bubbling upwards through 5 feet or more of strong brine, becomes intimately mixed with the brine, and until recent years these springs were classed as true brine springs and had considerable local fame as medicinal springs. Three of them had a flow sufficient to keep the ice open immediately above them during the winter of 1923-24. The combined flow from the three largest was roughly estimated at one-half cubic foot per second. The temperature of all of the springs is $4\frac{1}{2}$° C. The chemical analysis of the water of the largest of the three springs is given below. The first sample was obtained by letting down a pipe to the orifice of the spring and collecting the sample from the water as it flowed from the upper end of the pipe above the level of the brine. The second sample was taken from where the spring bubbled up.

Analyses of Waters from Largest Spring at Paint Point

Constituents	1		2	
	Parts per million	Per cent of solids	Parts per million	Per cent of solids
Al_2O_3 and Fe_2O_3				
$Ca(HCO_3)_2$	364	26·49	405	12·55
$CaSO_4$	211	15·36	197	6·10
$MgSO_4$	655	47·67	1,939	60·09
$MgCl_2$			245	7·59
Na_2SO_4	77	5·60		
NaCl	66	4·88	441	13·67
Totals	1,373	100·00	3,227	100·00
Sp. Gr. at 15°C	1·002		1·003	

On the south side of Paint point, 600 feet east of the end of the point and about 400 feet out in the lake, are three more springs. These springs, more in the nature of seepages than true springs, were frozen over in February, 1924, but late in March they appeared through the ice and commenced to flood over a large area. The definite orifices could not be located, and no samples were obtained. At all of these springs the flow of water seemed very steady and was unaccompanied by gas.

At the plant of the Salts and Chemicals Ltd., on the shore, about 400 feet inland, an artesian well was sunk to a depth of 80 feet, at which depth a water-bearing stratum was encountered. The well provides water at a pressure of 20 pounds per square inch with a temperature of 4° C. This water is used for drinking and cooking purposes, but is rather unpleasant to the taste until one becomes accustomed to it. It is also used in the plant, but before being employed in the boilers it must be treated in a water softener.

An analysis of a sample of the water from this well, taken in February, 1924, is given below. An analysis of this water made some time previously by a private concern is given for comparison.

Constituents	Parts per million	Per cent of total solids	Constituents	Grains per U.S. gal.	Per cent of total solids
Al_2O_3 and Fe_2O_3	250	9·59	SiO_2 and	1·68	1·29
			Al_2O_3 Fe_2O_3	0·92	0·71
$Ca(HCO_3)_2$	203	7·79	$CaCO_3$	28·90	22·16
$CaSO_4$	510	19·57	$CaSO_4$	9·65	7·40
$MgSO_4$	1,125	43·17	$MgSO_4$	42·24	32·39
Na_2SO_4	518	19·88	Na_2SO_4, K_2SO_4	45·30	34·74
NaCl			NaCl, KCl	1·70	1·31
Totals	2,606	100·00		130·39	100·00

Sp. Gr. at 15°C.................1·003

As can be seen from the map, the springs in the central section are roughly in line, and this line coincides with a valley running almost north

#1689

A. Frederick lake, Sask.: in centre of picture the brine is completely crystallized; in the foreground the crystallization is in progress.

1690

B. Surface of crystal bed, Vincent lake, Sask., when completely crystallized.

#1692.

A. Orifice of freshwater spring in crystal bed, Vincent lake, Sask.

1693

B. Brine gushing from hole in top of crystal cone, Ingebright Lake No. 1 deposit.

and south, in which the Prince Albert branch of the railroad is located. In this valley, about 6 miles south of Totzke station, is a very large spring. It is possible that the line of springs marks the location of a fault in the formations beneath.

The Crystal Bed

The sulphate deposit in the bed of Muskiki lake was investigated during the period from February 14 to March 12, 1924. The cores of crystal obtained from the several drill holes put down through the crystal bed were sampled and analysed and the composition of the crystal bed at various depths was determined.

In addition to the diamond drilling, which disclosed the fact that the basin of the lake was comparatively shallow and that there was only one permanent crystal bed horizon, a systematic testing of the lake bed with 12-foot, chisel-pointed iron bars was conducted. Over 300 tests, covering the entire bed of the lake, were made in this way.

A few preliminary drill holes showed that the permanent crystal bed was shallow and uneven, being entirely absent in many parts of the lake bed. The drill was then moved to the middle of the central section of the lake and a hole drilled to prove the presence of a second extensive bed of salts at depth. The log of this drill hole, as shown below, disposes of the theory of the existence of another extensive crystal bed under the present known bed.

0 ft.	to	1 ft.	Ice and magnesium sulphate crystal.
1 "	"	1½ "	Sodium sulphate crystal—intermittent bed.
1½ "	"	2 "	Mud and crystal—mainly mud.
2 "	"	14 "	Black, oozy mud.
14 "	"	17 "	Hard, blue mud—obtained core 16 ft. to 17 ft. even with pump operating.
17 "	"	25 "	Soft, black mud.
25 "	"	26 "	Hard, black mud.
26 "	"	27 "	Soft, chocolate-coloured mud.
27 "	"	30 "	Light-coloured calcareous clay.
30 "	"	34 "	Hard, light-coloured calcareous clay.
34 "	"	37 "	Hard, light chocolate-coloured calcareous clay containing water-worn quartz and limestone pebbles. Obtained core 35 ft. to 36 ft. 6 in.

Referring to the above log, it can be seen that beneath the first crystal only mud strata of varying degrees of hardness were encountered until the stoneless clay was reached at a depth of 27 feet from the surface. The boulder clay was encountered at a depth of 34 feet, but the hole was continued for 3 feet. The possibility of a bed of soluble salts existing beneath the stony boulder clay in this area is highly improbable.

The cores of mud obtained from this hole have the following composition:—

		16 ft. to 17 ft.	35 ft. to 36 ft. 6 in.
Insoluble (HCl)	Per cent	46·88	63·63
Al_2O_3	"	4·32	7·42
Fe_2O_3	"	3·32	6·00
CaO	"	13·15	5·93
MgO	"	3·44	4·00
Cl	"	0·50	0·20
CO_2	"	16·06	12·32
SO_3	"	12·60	1·20
Totals	"	100·27	100·70

After proving the patchy and shallow nature of the permanent crystal bed and testing for a further crystal bed at depth, chisel-pointed iron bars were employed to delimit the various crystal areas in the lake bed and also to ascertain the thickness of crystal.

In the southern section of the lake the crystal bed was found to underlie practically all of the area, and bars were used only to determine the distance of the crystal bed from the shore.

After the various crystal areas had been outlined, detailed drilling was carried out and cores giving samples of each crystal area were obtained for chemical analysis.

The various crystal areas and the depth of crystal encountered at the corners of each 1,000-foot square may be seen by referring to the accompanying Map No. 648. The map is adapted from the township plans and consequently the shorelines of the lake are in places only given approximately, since the complete outline of the lake is not shown on the original plans.

CHARACTER OF THE CRYSTAL

The Muskiki deposit, in common with the other sodium sulphate deposits of western Canada, consists of a permanent crystal bed and an intermittent bed, the two being separated by a layer of mud varying from a few inches to 2 feet in thickness. The intermittent crystal is deposited from solution in the late summer and autumn and remains as a solid bed all winter, but is dissolved again in the spring and forms a saturated brine. Thus we may have the salts in three conditions:—

1. In solution, as a brine of varying degrees of saturation.
2. In an intermittent crystal layer.
3. As a permanent bed protected from solution by a layer of mud.

THE BRINE

The brine at Muskiki is notable for the high percentage of magnesium salts that it contains, as compared with the magnesium content of the brines on the other sodium sulphate deposits of western Canada. The proportion of the magnesium compounds to sodium compounds in the brine varies with the seasons and is greatest in the early spring, when the intermittent crystal is first beginning to dissolve, and late in the autumn, when practically all the sodium sulphate has been precipitated, leaving the magnesium sulphate in solution.

The depth of brine over the central and northwestern sections of the lake in normal years does not exceed two feet and about 10 to 12 inches of intermittent crystal is deposited during the autumn. In the southern section, the depth of brine rarely exceeds one foot, and only about 3 inches of crystal is deposited during the autumn in this portion of the lake. Indeed, during a dry season, the southern part of the lake is often completely dry.

Samples of brine taken at the same time over various parts of the lake may have the same specific gravity and the same chemical composition, but when taken at different seasons of the year, both the specific gravity and chemical composition will vary.

The following analyses show the composition of the brine at different seasons:—

	July, 1920	August,1920
$NaHCO_3$	1,322	1,451
Na_2CO_3	530	848
$MgSO_4$	163,500	178,000
Na_2SO_4	102,337	113,576
NaCl	18,926	23,200
Total[1]	286,585	317,075
Sp. Gr. at 15°C	1·250	1·270

(Results expressed in parts per million.)

THE INTERMITTENT CRYSTAL

The intermittent crystal bed at Muskiki is deposited from the brine in three stages.

The first stage is the deposition of the sodium sulphate layer with only small proportions of the other salts coming down. This stage begins during the cool nights of the late summer and as the weather gets progressively colder, increasing quantities of the sodium sulphate in the brine is deposited, leaving the more soluble salts in solution. When this stage is completed, practically all of the sodium sulphate in the brine is deposited as the decahydrate (mirabilite) in a layer 4 to 6 inches thick, of slightly yellowish, elongated rhombic crystals.

The second stage is the deposition of magnesium sulphate, which begins after the temperature of the brine has fallen below 5° C. This stage is of comparatively short duration and the deposited bed of salts is massive and not distinct in crystals.

The third stage, that of the freezing of the residual brine, is more or less connected with the second stage and there is no sharp line of demarcation between the ice and the magnesium sulphate layer.

The thickness of the intermittent crystal bed varies, depending on the original depth of the brine. When the deposit was examined during the winter of 1923-24 the intermittent crystal bed over the central and northwestern section of the lake was 1½ foot thick, composed of 6 inches of sodium sulphate, 6 inches of magnesium sulphate, and 6 inches of ice. The brine on the deposit during the previous autumn had been about 6 inches deeper than usual. In the southern section, the total depth of the intermittent crystal was 6 inches.

The following are the analyses of the two lower layers in different parts of the lake:—

—		A–2	B–2	C–2	A–3	B–3	C–3
Insoluble	Per cent.	0·31	0·13	0·42	0·80	0·48	1·20
NaCl	"	2·30	5·89	1·49	1·07	0·41	0·53
$NaHCO_3$	"	1·11	2·08	0·76	0·32	0·24	0·32
Na_2CO_3	"	....	0·12	0·55	....	....	....
$CaSO_4$	"	0·76	0·77	0·91	6·80	1·09	7·48
$MgSO_4$	"	77·56	82·67	23·31	7·30	7·40	7·80
Na_2SO_4	"	17·96	8·87	72·54	84·10	90·10	82·20
Totals		100·00	100·53	99·98	100·39	99·72	99·53

A, B, and C, northwestern, central, and southern sections respectively.
2=magnesium sulphate layer. 3=sodium sulphate layer.

The top layer of ice in each section was sampled, as well as a brine obtained between the sodium and magnesium layers in the northwestern and central sections, and analysed with the following results.

—	A-I		A-Br		B-I	
	Parts per million	Per cent total solids	Parts per million	Per cent total solids	Parts per million	Per cent total solids
Al_2O_3 and Fe_2O_3	246	0·32	151	0·08	....	....
Ca $(HCO_3)_2$	182	0·23	162	0·08	203	0·15
$NaHCO_3$	....	....	777	0·39	....	....
Na_2CO_3	....	....	504	0·25	....	....
$CaSO_4$	255	0·33	....	....	636	0·46
$MgSO_4$	49,000	63·86	132,500	66·70	91,500	67·23
Na_2SO_4	22,479	29·29	35,229	17·73	40,448	29·72
NaCl	4,571	5·97	29,322	14·77	3,300	2·44
Totals	76,733	100·00	198,645	100·00	136,087	100·00
Sp. Gr. at 15° C	1·075		1·175		1·124	

—	B-Br.		C-I	
	Parts per million	Per cent total solids	Parts per million	Per cent total solids
Al_2O_3 and Fe_2O_3	60	0·02	470	0·33
Ca $(HCO_3)_2$	....	....	182	0·13
$NaHCO_3$	2,671	1·04	....	....
Na_2CO_3	2,969	1·15	....	....
$CaSO_4$	....	....	255	0·18
$MgSO_4$	175,000	68·14	92,500	66·31
Na_2SO_4	11,083	4·31	42,621	30·55
NaCl	65,038	25·34	3,465	2·50
Totals	256,821	100·00	139,493	100·00

A, B, and C, northwestern, central, and southern sections respectively.
I=Ice. Br.=Brine.

Samples of the intermittent crystal were also taken from the northwestern and central sections, vertically through the ice, magnesium sulphate and sodium sulphate layers. These two samples were analysed, with the following results:—

		A	B
Insoluble	Per cent	0·84	1·53
NaCl	"	2·37	1·48
$NaHCO_3$	"	0·35	0·24
Na_2CO_3	"	....	....
$CaSO_4$	"	0·67	1·94
$MgSO_4$	"	47·28	23·50
Na_2SO_4	"	48·29	71·50
Total		99·80	100·19

A=northwestern section. B=central section.

The sodium sulphate layer in the intermittent crystal is, at present, the only portion of the deposit utilized in the salt cake plant. The layer of mirabilite crystals is, after being stripped of its covering of magnesium crystal, scraped up and trammed to storage piles just outside the mill.

PERMANENT CRYSTAL BED

Reference has been made to the uneven character of the crystal bed as referred to the lake bed as a whole. The uneven nature is also characteristic of the crystal bed itself, and relatively large differences in depth of crystal were noted in a very small area. It could not be assumed, for example, that because at the four corners of a 1,000-foot square a depth of 3 feet of permanent crystal was found, the depth would be uniform over that square. The depth might vary from a few inches to 6 feet. The same characteristic is typical of the areas marked as showing mud and intermittent crystal only. There are in areas pockets of permanent crystal, but they are small in extent. The lake bottom was evidently very hummocky and uneven before the salts were deposited.

The greatest depth of permanent crystal was found to be 6 feet 10 inches, and that only in two places and over a very limited area.

The permanent crystal is friable and contains considerable included mud, the proportion of included mud increasing in all directions from the centre of the crystal bed, so much so that there is a gradual transition from fairly clean crystal through muddy crystal to pure mud. This makes it extremely hard to assign a definite area to the crystal bed and an arbitrary line must be chosen as the dividing line between crystal and mud. Vertically, the limit of the crystal beds is well defined as they lie on soft mud. The above general description applies to all the various patches of the permanent crystal bed. By referring to Map No. 648, the location and extent of the permanent crystal bed areas can readily be seen. Each area is numbered on the map and these identification numbers correspond to the numbers used in the detailed descriptions which follow.

Crystal Bed No. 1

This bed occupying the western part of the northwestern section of the lake is composed of a fair quality of crystal which grades out gradually into mud, especially on the northern and eastern limits.

Six drill holes, Nos. 6 to 11, were put down in this bed and numerous tests were made with chisel-pointed iron bars. The greatest thickness of crystal found was 4 feet and the minimum about 2 feet. In the southern extremity of the bed the mud layer between the intermittent crystal and the permanent crystal was very thin, in some places being entirely absent, but for the most part there was an intervening layer of mud from 6 inches to 1½ foot thick.

The drill cores obtained from this area were sampled and analysed with the following results:—

—	1-6-0	1-6-1	1-6-2	1-8-0	1-9-0	1-10-0
Insoluble....Per cent	5·00	8·72	4·15	3·55	14·52	22·52
NaCl........ "	0·49	0·94	0·51	0·89	1·17	3·10
$NaHCO_3$.... "	0·31	0·38	0·38	0·10	0·31	0·53
Na_2CO_3..... "	....	0·20	0·30	0·31	0·10	....
$CaSO_4$....... "	1·72	3·08	1·80	2·48	5·49	5·28
$MgSO_4$...... "	21·39	12·63	20·72	5·73	15·24	6·87
Na_2SO_4...... "	71·55	74·20	72·57	87·18	63·38	59·00
Totals..........	100·46	100·15	100·43	100·24	100·21	97·30

1-6-0 Hole No. 6. Sample of permanent crystal, complete hole 2 ft. to 6 ft.
1-6-1 " " " " 2 ft. to 4 ft.
1-6-2 " " " " 4 ft. to 6 ft.
1-7-0 Hole No. 7. No core obtained.
1-8-0 Hole No. 8. Sample of permanent crystal, complete hole 2 ft. 6 in. to 5 ft.
1-9-0 Hole No. 9. Sample of permanent crystal, complete hole 2 ft. to 5 ft.
1-10-0 Hole No. 10. " " " 3 ft. to 5 ft. (muddy).
1-11-0 Hole No. 11. No core obtained.

Crystal Bed No. 2

This bed occupies the middle portion of the northwestern section and is, with the exception of the western half, composed of extremely muddy crystal. The depth of permanent crystal is from 3 to 4 feet in the centre of the bed and this depth is maintained almost to the edges. In the western part of this area 6 feet 10 inches of comparatively clear crystal was drilled through (hole No. 5) but this depth was of very local extent.

The whole bed was covered with from 3 to 6 inches of black mud. The crystal here is mixed with about an equal volume of mud and is very soft and friable.

Drill holes Nos. 1 to 5 were put down in this bed and samples of the cores taken for analysis. The following results were obtained:—

—	1-2-0	1-3-0	1-5-1	1-5-2
Insoluble..............................Per cent	19·86	10·74	5·85	8·87
NaCl.................................. "	1·40	0·96	0·76	0·73
$NaHCO_3$.............................. "	0·31	0·31	0·38	0·31
Na_2CO_3.............................. "	....	....	....	....
$CaSO_4$................................. "	6·60	4·54	5·22	6·26
$MgSO_4$................................ "	14·50	12·63	20·37	20·07
Na_2SO_4................................ "	57·34	71·00	67·58	64·25
Totals..........................	100·01	100·18	100·16	100·49

1-1-0 Hole No. 1. Too muddy to give core.
1-2-0 Hole No. 2. Sample permanent crystal, complete hole, 2 ft. to 6 ft.
1-3-0 Hole No. 3. " " " 2 ft. to 5 ft.
1-4-0 Hole No. 4. Too muddy to give core.
1-5-1 Hole No. 5. Sample permanent crystal, 1 ft. 9 in. to 5 ft.
1-5-2 Hole No. 5. " " 5 ft. to 8½ ft.

Crystal Bed No. 3

This is a very small bed of muddy crystal in the northern portion of the central section of the lake. The depth is from 2 to 3 feet and it is covered with from 3 to 6 inches of mud. Two holes, Nos. 12 and 13, were drilled in this area. Only one sample was obtained from the core from this area, namely, from hole No. 12, 3 feet to 6 feet. The analysis of this sample is as follows:—

		1–12–0
Insoluble	Per cent	13·28
$NaCl$	“	1·43
$NaHCO_3$	“	0·53
Na_2CO_3	“	0·10
$CaSO_4$	“	4·20
$MgSO_4$	“	9·80
Na_2SO_4	“	71·00
Total	“	100·34

Crystal Bed No. 4

This bed, which is very irregular in outline, occupies the southern portion of the central section of the lake. In its western extent the depth of crystal varies from 2 to 4 feet, but throughout its central part the depth is from 9 inches to 2½ feet with the exception of one small locality where there is about 5½ feet of crystal. In the eastern part the depth is from 6 inches to 2 feet.

The crystal is fairly clean and hard over the major part of this bed. There is from 2 to 6 inches of mud between the intermittent crystal and the permanent bed.

Seven drill holes, Nos. 14 to 20, were put down in this crystal. Samples of the cores obtained from these drill holes were analysed with the following results:—

—		1–14–0	1–15–0	1–16–0	1–17–0	1–18–0	1–19–0	1–19–1	1–19–2	1–20–0
Insoluble	Per cent	9·45	5·73	5·60	3·52	7·10	9·05	14·52	4·54	5·84
$NaCl$	“	1·18	0·59	1·00	0·58	0·87	0·80	0·90	0·53	0·48
$NaHCO_3$	“	0·84	2·70	0·62	0·76	0·62	0·84	0·53	0·30	0·38
Na_2CO_3	“	....	tr.	....	....	....	....	tr.	0·10	....
$CaSO_4$	“	2·19	2·55	2·52	2·55	3·74	3·35	4·90	2·30	2·55
$MgSO_4$	“	8·13	6·00	16·60	4·38	7·82	6·50	8·50	4·60	5·91
Na_2SO_4	“	78·30	82·00	74·11	88·64	80·26	79·78	71·00	88·00	85·00
Totals		100·09	99·57	100·45	100·43	100·41	100·32	100·35	100·37	100·16

1–14–0	Hole No. 14.	Permanent crystal, complete hole	(2 ft. to 5½ ft.)
1–15–0	Hole No. 15.	“ “ “	(1 ft. 8 in to 5 ft.)
1–16–0	Hole No. 16.	“ “ “	(1 ft. 8 in. to 4 ft.)
1–17–0	Hole No. 17.	“ “ “	(1 ft. 9 in. to 5 ft. 6 in.)
1–18–0	Hole No. 18.	“ “ “	(1 ft. 8 in. to 3 ft. 8 in.)
1–19–0	Hole No. 19.	“ “ “	(1 ft. 8 in. to 3 ft. 8 in.)
1–19–1	Hole No. 19.	“ “ 1st half	(1 ft. 8 in. to 2 ft. 8 in.)
1–19–2	Hole No. 19.	“ “ 2nd half	(2 ft. 8 in. to 3 ft. 8 in.)
1–20–0	Hole No. 20.	“ “ complete hole	(3 ft. 6 in.)

Crystal Bed No. 5

This bed of crystal occupies practically all of the southern section of Muskiki lake. The crystal is friable and comparatively free from mud and has a fairly uniform thickness of from 2½ to 3½ feet. In one place, near hole No. 28, a depth of 7 feet of crystal was found but this deep area was less than 30 feet in diameter.

Eight holes, Nos. 21 to 28, were dug with crowbar and shovel in this section. The covering of mud varies from 2 inches at the centre of the bed to about 1½ foot at both the northern and southern extremities.

Analyses of samples taken from this area give the following results:—

Analyses of Crystals from Muskiki Deposit

—		1-21-0	1-22-0	1-22-1	1-22-2	1-22-3	1-22-4	1-23-0	1-23-1	1-23-2	1-23-3
Insoluble	Per cent	6·13	27·40	13·40	16·02	8·35	15·13	11·47	15·58	10·27	7·58
NaCl	"	0·91	1·48	0·89	1·09	0·83	1·11	1·01	1·09	1·01	0·99
$NaHCO_3$	"	0·38	0·38	0·38	0·76	0·59	0·67	0·67	0·76	0·67	0·67
Na_2CO_3	"	......	......	tr.	......	......	......	......	......	......	......
$CaSO_4$	"	1·17	5·22	2·48	3·20	1·56	2·45	1·70	2·38	1·36	1·36
$MgSO_4$	"	7·90	11·13	8·19	9·73	7·57	12·78	7·13	6·16	7·78	10·72
Na_2CO_4	"	81·44	53·78	75·14	68·32	81·15	65·92	77·74	72·42	77·67	79·41
Totals	"	97·93	99·39	100·48	99·12	100·05	98·06	99·72	98·39	98·76	100·73

—		1-24-0	1-24-1	1-24-2	1-24-3	1-25-0	1-25-1	1-25-2	1-25-3	1-25-4	1-26-0
Insoluble	Per cent	8·67	9·33	7·23	10·93	6·68	11·97	8·40	7·10	2·70	6·99
NaCl	"	0·89	0·73	0·74	1·78	0·79	0·96	0·99	0·83	0·41	0·60
$NaHCO_3$	"	0·76	0·76	0·67	0·59	0·51	0·84	0·76	0·67	0·67	0·92
Na_2CO_3	"	......	......	......	......	......	......	......	......	......	......
$CaSO_4$	"	1·67	1·53	1·60	1·53	1·56	1·63	1·22	0·88	0·27	1·43
$MgSO_4$	"	6·16	6·00	7·03	6·16	6·19	7·24	8·11	7·52	3·68	6·27
Na_2CO_4	"	80·77	80·48	80·73	79·40	83·64	78·01	79·70	83·66	92·68	83·92
Totals	"	98·92	98·83	98·00	100·39	99·37	100·65	99·18	100·66	100·41	100·13

1-21-0 Hole No. 21. Permanent crystal, complete hole (1½ ft. to 5 ft.)
1-22-0 Hole No. 22. " " " " (1 ft. to 4½ ft.)
1-22-1 " " " " (1 ft. to 1½ ft.)
1-22-2 " " " " (1½ ft. to 2½ ft.)
1-22-3 " " " " (2½ ft. to 3½ ft.)
1-22-4 " " " " (3½ ft. to 4½ ft.)
1-23-0 Hole No. 23. " " complete hole (1½ ft. to 4½ ft.)
1-23-1 " " " " (1½ ft. to 2½ ft.)
1-23-2 " " " " (2½ ft. to 3½ ft.)
1-23-3 " " " " (3½ ft. to 4½ ft.)
1-24-0 Hole No. 24. " " complete hole (8 in. to 3 ft.)
1-24-1 " " " " (8 in. to 1 ft.)
1-24-2 " " " " (1 ft. to 2 ft.)
1-24-3 " " " " (2 ft. to 3 ft.)
1-25-0 Hole No. 25. " " complete hole (8 in. to 4½ ft.)
1-25-1 " " " " (8 in. to 1½ ft.)
1-25-2 " " " " (1½ ft. to 2½ ft.)
1-25-3 " " " " (2½ ft. to 3½ ft.)
1-25-4 " " " " (3½ ft. to 4½ ft.)
1-26-0 Hole No. 26. " " complete hole (1½ ft. to 3½ ft.)

Analyses of Crystals from Muskiki Deposit—Concluded

—		1-26-1	1-26-2	1-27-0	1-27-1	1-27-2	1-27-3	1-28-0	1-28-1	1-28-2	1-28-3
Insoluble	Per cent	7·70	6·47	13·18	22·27	5·67	11·50	12·05	15·23	8·92	9·45
NaCl	"	0·66	0·66	1·00	1·34	1·06	1·11	1·02	1·47	0·48	0·78
$NaHCO_3$	"	0·67	0·51	0·53	0·67	0·76	0·59	0·67	0·67	1·94	1·92
Na_2CO_3	"	......	......	......	......	......	......	......	......	0·50	0·30
$CaSO_4$	"	1·90	0·54	1·92	3·74	1·43	0·54	1·36	1·56	1·17	1·29
$MgSO_4$	"	6·27	6·00	8·58	10·53	8·14	7·82	3·85	10·72	7·12	6·18
Na_2CO_4	"	83·14	84·87	71·83	59·31	80·82	76·37	80·17	65·35	80·52	80·22
Totals	"	100·34	99·05	97·04	98·36	97·88	97·93	99·12	95·00	100·65	100·14

1-26-1 Hole No. 26. Permanent crystal, (1½ ft. to 2½ ft.)
1-26-2 " " " " (2½ ft. to 3½ ft.)
1-27-0 Hole No. 27. " " complete hole (8 in. to 3½ ft.)
1-27-1 " " " " (8 in. to 1½ ft.)
1-27-2 " " " " (1½ ft. to 2½ ft.)
1-27-3 " " " " (2½ ft. to 3½ ft.)
1-28-0 Hole No. 28. " " complete hole (8 in. to 3½ ft.)
1-28-1 " " " " (8 in. to 1½ ft.)
1-28-2 " " " " (1½ ft. to 2½ ft.)
1-28-3 " " " " (2½ ft. to 3½ ft.)

ESTIMATED TONNAGES OF SOLUBLE SALTS IN BASIN OF MUSKIKI LAKE

The tonnage of crystal is considerable as may readily be seen by referring to the following estimates, but as the crystal is distributed over an area exceeding 7 square miles it cannot be considered as available by direct mining operations. It should be looked upon, however, as a reserve to be eventually recovered through solution and subsequent recrystallization of the soluble salts. The present method of working the deposit utilizes the intermittent crystal deposited from solution during the previous autumn, and, if this means of recovery is utilized throughout the working of the deposit, the tonnage as estimated below can be considered available.

	Tons
Permanent crystal bed	4,760,000
Crystal in mud	557,000
Intermittent crystal[1]—	
Sodium sulphate layer	2,463,000
Magnesium sulphate layer	2,463,000
	10,243,000

HISTORY AND DEVELOPMENT OF MUSKIKI LAKE DEPOSIT

Muskiki lake, known at one time as Houghton lake, has long been known for the medicinal properties of its waters, but it was not until 1915 that the commercial possibilities of the lake were investigated.

During the Great War, the high price of potash caused an intensive search to be made for that mineral in Canada and it was in the course of

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[1] The area of the deposit has not been accurately obtained, since only a rough outline of the lake was available from the township maps, hence the tonnage of intermittent crystal on the above areas is purely approximate. No differentiation has been made in these calculations between magnesium and sodium sulphate so that the tonnage as given represents the amount of hydrous soluble salts.

this search that Muskiki lake was investigated by a New York syndicate. In July, 1915, an engineer from New York, accompanied by Mr. Sloan of the Canadian Northern railway, examined the deposit but, finding no potash either in solution or in the solid state, abandoned any idea of developing the lake.

In August of the same year, Mr. Sloan met Messrs. Ide and Klotz of Kitchener, Ontario, and a syndicate was formed to further investigate Muskiki lake with a view of developing an Epsom salt industry, which material had been proven by the previous investigation to be present in considerable quantities. The company then formed was known as the Canadian Salts and Potash Company, Ltd., with a capital of $500,000.

In December, 1915, a dredging-lease for the bed and banks of Muskiki lake was applied for at Ottawa, the intention being to dredge the lake bottom for magnesium salts. No regulations existed under which the application could be dealt with, and an Order in Council had to be passed by the Dominion Government in June, 1916, granting a dredging-lease to J. O. Carss, Barrister of Ottawa, on behalf of the Canadian Salts and Potash Company of Canada, Ltd.

The lease permitted the extraction of magnesium salts only, and while these salts were undoubtedly present in large quantities, further examinations proved that the greater proportion of the salts present in this deposit was sodium sulphate. Another Order in Council was therefore applied for, and this was granted in August, 1921, covering all the soluble salts present in the lake and mud beneath.

In 1918 a tank car of brine from Muskiki lake was shipped to Kitchener, Ontario, where extensive tests were made.

During the early part of 1919, a pilot plant was erected at Kitchener with the idea that it would eventually form the nucleus of a main plant. The test runs made in this plant seemed very encouraging, but the freight rates on brine from the lake to Kitchener prevented the arrangement being continued.

An evaporating plant was next built at Muskiki, and the dried salt was shipped to the plant at Kitchener, where refined Epsom salt, Glauber's salt and magnesium carbonate were manufactured. The cost of production, however, coupled with the high freight rates, prevented this plan from being successful.

The question of manufacturing salt cake was then considered, and a process was patented by Messrs. Ide and Handcock to manufacture salt cake from the crystal of Muskiki lake.[1] The intermittent crystal was harvested and a carload shipped to Kitchener to try out the process, the results of which test, encouraged the company to plan a larger plant. At this juncture a new company, Salts and Chemicals, Ltd., with an authorized capital of $2,500,000, was formed and a new plant using the Ide and Handcock process was erected at Muskiki lake.

Salt Cake Plant of Salts and Chemicals, Ltd.

The company erected on the shore of Muskiki lake a number of substantial buildings, housing a modern plant for the production of salt cake from the crude crystals of the deposit. The process used at present

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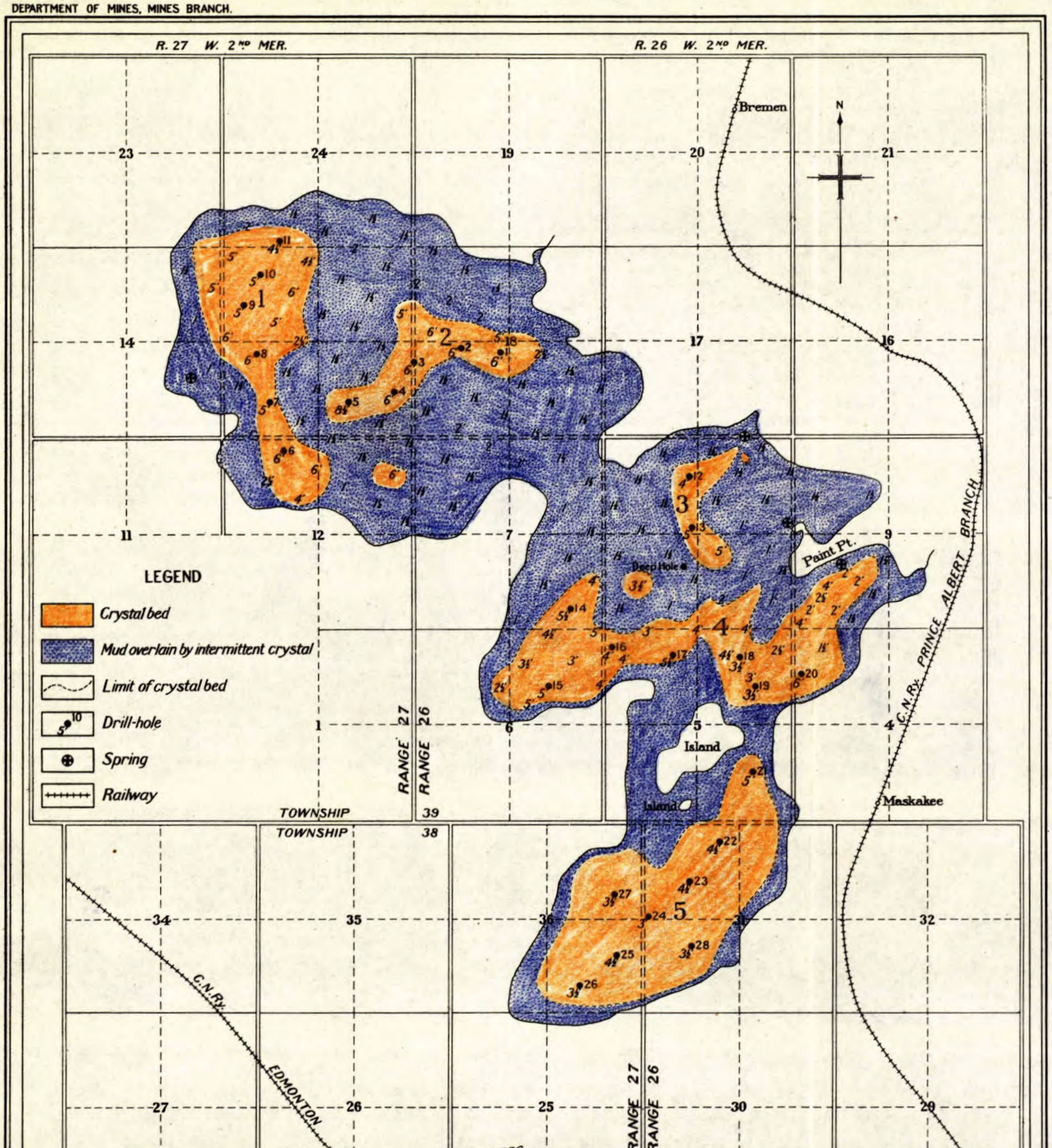
[1] See further description of this patent in Chapter on Technology, p. 47.

DEPARTMENT OF MINES, MINES BRANCH.



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DEPOSIT No. 1

MUSKIKI LAKE SODIUM SULPHATE DEPOSIT

Tp. 38, R. 26, 27 and Tp. 39, R. 26, 27

West of 2nd. Meridian

SASKATCHEWAN

Scale in chains

40 20 0 20 40 60 80

is one based on the patent granted Messrs. Ide and Handcock, known as the "Salt Process" and is similar to "Pechiney's Process" patented in 1878. The capacity of the plant is theoretically 100 tons of salt cake per day of 20 hours, but it has never been operated to full capacity.

The power plant has two 200-h.p. boilers, which furnish steam for the digesters and for the steam turbine driven alternating current generator which is the main power unit. Each machine in the mill is individually driven by an electric motor. There is a Cochrane water softener used at the plant to treat the boiler feed water.

The crude crystal, harvested from the deposit by ice-cutting machines, is piled in large stock piles outside the mill.

It is removed from the stock pile by suitable means and dissolved in digesters into which certain quantities of sodium chloride are added which precipitates the sodium sulphate in the anhydrous form. The anhydrous crystals are removed from the digesters together with the remaining brine and passed to a dewaterer, which discharges the crystal with only 12 per cent of moisture. The remaining moisture is removed in a revolving drier.

The warm brine from the anhydrous crystals is conducted by launders to the crystallizing pans, where, on cooling, crystals are deposited. The residual liquor is then fed to the evaporating pans where complete evaporation over a coal fire is carried on, and the sodium chloride along with the magnesium salts are recovered. These pans are the standard open pans used for salt recovery.

The commercial product "salt cake" is obtained in the form of a finely crystalline mass with less than 1 per cent of moisture. When examined under the microscope, the minute crystals are easily discernible. A sample was taken from the stock on hand and analysed with the following results:—

Insoluble	Per cent.	0·28
$NaHCO_3$	"	0·31
$CaSO_4$	"	1·22
$MgSO_4$	"	0·50
$NaCl$	"	3·04
Na_2SO_4	"	93·00
Total	"	98·35

The product carries no free sulphuric acid and ferrous salts are entirely absent.

Deposit No. 2—(Frederick Lake Deposit)

LOCATION AND TRANSPORTATION

This lake, situated in parts of sections 20, 21, 29, and 33, township 12, range 28, west of the 2nd meridian, has a large deposit of crystal salts composed principally of sodium sulphate with small percentages of magnesium sulphate and carbonate, and sodium chloride.

The deposit is approximately 38 miles southwest of Moose Jaw, Sask., and is served by a spur line about 200 yards in length, from the Moose Jaw-Assiniboia branch of the Canadian Pacific railway. The town of Expanse is 3 miles southwest of the deposit.

TOPOGRAPHY

The deposit occupies a depression between a number of morainic ridges of the Missouri coteau, and covers an area of approximately 825 acres. It is separated from Johnson lake, on the north, by a narrow ridge composed of sand and gravel, which rises, in places, 30 to 40 feet. The level of Frederick lake is, approximately, 3 feet lower than Johnson lake. There is no apparent outlet, and some of the adjacent morainic ridges rise to a height of over 100 feet above the level of the crystal bed.

Frederick lake is in the same drainage basin as Johnson lake, a large body of faintly alkaline water exceeding 100 square miles in area. The immediate drainage basin of the deposit, however, lies to the south and east where the ground has a gradual rise for a distance of from 3 to 4 miles back from the lake. There is also a small sub-surface drainage through the gravel bar from Johnson lake.

It is probable that at one time this lake was a bay of Johnson lake, since there are strong evidences of beaches on the morainic slopes surrounding the lakes, at an elevation of from 30 to 40 feet above the present level. A rise of 40 feet in the present level of the water of the lake would submerge the narrow neck of land separating the two lakes to a depth of 10 feet. Conditions would, therefore, be favourable in this particular instance, for deposition of salts in the present basin of Frederick lake, as a partly-entrapped arm of Johnson lake.

SPRINGS

Three springs feed into the depression from the shores and another one was noticed in the crystal bed. Springs Nos. 1 and 2 are very similar in composition. Spring No. 3 varies considerably from the other two, but is very similar in composition to the water in Johnson lake. Inasmuch as this spring is situated on the shore nearest Johnson lake, it is quite probable that it is the result of seepage from the larger lake. The temperature of the water coming from these springs was 5·6° C. in August, 1921.

The waters from the three springs flowing into the lake were analysed as well as the water from Johnson lake, and the results are expressed in parts per million.

—	Spring No. 1	Spring No. 2	Spring No. 3	Johnson Lake
Insoluble	30·2	30·0	20·0	47·0
Fe_2O_3, Al_2O_3	7·9	3·6	5·6	10·0
$CaCO_3$	310·4	304·2		
$CaSO_4$			180·6	125·6
$MgCO_3$	209·8	242·0		
$MgSO_4$			1,222·0	1,288·0
NaCl	5·14	8·8		
Na_2SO_4	968·8	925·8	4,395·0	4,842·0

THE CRYSTAL BED

The salts occur in solution, as well as intermittent crystal and permanent crystal.

The brine, when present, will vary in depth from 2 to 8 inches and carries a high percentage of salts in solution. When no intermittent crystal is being formed, there is always a thin layer of mud on top of the

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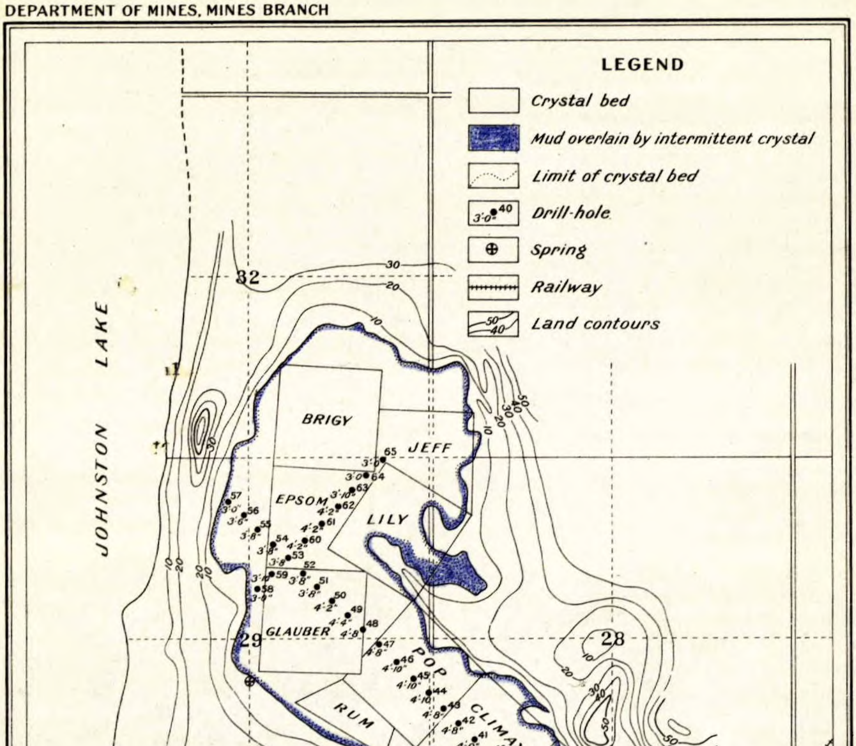

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DEPOSIT No 2

FREDERICK LAKE SODIUM SULPHATE DEPOSIT

Sec^s 20, 21, 28, 29, 32, 33. Tp. 12, R. 28

West of the 2nd Meridian

SASKATCHEWAN

Scale of Feet

1000 0 1000 2000 3000 4000

permanent crystal composed of material which has either been blown into the lake or else washed in from the shore. The brine becoming sufficiently concentrated yields a layer of intermittent crystal from 2 to 6 inches in thickness on top of the mud. The purity of this crystal varies according to the season of the year. One sample collected from this "harvest" bed when the lake was completely crystallized in August, 1921, and another sample taken in March, 1924, are given to show the composition.

		Aug., 1921	Mar., 1924
Insoluble	Per cent	......	0·40
NaCl	"	0·66	0·49
$NaHCO_3$	"	......	0·33
$CaSO_4$	"	0·72	0·88
$MgSO_4$	"	3·00	0·55
Na_2SO_4	"	95·50	97·70
Totals	"	99·88	100·35

It will be noted that both these samples were collected when complete crystallization had taken place and all the brine had disappeared, consequently any magnesium sulphate present in the brine had also crystallized. If, then, a sample were collected when crystallization first commences, it is probable that the salts would run considerably higher in sodium sulphate.

Sixty-five holes were drilled, and it was found that the permanent crystal bed averaged 4·2 feet in depth. Beneath the bed was an irregular thickness of silty mud with salt crystals interspersed through it, resting on a compact stoneless and highly calcareous clay. A typical hole gave the following results:—

4 inches loosely compacted crystals—Intermittent crystal
1 inch mud.

0	to	5 ft. 6 in.	hard compact crystals—Permanent crystal.
5 ft. 6 in.	"	10 "	soft mud and crystals.
10 "	"	15 "	silty clay, calcareous (stoneless).
15 "	"	20 "	coarse sand, calcareous bond.
20 "	"	28 "	boulder clay.

Map No. 649 gives the location of the drill holes and the depth of permanent crystal encountered in each hole.

From the different cores obtained from the drill holes a number of samples were taken to determine the composition of the crystal bed. From the analyses of these samples an average analysis was obtained as given below. A number of pits were also dug completely through the permanent crystal bed and samples taken from each one, every foot in depth. These results were also averaged, with the following results:—

—		Average of samples from all holes	Average of Samples from Pits			
			1st foot	2nd foot	3rd foot	4th foot
Insoluble	Per cent	4·44	2·23	3·73	2·62	3·73
NaCl	"	0·62	0·76	0·72	1·21	1·00
$CaSO_4$	"	3·23	2·88	5·36	4·20	4·25
$MgSO_4$	"	6·63	5·67	7·25	8·66	8·56
Na_2SO_4	"	84·76	88·46	82·94	83·31	82·46

The amount of hydrous salts in this deposit, including both intermittent and permanent crystal, is approximately 6,400,000 tons.

HISTORY OF THE DEPOSIT

Frederick lake was staked by local parties in June, 1920, under the Quartz Mining Regulations. In July, 1921, the Bishopric and Lent Company of Cincinnati, Ohio, took over the claims, 14 in all, and later the same year commenced the erection of an experimental plant. Tests have been carried on continuously to date, with the result that the company is now producing commercially.

The first plant erected employed triple effect vacuum evaporators, but the present plant is based on entirely different principles, namely, spray evaporation or evaporation in space.

The harvested salts are put into solution, filtered and sprayed through a series of nozzles at the top of the spraying chamber. The finely divided spray falls through a rising current of heated air, which causes the salts to drop to the bottom of the spraying chamber as a finely divided dry powder and the moisture is carried off at the top. The process permits of a close control of the product produced. Thus if the salts are carried to complete dryness in the spraying chamber, a clean white fluffy powder is obtained carrying less than 0·5 per cent moisture and weighing around 30 pounds per cubic foot. If, on the other hand, a heavier product is required the evaporation in the spraying chamber is so regulated that a small percentage of moisture is left in the salts and this is driven off in a rotary drier. Several grades of material can, therefore, be prepared. The rated capacity of the plant is 50 tons of dried salts per day.

Small quantities of pure recrystallized Glauber's salt are also prepared whenever the demand justifies its manufacture.

Deposit No. 5—(Fusilier Deposit)

LOCATION AND TRANSPORTATION

The deposit is situated in sec. 17, tp. 34, range 27, west of the 3rd meridian. It is 5 miles northwest of Fusilier, a station on the Coronation division of the Canadian Pacific railway. A fairly good dirt road connects the deposit with the railroad. The Soda Deposits, Ltd. (Head office, Calgary, Alta.), who operated this deposit from 1920 to 1922 used a motor truck to haul material to and from the railroad.

TOPOGRAPHY

The country for several miles around the deposit is very hilly, the hills being gravelly mounds about 100 feet high and probably of morainic origin. The deposit is about 1 mile long, north and south, and 1,000 feet wide. The banks of the deposit conform to the slopes of the morainic gravel ridges, and, although steep, are not precipitous. The drainage basin is comparatively small.

SPRINGS

A few small springs were observed around the margin of the deposit but none in the crystal bed. A well sunk near the summit of one of the gravelly knolls, 300 yards east of the southeast end of the deposit, was flowing freely. The temperature of the water both winter and summer was around 4½°C. The water tasted slightly alkaline, but was used by the company for all domestic purposes.

THE CRYSTAL BED

The crystal bed of this deposit in March, 1922, consisted of 5 to 6 inches of intermittent crystal, immediately underlain by from 5 to 14 inches of permanent crystal more or less mixed with mud. Two samples taken from this deposit gave the following results on analysis:—

		Intermittent crystal	Permanent crystal
Insoluble	Per cent	0·37	0·40
$NaCl$	"	0·30	0·66
$NaHCO_3$	"	0·43	0·25
$CaSO_4$	"	......	0·34
$MgSO_4$	"	1·24	2·05
Na_2SO_4	"	93·58	94·53
Totals	"	95·92	98·23

The tonnage of crystal is very small, but it is of interest since it was one of the first deposits from which a shipment of anhydrous sodium sulphate was made.

PLANT AND PROCESS

The method employed for dehydrating the harvested salts was air-drying. The process is fully described in the chapter on Technology and will not be referred to here. The method proved slow and yielded only small tonnages and the property was abandoned in 1923.

HISTORY OF DEPOSIT

The lake was staked on December 29, 1919, by D. R. McKinnon of Fusilier. The two claims were assigned to A. Kelly and J. O. Williams of Calgary in 1920, and work was commenced the same year.

In February, 1922, the claims were again assigned to the Soda Deposits, Ltd., of Calgary, Alta.

Work ceased on the property in 1923 and the plant was dismantled.

Deposit No. 6—(Chain Lake)

LOCATION AND TRANSPORTATION

Chain lake is a long narrow lake situated in secs. 10, 15, 16, and 21, tp. 18, range 20, west of the 3rd meridian. The deposit is about 16 miles southwest of Cabri, and 15 miles south of Shackleton, both these stations being on the Empress branch of the Canadian Pacific railway. The wagon roads are quite level.

TOPOGRAPHY

The deposit occupies a narrow depression, about 3 miles long, which has a northwesterly and southeasterly trend. The greatest width of the deposit is 2,000 feet but the width of the major part is only 1,000 feet or less.

The surrounding country is flat rolling prairie and well cultivated; the soil is ground moraine with occasional patches of boulders. The depression containing the deposit is shallow, the banks being not more than 30 feet high. The crystal surface is about 50 feet below the general level of the country. The drainage basin is small.

SPRINGS

Three marginal springs were noted but none in the crystal bed. Spring No. 1 at the southeast end of the lake, which had the largest flow, (temperature 4°C), is used by all the surrounding farms for drinking water. Spring No. 2, which is on the west shore, has a temperature of 5½°C. and flows out of a marshy recess in the bank. Spring No. 3 was on the western bank 2,500 feet north of spring No. 2. Its flow was very small and the temperature was 6°C. Analyses of the samples taken from springs Nos. 1 and 2, gave the following results:—

	No. 1	No. 2
Insoluble	28	32
$CaCO_3$	320	136
$MgCO_3$	100	360
NaCl	25	63
Na_2SO_4	1,090	1,100

(Results expressed in parts per million.)

These are practically freshwater springs.

THE BRINE

The brine averaged 2 feet in depth in July, 1922. A sample was analysed, as well as the brine in another lake lying half a mile to the south, in which there was, however, no crystal bed.

	Brine 1	Brine 2
$MgSO_4$	32,700	8,300
NaCl	4,800	3,900
Na_2SO_4	126,000	102,000

(Results expressed in parts per million.)

THE INTERMITTENT CRYSTAL

The intermittent crystal averaged 4 inches in depth but was contaminated with considerable mud.

THE PERMANENT CRYSTAL

The permanent crystal bed covers an area of 70 acres, and averages 2¼ feet in depth. The accompanying map gives the location of the bed. It is very patchy but is fairly pure. Eighteen holes were drilled in this deposit and samples taken which analysed as follows:—

Analyses of Samples from Drill Holes in Deposit No. 6

—		1	2	3	4	5	6	7
Insoluble	Per cent.	0·40	0·65	1·60	1·80	1·77	5·65	5·15
Fe_2O_3, Al_2O_3	"	0·40	0·40	0·65	0·57	0·50	1·50	1·40
$CaCO_3$	"	......	......	......	......	......	......	......
$CaSO_4$	"	0·36	0·96	2·64	2·64	1·26	4·60	3·00
$MgSO_4$	"	1·35	2·70	3·83	2·80	2·59	2·97	3·35
Na_2SO_4	"	96·60	94·70	90·50	91·55	93·30	84·00	86·00

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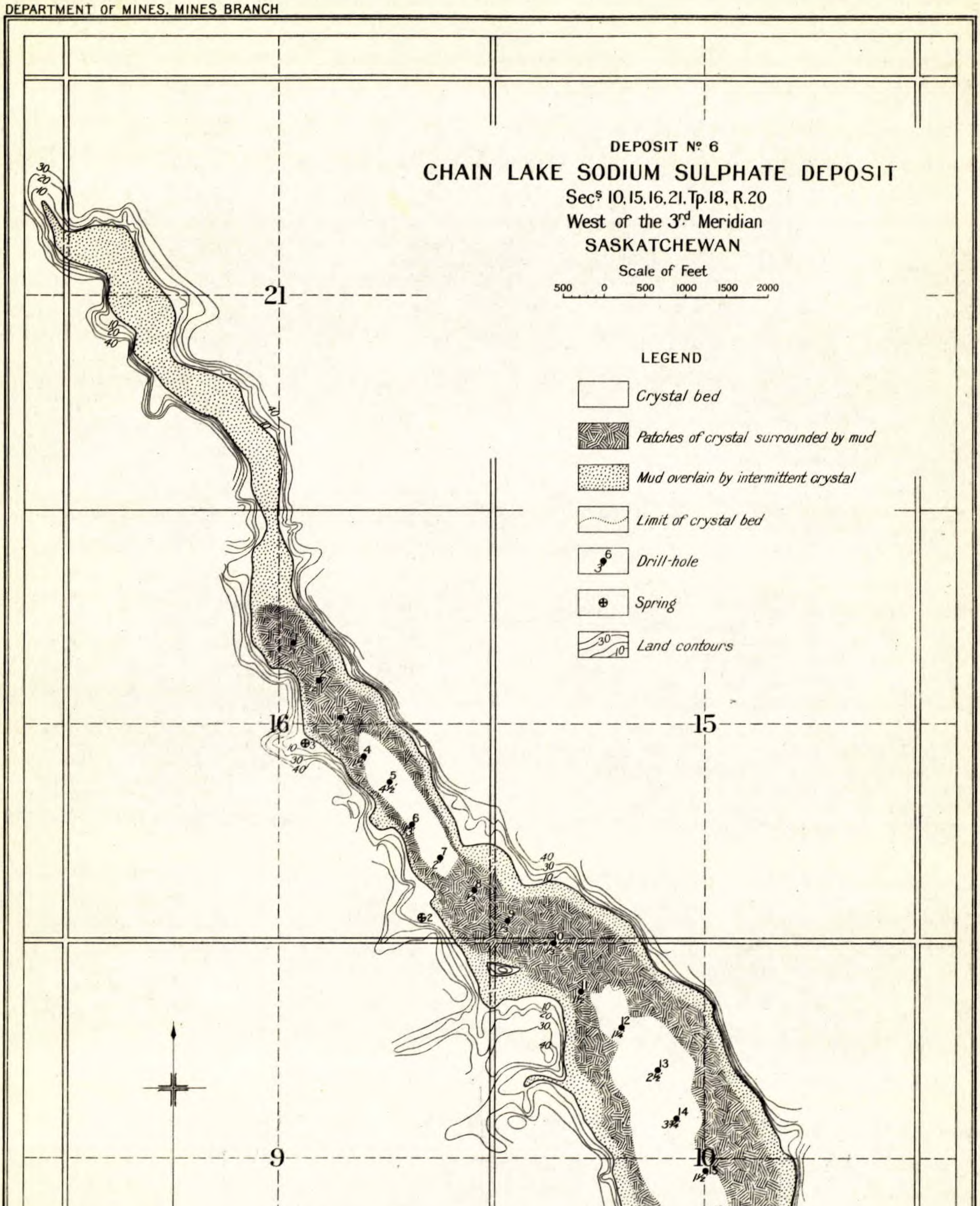

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A. Cone formed around brine spring, Ingebright deposit, Sask.

#1695

B. Large cone built around brine spring, Ingebright deposit No. 1, Sask.

#1696

A. Mud flats showing mud cracks and salt plants.

#1697

B. Vincent lake, Sask., showing mud margin to crystal bed. The tracks shown were made when walking out to the hard crystal surface.

Analyses of Samples from Drill Holes in Deposit No. 6—Concluded

—		8	9	10	11	12	13
Insoluble	Per cent.	2·05	1·10	14·60	7·75	12·30	6·00
Fe_2O_3, Al_2O_3	"	0·40	0·40	3·60	2·00	3·00	1·90
$CaCO_3$	"	....	....	6·49	2·05	7·65	....
$CaSO_4$	"	1·38	1·44	....	3·00	3·02	4·05
$MgSO_4$	"	2·52	1·29	4·05 ($MgCO_3$ 2·85	4·48	4·30	3·56
Na_2SO_4	"	93·00	95·00	67·50	79·50	69·00	83·50

The quantity of hydrous salts in the deposit is estimated to be 300,000 tons.

Deposit No. 7—(Snakehole Lake)

LOCATION AND TRANSPORTATION

The deposit is in secs. 7 and 18, tp. 18, range 18, and secs. 1, 2 and 12, tp. 19, range 18, west of the 3rd meridian. It is 9 miles by road southwest of Battrum and 8 miles south of Cabri, both of these stations being on the Empress branch of the Canadian Pacific railway. The roads are hilly and, in wet weather, very muddy.

TOPOGRAPHY

The deposit is about 2¼ miles long and is 1 mile wide at the northeast end, but for the greater part of its length it is only about 2,000 feet wide. The banks are steep and high except at the southern end where they slope off more gradually. At the north end of the lake a cliff of stiff boulder clay rises precipitously to a height of about 100 feet. Approximately one-quarter mile northeast of the deposit is a small slough, the water of which is slightly alkaline, separated from the main deposit by a narrow ridge about 30 feet above the level of the crystal bed. The water in this slough is 15 feet above the level of the main deposit. Half a mile north of the small slough, and about 10 feet higher in elevation, is a circular, freshwater lake about three-quarters of a mile in diameter, in which the water is nowhere more than 3 feet deep. The bottom of the lake is a hard, compact, greyish mud.

At the southwest end of the main deposit there is a short valley trending southwest, which opens up into a large, long valley some 2 miles in length north and south, and over half a mile in width, with sloping sides 60 to 80 feet in height. There are a number of springs in this valley discharging into a small creek which flows into the southwest end of the main deposit. The general level of the bottom of this valley is only some 15 to 20 feet above the level of the crystal in the main deposit.

SPRINGS

There are a number of marginal springs around the deposit, some of which have a considerable flow. The temperature of these waters ranged from 4° to 7°C. As can be seen from the following analyses, they are all practically freshwater springs and the waters in those that are flowing are potable. There are a number of freshwater springs in the bed of the deposit but no cone-building springs were observed. Samples were taken from five of the largest springs and analysed:—

—	1	2	3	4	5
Insoluble	35	24	30	20	10
$CaCO_3$	300	210	270	220	140
$MgCO_3$	330	310	145	120	165
$MgSO_4$	....	120	175	240	110
NaCl	250	120	20	20	15
Na_2SO_4	1,720	1,300	296	285	410

(Results expressed in parts per million.)

1. Flowing spring at Halberg's farm, one-half mile northeast of deposit.
2. " " farmhouse on northeast shore.
3. " " cove on east shore.
4. " stream from valley at south end of deposit.
5. Well on western shore at centre of deposit.

THE BRINE

In the early months of the summer the brine is from 18 inches to 2 feet deep, but in normal seasons it completely disappears by the end of August. The brine is very clear and fairly free from mud, except around the numerous sink holes in the crystal. A sample of the brine taken in March, 1924, was collected and analysed.

	March, 1924 Brine beneath ice	July, 1922
$Ca(HCO_3)_2$	1,420	......
Na_2CO_3	424	......
$CaSO_4$	578	3,260
$MgSO_4$	50,240	20,260
$MgCl_2$	2,580	......
NaCl	15,563	7,340
Na_2SO_4	......	111,680
Total	70,805	142,540
Sp. Gr. at 15°C	1·061	1·095

(Results expressed in parts per million)

It is interesting to note that in the sample taken in March, 1924, all of the sodium sulphate had evidently crystallized out of the brine leaving it rich in magnesium sulphate and sodium chloride.

THE INTERMITTENT CRYSTAL

A good crop of harvest crystal is deposited on the top of the permanent crystal each year. In normal years the thickness will average from 6 to 10

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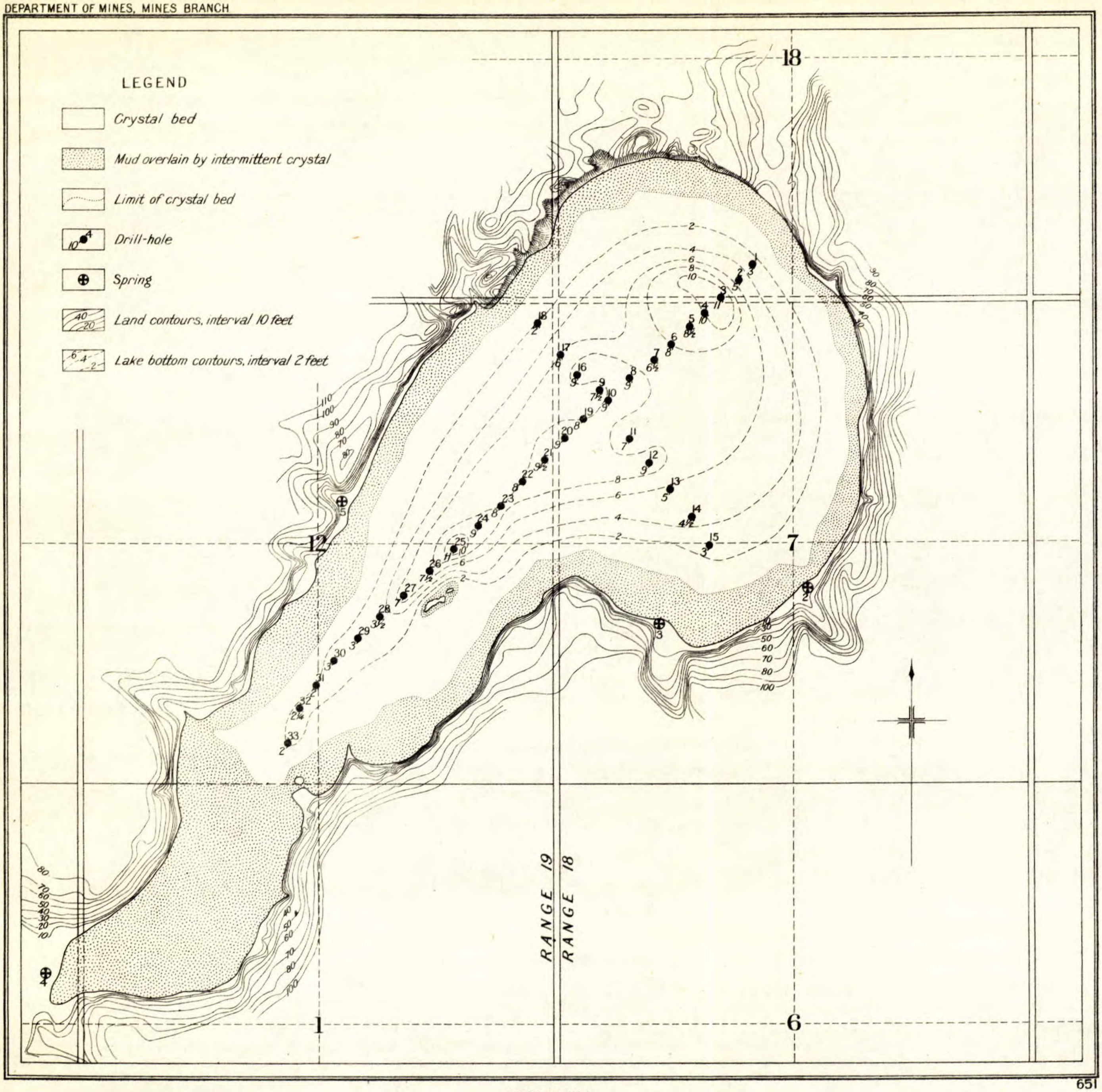

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DEPOSIT Nº 7

SNAKEHOLE LAKE SODIUM SULPHATE DEPOSIT

Sec^{s} 1, 2, 12 Tp. 18, R. 19 and
Sec^{s} 7, 18 Tp. 18, R. 18
West of the 3rd Meridian

SASKATCHEWAN
Scale of Feet
500 0 500 1000 1500 2000

inches. It is comparatively free from mud except around the mud chimneys. An analysis of this crystal gave the following results:—

Insoluble	Per cent.	0·30
NaCl	“	0·66
$NaHCO_3$	“	0·33
$MgSO_4$	“	1·08
Na_2SO_4	“	96·40
Total	“	98·77

Wherever the mud chimneys occur there is a corresponding hole in the harvest crystal around the edges of which the mirabilite forms beautiful crystal groups. A number of these groups were collected and photographed (Frontispiece and Plate I).

THE PERMANENT CRYSTAL

The permanent crystal bed covers an area of approximately 460 acres with an average depth of 6 feet. Scattered through the crystal bed are numerous mud holes or chimneys, varying from a few feet to many feet in diameter. These caused considerable trouble in moving the drill from place to place on the deposit (Plate XII B).

Thirty-three drill holes were put down; samples were obtained from 27 which analysed as follows:—

Analyses of Samples from Drill Holes in Deposit No. 7 (Snakehole Lake)

Constituents		1	2	3	4	5	6	7	8	9
Insoluble	Per cent.	11·25	9·50	5·30	4·00	3·65	5·70	3·85	4·00	5·00
Al_2O_3, Fe_2O_3	“	2·30	1·75	0·95	1·10	1·15	1·40	1·30	0·55	1·20
NaCl	“	1·40	1·15	0·74	0·61	1·15	1·17	0·97	0·71	0·90
$CaCO_3$	“	......	......	......	......	......	......	......	......	......
$CaSO_4$	“	5·61	5·26	3·51	2·18	2·90	4·17	3·81	2·06	5·80
$MgCO_3$	“	......	......	......	......	......	......	......	......	......
$MgSO_4$	“	9·50	9·66	7·29	4·64	5·45	6·21	6·37	5·24	4·63
Na_2SO_4	“	69·94	72·68	82·21	87·47	85·70	81·25	83·70	87·44	82·47

Constituents		10	11	12	13	14	15	16	17	18
Insoluble	Per cent.	14·10	9·50	5·90	5·20	6·20	7·00	29·25	13·55	6·00
Al_2O_3, Fe_2O_3	“	2·75	2·00	0·95	1·85	1·00	1·50	3·20	1·50	0·85
NaCl	“	0·75	0·80	0·90	1·00	0·90	0·90	......	......	......
$CaCO_3$	“	......	......	......	......	......	....	26·20	4·40	2·66
$CaSO_4$	“	10·50	4·23	3·87	4·84	4·11	(CaO) 4·84	......	......	......
$MgCO_3$	“	......	......	......	......	......	(MgO) 6·50	9·02	10·38	4·45
$MgSO_4$	“	6·05	6·21	5·88	4·59	6·10	....	....	2·55	6·64
Na_2SO_4	“	65·85	77·26	82·50	82·50	81·69	79·26	31·58	67·42	79·69

Analyses of Samples from Drill Holes in Deposit No. 7 (Snakehole Lake)—Con.

Constituents		19	20	21	22	23	24	25	26	27
Insoluble	Per cent.	7·26	3·05	10·96	7·14	11·85	10·17	8·21	4·23	4·74
Al_2O_3, Fe_2O_3	"	2·34	1·00	3·42	2·02	4·02	2·21	1·54	1·03	0·75
NaCl	"	1·06	0·99	1·16	0·71	1·04	1·75	1·46	0·55	0·70
$CaCO_3$	"	4·69	1·82	7·56	5·21	6·40	8·85	7·52	2·43	2·19
$CaSO_4$	"	......	......	......	......	......	......	......	......	......
$MgCO_3$	"	2·55	3·66	4·32	5·08	3·21	3·84	3·78	2·63	2·59
$MgSO_4$	"	2·29	2·66	6·17	7·25	4·59	5·48	5·38	3·55	3·68
Na_2SO_4	"	77·05	86·16	66·46	72·69	69·67	66·62	71·89	85·64	84·85

The amount of hydrous salts, including the intermittent crystal and brine, is estimated to be 4,800,000 tons.

Deposit No. 8—(Corral Lake)

LOCATION AND TRANSPORTATION

This lake, situated in secs. 14 and 23, tp. 14, range 20, west of the 3rd meridian, is approximately 12 miles northwest of Gull Lake, and 9 miles directly north of Carmichael. Both towns are on the main line of the Canadian Pacific railway. The wagon roads leading to both towns are very hilly and rough.

TOPOGRAPHY

The deposit lies in an undrained depression in the eastern edge of the great belt of morainic sand hills extending along the north side of the Canadian Pacific railway, between Swift Current and Maple Creek.

The surrounding hills are composed entirely of fine sand, no boulder clay or gravel areas of any extent being noticed.

SPRINGS

There is one marginal spring at the south end of this lake, the water of which is quite potable. An analysis of this water is as follows:—

Insoluble	80
Al_2O_3, Fe_2O_3	22
$CaCO_3$	366
$MgCO_3$	419

(Results expressed in parts per million)

THE SODIUM SULPHATE

The sodium sulphate is mostly in the form of permanent crystal, since, the drainage basin being small, there is only from 3 to 4 inches of brine in the early spring. The intermittent crystal is rarely more than 1 inch in depth.

The deposit covers an area of 60 acres, and 15 test holes proved the average depth of crystal bed to be 5 feet.

On account of the sandy nature of the shore the brine has penetrated through the porous sand strata for a number of feet and the salts have

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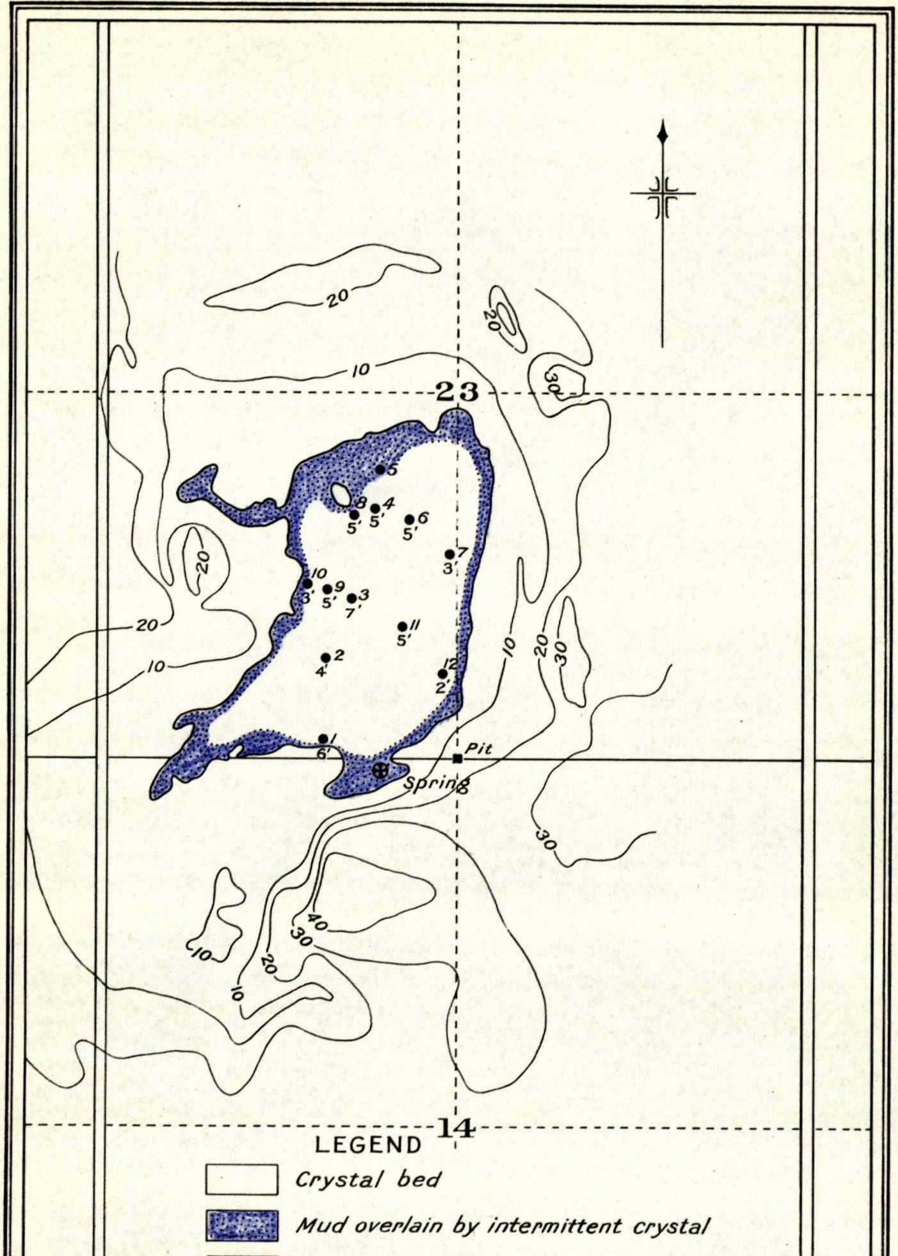

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DEPOSIT No 8

CORRAL LAKE SODIUM SULPHATE DEPOSIT

Sec. 23 Tp. 14, R. 20
West of the 3rd Meridian
SASKATCHEWAN
Scale of Feet
1000 500 0 1000 2000

crystallized out in the spaces between the sand grains. It was thought at first that the crystal bed extended under the shore, since hard, compact material was encountered at a depth of two feet below the grass roots ten feet back from the edge of the lake. A test pit was sunk but the hard material proved to be only the sand cemented together by crystallized salts. Material from this pit was sampled every foot to a depth of 5 feet at which depth the sand again became soft and uncemented.

——	1st foot	2nd foot	3rd foot	4th foot	5th foot
Insoluble...............Per cent.	70·09	67·87	59·13	67·87	70·52
Al_2O_3, Fe_2O_3............ “	1·83	1·60	1·50	0·42	0·63
$CaCO_3$................ “	0·84	0·35	0·68	0·71	1·49
$CaSO_4$................ “	....	....	....	....	2·07
$MgCO_3$................ “	1·36	....	1·47	....	....
$MgSO_4$................ “	....	1·94	2·11	1·83	3·50
NaCl.................. “	0·60	0·50	0·40	0·55	0·81
Na_2SO_4................ “	25·03	27·55	34·64	28·10	20·69
Totals.......... “	99·75	99·74	99·48	99·48	99·71

The average analyses for each foot in depth for the main deposit are as follows:—

——	1st foot	2nd foot	3rd foot	4th foot	5th foot
Insoluble...............Per cent.	10·42	6·09	8·68	9·11	11·80
Al_2O_3, Fe_2O_3............ “	0·30	0·08	0·18	0·01	0·01
$CaCO_3$................ “	2·11	0·98	1·35	0·76	0·86
$CaSO_4$................ “	....	....	....	....	....
$MgCO_3$................ “	3·08	1·48	1·51	2·10	1·53
$MgSO_4$................ “	0·62	1·76	1·87	....	1·24
NaCl.................. “	0·49	0·43	0·56	0·25	0·29
Na_2SO_4................ “	82·66	88·53	85·48	87·49	83·93
Totals.......... “	99·68	98·35	99·63	99·71	99·66

The estimated amount of hydrous salts is approximately 530,000 tons.

Deposit No. 9—(Ingebright Lake No. 1)

LOCATION AND TRANSPORTATION

Ingebright No. 1 deposit is the centre of a large undrained area in which there are a number of other smaller deposits. The deposit occurs in secs. 13, 14, 23, 24, 25, and 26, tp. 16, range 25, west of the 3rd meridian, and it is somewhat remote from railway transportation, being 38 miles south of Leader, a station on the Empress branch of the Canadian Pacific railway. The nearest railway point on the main line of the same railway is Maple Creek, 40 miles south of the deposit. Plans have been prepared, however, by the Canadian Pacific railway, for a branch line to be built as soon as conditions warrant and this will greatly improve transportation, as it will probably pass very close to the deposit.

TOPOGRAPHY

The deposit occupies a crescent-shaped basin over 700 acres in area. The level of the crystal bed is about 70 feet below the general level of the country, the banks of the basin rising sharply, 40 to 50 feet above the crystal bed around the major part of the deposit and then sloping gradually up to the general level of the prairie.

The accompanying map shows the approximate contours of the bottom of the crystal bed, as well as the surface contours of the surrounding territory, the datum level for both sets of contours being the surface of the crystal at the shore directly east of the island.

The land contour interval is 10 feet, while the contours of the crystal bed, shown by dotted lines, have an interval of 5 feet down to the 20-foot contour, and then a 10-foot interval from the 20-foot to the 130-foot contour.

No rock outcrops were encountered anywhere in the district and the banks are sandy boulder clay with occasional large drift boulders lying on the surface.

SPRINGS

The immediate drainage area is not very large and no streams flow into the basin. There are, however, numerous seepages and springs around the margin of the crystal. Of these marginal springs, five are of considerable size and maintain a steady flow throughout the year. The water, though carrying small quantities of alkali, is potable. The analyses of waters from these springs are given below. The numbers refer to their location on the map.

Constituents	1	2	3	4	5
Na_2SO_4	109	2,289	1,600	1,642	414
NaCl		330	462	248	231
$NaHCO_3$	125				
Na_2CO_3	201				
$Ca(HCO_3)_2$		1,296	366	689	1,061
$CaSO_4$					
$MgSO_4$		115	335		550
$Mg(HCO_3)_2$	189	388	627	695	
Totals	624	4,418	3,390	3,274	2,256
Sp. Gr. at 15° C	1·000	1·003	1·002	1·001	1·002

The temperature of all the above springs is about 7° C.

In addition to the marginal springs there are many springs welling up through the crystal bed. In the northern part of the deposit these sub-crystal springs are cold and are nearly all freshwater springs. In that part of the deposit south of the island, there are a number of springs which might possibly be classed as brine springs. The temperature of these springs varied from 15° C to 18° C (59°–64°F), the largest having the highest temperature.

In addition to the brine springs there are several large freshwater springs in the southern end of the lake. During the summer it is hard to distinguish between the brine and freshwater springs, but when cold weather comes, the difference becomes very apparent, for mounds or cones of crystal are soon built up around the orifices of the brine springs. These mounds or cones build up as high as 10 feet in some cases and have a diameter of over 20 feet at the base.

Samples of the brine flowing from two of the brine springs in the southern part of the lake were obtained and analysed as follows:—

	1	2
$NaHCO_3$	2,604	2,856
$MgSO_4$	31,800	63,900
Na_2SO_4	102,574	15,794
NaCl	18,480	48,263
Al_2O_3, Fe_2O_3		48
Totals	155,458	130,861
Sp. Gr. at 15° C	1·120	1·112

(Results expressed in parts per million.)

A sample of crystal taken in the winter of 1924 (March) from one of the largest cones in the south end of the lake was analysed, with the following results:—

Insoluble	Per cent	0·45
NaCl	"	0·36
$NaHCO_3$	"	0·34
$MgSO_4$	"	0·66
Na_2SO_4	"	98·41
Total	"	100·22

The cone-building springs do not occur in the deep crystal in the southern end of the deposit, but lie to the east and north of it.

It is interesting to note that the top of the crystal bed in the southern part of the deposit is more than 1½ foot higher than is the crystal bed in the northern end, where there are no cone-building springs. This difference in elevation of the crystal bed surface is very noticeable on a calm day in the summer, when there is still some brine on the surface of the deposit. When the brine at the northern end of the crystal bed is 2 feet deep, opposite the island there is only 1 foot, while over the larger portion of the southern part there is no brine at all. The higher level of the crystal in the southern end of the deposit is probably due to the large amount of sodium sulphate deposited from the waters of these brine springs.

Freshwater springs in the crystal bed are fairly numerous. Practically the whole of the cove in the northwestern corner of the deposit is occupied by these springs, the crystal bed here being of a fragmentary nature. The freshwater springs have no definite orifice in the crystal bed, but well up from the bottom of the basin through "pipes" or "chimneys" of mud. These mud chimneys are characteristic of the freshwater springs. In the southern part of the deposit just south of the island there are several of these mud chimneys 20 feet or more across, but the actual flow of water seems very small.

A spring with sodium chloride and magnesium sulphate as its predominating salts was tapped during the drilling of hole No. 13. The crystal bed at this place was 15 feet thick; beneath the crystal was a greyish mud, which was penetrated to a depth of 6 feet. At a depth of 20 feet the spring was encountered, i.e., 5 feet under the bottom of the crystal bed. The clear water came rushing up around the drill-rods and when the rods were pulled, a stream of water, 4 inches in diameter, gushed up about 6 inches into the air. The flow was intermittent, the water rushing out strongly for about a minute and then stopping entirely for about 30 seconds, then gushing forth again. These sudden gushes were heralded by a large amount of hydrogen sulphide gas coming up through the water. After several days the flow became scanty, but steadied down to a continuous flow with no gas.

As soon as possible after the spring was tapped a sample for analysis was obtained. The temperature of the spring was 11·5° C. (52·7° F.). The results of the analysis follow:—

Na_2SO_4	27,638
$NaCl$	71,775
$Ca(HCO_3)_2$	3,187
$CaSO_4$	14,324
$MgSO_4$	73,500
Total	190,424
Sp. Gr. at 15° C.	1·159

(Results expressed in parts per million.)

THE BRINE

Sodium sulphate occurs in brine form during the spring and early summer.

The quantity of brine is usually greatest when the snow melts in the early spring and the surface waters drain into the basin. It is hard to give a true idea of the composition of the brine, since it changes from day to day, but the following analyses of two samples taken on the same day will serve to give an idea of the different constituents present.

	North end	South end
$NaHCO_3$	840	1,932
Na_2CO_3	106	—
$MgSO_4$	19,200	12,000
Na_2SO_4	20,556	23,662
$NaCl$	13,860	7,013
Totals	54,562	44,607
Sp. Gr. at 15° C.	1·047	1·042

(Results expressed in parts per million.)

The depth of brine will vary according to the season and also in different parts of the basin. In general, the brine is deeper in the north end of the basin and a depth of between 3 and 4 feet of brine in the early spring is not uncommon. When such depths are recorded in the north end there may be only 2 to 3 feet at the south end.

THE INTERMITTENT CRYSTAL

The intermittent crystal is formed by crystallization of the brine. When first deposited it is somewhat loosely compacted, but very soon the crystals become so closely interlocked that a hard solid mass of pure crystals results. The depth will vary in different parts of the deposit from 6 inches in the south end to over 2 feet in the north. Analyses of two samples of intermittent crystal are given below.

		North end	Middle
Insoluble	Per cent.	0·60	0·12
NaCl	"	1·32	0·92
$NaHCO_3$	"	0·33	0·43
$MgSO_4$	"	2·92	2·16
Na_2SO_4	"	94·17	96·85
Totals	"	99·34	100·48

THE PERMANENT CRYSTAL

The permanent crystal occupies an area of approximately 680 acres and has an average depth of 22 feet, and together with the intermittent crystal makes up a total of over 25,000,000 tons of hydrous salts.

The permanent crystal is remarkable inasmuch as it contains two areas in which the solid crystal extends to a depth of over 100 feet. These deep areas occur, one in the north and the other in the southern part of the deposit, both being shown on the accompanying map. In the deep area in the north, 139 feet of solid crystal was encountered before the underlying mud was penetrated. The bottom of the crystal was not reached in the southern area but it is over 120 feet.

North of the island, the permanent crystal for the first 25 feet is friable and contains numerous mud partings as well as mud flakes included between the crystals. In a number of holes in the north end a 1- to 2-foot mud seam was encountered at between 25 and 30 feet. The mud strata were very persistent and carried numerous flat rhombic crystals of gypsum, some over an inch in length, many of which were beautifully twinned. Below the mud layer the crystal became hard and compact and practically free from mud in any form, and continued until a depth of 70 feet was reached. Below this level the crystal became friable and mud parting-planes, varying from ¼ inch to 2 inches in thickness, again appeared.

In the southern part of the deposit the crystal was of different character. It was hard and compact from top to bottom, most of it being free from mud partings and included mud.

Thirty-six holes were drilled and samples taken of each 5 feet of core obtained. The results of the analyses of all these samples were tabulated and averages taken for each 5-foot section in depth over the whole deposit. The results obtained are as follows:—

Averages of all Analyses of Samples from Deposit No. 9 Ingebright No. 1 (Sask.)

—	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50
Insoluble.............Per cent	8·36	10·95	12·52	13·29	16·99	19·66	21·76	12·61	8·52	9·70
NaCl................. "	1·45	1·65	2·01	2·06	2·75	2·76	2·20	2·11	1·71	1·77
$NaHCO_3$............. "	0·66	0·70	0·64	0·69	0·72	0·68	0·69	0·72	0·71	0·68
Na_2CO_3.............. "	0·06	0·03	0·03	0·01	0·05	0·05	0·04	0·19	0·12	0·12
$CaSO_4$................ "	5·01	5·78	6·50	6·46	7·52	6·68	4·62	3·74	3·73	3·80
$MgSO_4$................ "	2·30	2·61	3·25	3·43	4·17	4·39	4·67	2·52	3·31	3·62
Na_2SO_4.............. "	79·47	74·67	70·97	69·66	63·96	62·77	62·41	75·97	80·55	78·80

—	50–55	55–60	60–65	65–70	70–75	75–80	80–85	85–90	90–95
Insoluble....................Per cent	7·16	7·43	7·27	7·94	10·09	9·02	6·23	9·55	9·30
NaCl........................ "	1·67	1·95	1·81	1·79	1·71	2·08	1·51	1·51	1·79
$NaHCO_3$.................... "	0·61	0·71	0·83	0·72	0·78	0·85	0·62	0·74	0·68
Na_2CO_3.................... "	0·05	0·04	......	0·04	0·05	0·03	0·03	0·06	0·03
$CaSO_4$...................... "	3·43	3·78	4·17	2·61	2·44	2·95	2·71	2·35	2·33
$MgSO_4$...................... "	2·83	3·15	3·03	3·14	2·64	3·96	3·19	2·67	3·07
Na_2SO_4.................... "	83·37	81·77	82·26	82·51	79·77	78·92	83·88	80·29	80·09

—	95–100	100–105	105–110	110–115	115–120	120–125	125–130	130–135	135–139½
Insoluble..........Per cent	10·24	4·00	7·66	8·74	13·34	13·94	22·55	13·13	23·67
NaCl............. "	2·03	1·19	1·52	1·27	1·58	1·77	1·72	1·07	1·90
$NaHCO_3$......... "	0·45	0·67	0·84	0·51	0·76	0·76	1·01	0·84	1·01
Na_2CO_3........... "	0·20	....	....	....	....	....	....	....	....
$CaSO_4$............ "	1·70	3·20	3·60	2·18	3·57	4·01	2·72	2·58	2·96
$MgSO_4$............ "	2·97	2·81	2·38	2·35	4·11	2·83	2·60	2·42	4·43
Na_2SO_4........... "	79·72	88·45	84·28	84·74	74·81	76·77	67·45	77·53	60·76

HISTORY OF DEPOSIT

The deposit has, so far, not been operated. Probably the first description of this deposit published was that by G. C. Cowper, D.L.S., in the Annual Report of the Topographical Survey, 1913–14. In part he said:—

> In township 16, range 25, a very unique lake was found. This lake is about 2 miles long by half a mile wide, and at the time of my survey, October 8, was dry, except for a few inches of water at the north end. The bottom of the lake is covered with a coating of hard crystalline and alkaline salt varying from a few inches to a foot in depth. At the south end of the lake there is a large mound of alkaline salt of snowy whiteness, about fifteen feet in diameter and eight feet high, and close to it there is a smaller mound about three feet high. The mounds are composed of clear crystalline salts which on exposure to the air breaks down to a white powder, and this powder covers the mounds to a depth of an inch. I cut about a foot into the larger mound without finding any change in its composition, but on cutting six inches into the smaller one, water spouted out and continued flowing. On returning next day this mound was found to be again sealed up.

#1731

DEPARTMENT OF MINES, MINES BRANCH

DEPOSIT No. 9

INGEBRIGHT LAKE SODIUM SULPHATE DEPOSIT No. I

Sec^s 13, 14, 23, 24, 25, 26, Tp., 16, R., 25

West of the 3rd. Meridian

SASKATCHEWAN

Scale of Feet

500 0 500 1000 1500

2 negatives on file Min. Res. Division.

These mounds are apparently formed by salt springs, which on coming to the surface deposit the salt. The mounds are said to disappear and to be built up again, and one settler informed me that he had seen five of these mounds at one time. It appears that when the lake fills up in the spring with the fresh snow water and heavy rains, these mounds are dissolved and the salt is then deposited over the lake bottom.

In July, 1918, the deposit was staked out under the Quartz Mining Regulations by local parties. Many of these persons claimed potassium salts only, and when analyses showed only traces of potash, all the claims were allowed to lapse the following year.

The entire deposit, with the exception of the part situated in section 26, which is a Hudson's Bay Company section, is leased under the Alkali Regulations by parties from Calgary, Alberta. These parties have carried on considerable preliminary investigational work, but no work on a commercial basis has been attempted.

Deposit No. 10—(Senlac Lake)

LOCATION AND TRANSPORTATION

An interesting lake was examined in secs. 19 and 30, tp. 39, range 25, west 3rd meridian, Saskatchewan. This lake is situated midway between the Macklin-Kerrobert branch and the Macklin-Unity branch of the Canadian Pacific railway, and is 13 miles by road from either Senlac, Macklin, or Denzil, the nearest railway stations. The wagon roads from the lake to these towns are fairly good.

TOPOGRAPHY

The country is somewhat hilly, and the shores of the lake have gentle slopes which rise gradually to hillocks 100 to 150 feet high. The drainage basin is small. The lake is nearly 1 mile in length in a northwesterly and southeasterly direction and is approximately 1,200 feet wide. The area of the lake is 185 acres and, unlike many of the other lakes examined, the predominant salt is sodium chloride.

On the south shore there is a narrow neck of land jutting out into the lake some 800 feet and on this point a small plant has been erected.

SPRINGS

The lake is fed by numerous springs in various parts of the lake bottom and along the shore, but none of them seem to have a very strong flow. When the lake was visited in September, 1923, the specific gravity of the waters in four of these springs varied from 1·007 to 1·047. The brine at that time had a specific gravity of 1·067. A sample of the brine taken in March, 1924, analysed as follows:—

$Ca(HCO_3)_2$	267
$CaSO_4$	4,335
$NaCl$	50,058
$CaCl_2$	1,854
$MgCl_2$	15,932
Total	72,446
Sp. Gr. at 15° C	1·055

(Results expressed in parts per million.)

CRYSTAL BED

No crystal bed was found under the mud in any part of the deposit, and the brine is the only source of salts in the lake. The depth of brine varies from 6 inches to 1 foot, according to the season of the year. Two samples of brine were collected in September, 1923, one from the lake and the other from the spring on the northeast shore. These brines were evaporated to dryness and the salts analysed as follows:—

		Lake brine	Spring brine
Insoluble	Per cent	0·25	4·53
Al_2O_3, Fe_2O_3	"	3·87	2·10
$NaHCO_3$	"	1·69	1·26
NaCl	"	79·60	63·02
$MgCl_2$	"	3·66	14·92
$CaCl_2$	"	1·86	10·40
$CaSO_4$	"	6·70	0·99
Totals	"	97·62	97·22

HISTORY OF THE DEPOSIT

The lake was staked early in 1918 and work on it was commenced the following year.

Wooden cribbing was placed around eight of the springs and the water pumped to shallow mud vats laid out on the shore of the lake. Solar evaporation caused the deposition of sodium chloride in the vats. The crystals were then shovelled and scraped on to drying platforms, where they were drained and afterwards bagged for shipment. Two samples, furnished by the operators, analysed as follows:—

		No. 1 Coarse	No. 2 Fine
Na	Per cent	38·13	36·87
Mg	"	0·23	0·45
Ca	"	0·05	0·18
SO_4	"	0·08	0·35
Cl	"	59·43	58·14
Insoluble in water	"	0·34	0·09
Loss at 110° C	"	1·02	2·24
Loss above 110° C	"	1·18	2·00
Totals	"	100·46	100·32

In November, 1920, control of the property was obtained by the Senlac Salt Co. (Head office, Calgary, Alta.), and a large building was put up to house three iron evaporating pans of approximate dimensions of 35 by 6 feet by 8 inches deep. These three pans were placed side by side about 6 feet apart and rested on brickwork. The three pans had heating space underneath them and the two outside ones were heated directly by coal fires, fired from the east end. The flues from the two outside pans each passed into the heating space under the centre pan. The hot gases thus passed beneath the two outside pans from east to west and returned beneath the centre pan from west to east before passing up the stack at the end of the centre pan. The brine evaporated in these pans and the crystal was gathered on drying-boards placed on the side.

The material produced was sold locally to the farmers.

Operations did not continue for very long, however, and there has been no production since 1921.

Deposit No. 11—(Berry Lake, Viscount, Sask.)

LOCATION AND TRANSPORTATION

The deposit occupies parts of the bed of a shallow saline lake situated in tp. 35, ranges 25 and 26, west of the 2nd meridian. It is about 5 miles north and 2 miles east of Viscount, a station on the Winnipeg-Saskatoon branch of the Canadian Pacific railway. It is also 7 miles distant from Rutan, on the Prince Albert branch of the Canadian National railway. The roads connecting the deposit with these shipping points are rough, hilly and in poor condition.

The deposit is under lease to the Watrous Glauber's Salt Co., the head office being in Watrous, Saskatchewan. The company has erected four small buildings; two at the northwest corner of the lake and the other two at the extremity of the long point about midway along the south shore of the lake. One of these buildings is intended for an office and the other for a storehouse. Two dirt roadways have been constructed to the crystal bed, and preparations were being made to build a plank roadway to the permanent crystal at a point 500 feet south of the buildings at the northwest end of the lake. Considerable intermittent crystal has been removed from the deposit and stored in piles on the shore. Some shipments of the crude crystal have been made to the eastern markets. No active development has as yet been attempted, but when conditions become favourable a plant for the production of salt cake and Glauber's salt is to be erected.

TOPOGRAPHY

The lake, which is dry for part of the season, occupies a depression among the low, morainic hills of the vicinity. In the neighbourhood are many other smaller shallow lakes, all of which are alkaline, but none of which contain any economic deposits of sodium sulphate.

The banks of the lake are, for the most part, shelving, and in no part is there anything approaching the nature of a cliff. The drainage basin is small, the other lakes in the neighbourhood all receiving their share of drainage from the same basin.

The shallowness of the lake may be inferred from the number of islands that dot the middle part of the lake. These islands, ten in number, range in size from one large one, 48 acres in area, down to small ones less than 200 feet in diameter. All, with one exception, are low and covered with bushes. The one exception is the most westerly island which rises steeply to a height of 16 feet and is devoid of bushes. The bushes, consisting of willows and saskatoons, are noteworthy in that the islands are the only places in the vicinity where they grow, the surrounding prairie being treeless. Due to the quantities of saskatoon berries found on the islands, the lake has been named Berry lake.

In outline the lake is L-shaped, the greater arm of the L extending easterly and westerly with the other arm running northerly from the eastern end of this arm. The area is about 935 acres, inclusive of the islands, which have a combined area of approximately 75 acres. About 70 acres of the remainder is covered with tufts of grass, these tufts covering the mud west of, and between the islands, and also considerable of the west tip of the lake.

There are no outcrops of rock in the vicinity of the lake, the underlying rock being covered with boulder clay to an unknown depth. The boulder clay is heavy and there is little sand or gravel in the neighbourhood. The boulders in the clay are few and consist chiefly of Archæan granites, gneisses and schists, together with some Palæozoic limestones.

SPRINGS

No marginal springs worthy of note were encountered. There are, however, a number of sub-crystal springs in the deposit. These springs are probably brine springs, no typical freshwater spring holes being observed. The flow from any one of these springs is probably small, but in the aggregate a very considerable amount of brine reaches the surface. These springs invariably well up through small, crooked, solution channels through the crystal bed, and were only observed in the permanent crystal. Tiny cones or rings of pure crystal are built up around their orifices, as well as a small amount of grey-black mud which is brought up by the springs and deposited in a circle.

Where the crystal bed is patchy these tiny springs are almost invariably found in the centre of a patch of crystal, the crystal being thickest at the spring orifice and gradually diminishing towards the circumference of the patch. Thus they are inverted bowl-shaped deposits of crystal, the centre of the bowl being, roughly, at the orifice of the spring. Many of these patches are irregular in outline, but the majority of the isolated patches are circular. Where the springs are sufficiently numerous, there is a solid bed of crystal extending over the spring area. There are also many isolated patches of crystal surrounded by mud in the lake bottom.

THE BRINE

Usually there is a depth of from 4 to 8 inches of brine during the early summer months, but when the deposit was examined in detail in July, 1924, the brine had almost entirely disappeared. The remaining brine in the pools was very clear and concentrated. The brine was also present, in some parts of the lake, under a top crust of intermittent crystal.

Two samples of brine were collected and analysed:—

—	Aug. 1, 1923	July 1924[1]	
	(Parts per million)	a (Per cent)	b (Parts per million)
$Ca(HCO_3)_2$	445	....	....
NaCl	2,125	7·10	73,425
$NaHCO_3$	....	0·50	3,305
Na_2CO_3	....	....	1,060
$Mg(HCO_3)_2$	1,394	....	....
$MgSO_4$	59,355	21·82	14,875
Na_2SO_4	130,903	69·43	19,914
Totals	194,222	98·85	112,579
Sp. Gr. at 15° C	1·173	....	....

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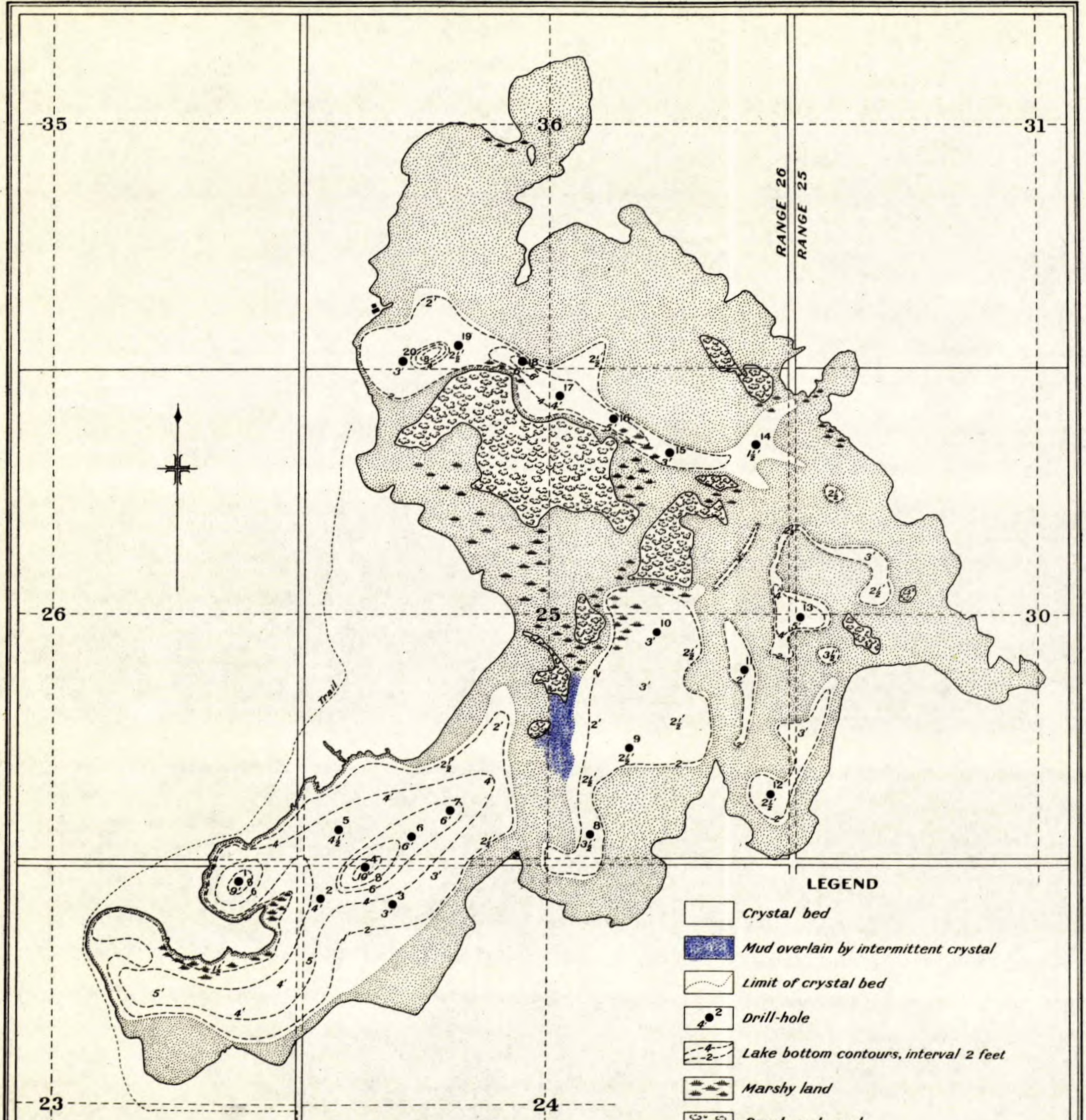
[1] When this sample of brine arrived in Ottawa for analysis a portion of it was crystallized in the bottle and even when heated moderately warm the contents did not become wholly liquid. The crystals were therefore dried and analysed as sample (a), while the liquid portion was sample (b).

DEPARTMENT OF MINES, MINES BRANCH



654

DEPOSIT No. II

BERRY LAKE SODIUM SULPHATE DEPOSIT

Sec. 30, Tp. 35, R. 25 and
Secs. 23, 24, 25, 36, Tp. 35, R. 26.
West of the 2nd. Meridian
SASKATCHEWAN
Scale of Feet
500 0 500 1000 1500

THE INTERMITTENT CRYSTAL

The intermittent crystal, when examined, varied in depth from ½ inch to 6 inches, but would probably average around 3 inches over the whole deposit. It extended over the major part of the lake, except that area between the islands and the northwest shore, and covered mud and permanent crystal alike. In places it was separated from the crystal bed by a thin layer of mud, but in most places it was in direct contact with the permanent crystal.

There was considerable anhydrous crystal just under the top crust of the intermittent layer.

The intermittent crystal can be obtained in a high degree of purity by scraping it off the surface of the crystal bed in the late autumn or in the winter.

Samples of the intermittent crystal and the anhydrous material were collected and analysed:—

		Intermittent crystal	Anhydrous layer
Water insoluble	Per cent	0·65	3·07
$NaCl$	"	3·66	6·96
$NaHCO_3$	"	0·50	0·59
$CaSO_4$	"	2·14	11·73
$MgSO_4$	"	23·24	20·87
Na_2SO_4	"	68·29	56·51
Totals	"	98·48	99·73

THE PERMANENT CRYSTAL BED

The permanent crystal bed does not occupy the entire area, but exists in patches separated from one another by areas of mud.

The main patch of permanent crystal occupies almost the whole bed of the western arm of the lake and on the north shore and in the western end the crystal extends up to the grass line, in some places being 5 feet deep only 20 feet from shore. On the southern shore of this arm the crystal does not extend into the coves, being in some places 500 feet from the lake margin. In the middle of this large area the greatest depth of crystal in the whole deposit was discovered, namely 10 feet. The 7 drill holes put down showed that the crystal is fairly clear. There are numerous mud holes in this patch, none of which are of any great extent. This area ends abruptly opposite the long point in section 24, and there is a stretch of mud 300 to 500 feet in width intervening between this and the next patch.

The second patch is shallower than the first mentioned, the greatest depth of crystal encountered being 3½ feet, and the average depth would not exceed 2½ feet. No drilling was done in this patch, there being numerous mud holes within its boundaries, but three holes were dug with shovels in order to obtain samples for analysis.

North and east of this patch are some small irregular patches in which the depth of crystal varies from 2 to 5 feet, but with an average depth not exceeding 2 feet. The boundaries assigned to these patches on the map are only arbitrary, as there are many mud holes within the crystal areas as shown. There are also patches of crystal in the areas shown as mud, but in the latter case the percentage of crystal to mud is very small, whereas in the areas shown as crystal there is probably less than 10 per cent of mud. Holes were dug in three of the main patches and samples for analysis obtained.

Occupying the middle of the northern arm of the lake is the third largest crystal area. The patch is very narrow and runs in close to the northeastern shore of the island. In common with the other patches of crystal, there are numerous springs welling up through it. The greatest depth of crystal found was 9 feet, but the average depth would not exceed 3 feet. In all of these patches of crystal the depth remains practically the same to near the edge and then shallows rapidly. Separated from the permanent crystal by a parting of mud 1 to 4 inches in thickness is a layer of 3 to 4 inches of intermittent crystal. There are numerous mud holes in this strip of crystal and the 7 drill holes put down were irregularly spaced in order to avoid these holes.

Averages made from the analyses of the samples taken from this deposit are as follows:—

		0 to 5′	5′ to 10′
Insoluble	Per cent	5·30	3·40
$NaCl$	"	0·97	0·67
$NaHCO_3$	"	0·53	0·44
$CaSO_4$	"	5·33	2·85
$MgSO_4$	"	3·62	2·59
Na_2SO_4	"	83·83	90·27
Totals	"	99·58	100·22

The amount of hydrous crystal in this deposit is approximately 2,240,000 tons.

Deposits Nos. 12 and 42 (Sybouts Lakes)

LOCATION AND TRANSPORTATION

The Sybouts deposits occupy the bottoms of two saline lakes locally known as the Salt lakes. These are situated in township 1, ranges 18, 19, and 20 west of the 2nd meridian, within 2½ miles of the International Boundary.

The deposits are about 30 miles south of Ceylon, which town on the Radville-Bengough branch of the Canadian National railway, is the nearest railway shipping point in Canada. The town of Dooley, Montana, 11 miles southward, is the shipping point nearest to the deposits.

The wagon roads in the vicinity are merely trails and, being hilly and rough, are not suited to heavy traffic.

REGIONAL TOPOGRAPHY

The two lakes containing the sodium sulphate deposits, within less than a mile of each other, but not connected by any stream or valley, occupy the bottom of a large undrained depression in the Missouri coteau. The brine level in the western lake (No. 12) is two feet above that of the eastern lake (No. 42).

The drainage basin has an area approximating 100 square miles. Within this large basin are numerous freshwater sloughs some of which are

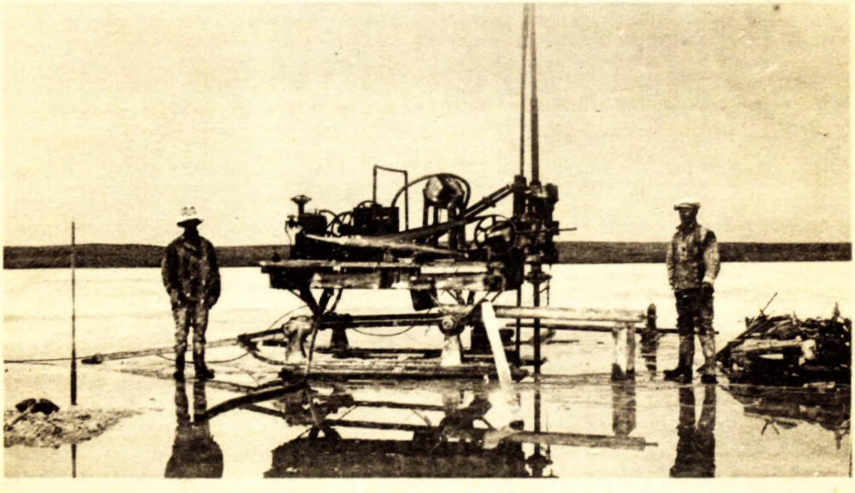
PLATE IX

1698

Prints on file Mineral Resources Division

A. Method of moving drill by its own power, Vincent lake, Sask.

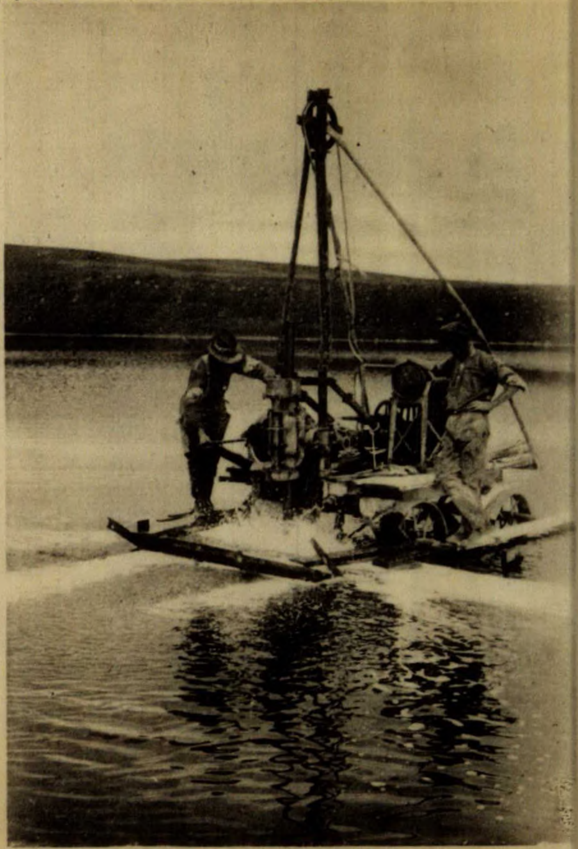
#1700



Negative on file Min. Res. Division

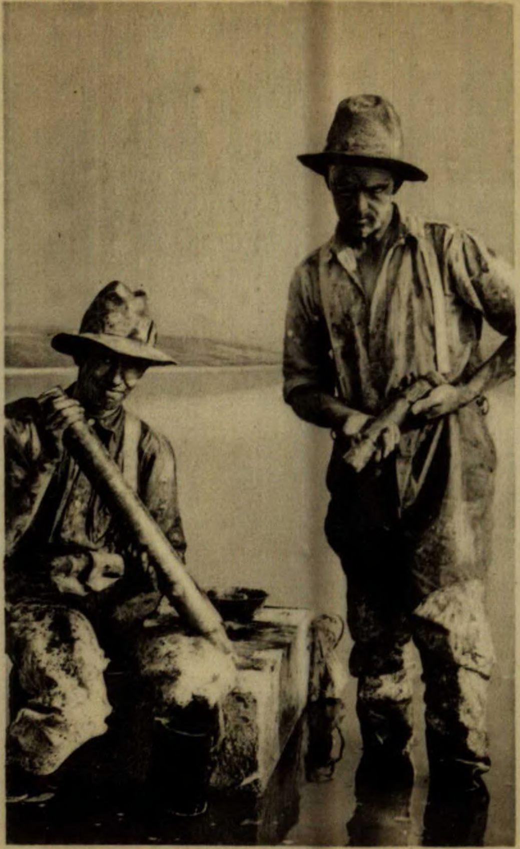
B. Drill in operation on surface of lake, Ingebright deposit No. 1. This view shows the skids used on drill while on the lakes.

#1703.



A. Drilling crystal bed on Regina Beach deposit, Sask. Brine is 3 feet deep.

#1704



B. Core barrel and core of crystal obtained by drill.

in the immediate proximity of the sulphate deposits. One mile south of the large lake (No. 12) is a smaller lake of practically fresh water. This lake is No. 43 on the map. An analysis of the water from this lake gave the following results:—

	Brine Lake No. 43
Na	1,500
Ca	360
Mg	2,560
Cl	500
SO_4	13,100
HCO_3	610
	18,630
Sp. Gr. at 15° C	1·014

(Results expressed in parts per million.)

The lake is known as Clearwater lake and was formerly a summer resort. The bed is composed of gravel and the water is quite deep, there being no crystal bed present.

The country surrounding the lakes is typically glacial in appearance and is characterized by small hills or mounds of boulder clay which rise steppe-like from the margins of the lakes back to the rim of the basin and beyond. Short disconnected valleys are common among these morainic hills. One valley, the valley of Reserve creek, a tiny stream flowing only in the springtime or during wet weather, and emptying into the western lake near its eastern end, is traceable for 15 miles or so northward. The valley of another minute creek traceable for 5 miles southwards, connects with the western end of the western lake. These are the main drainage valleys of the basin. Numerous small valleys extend back from the lake shores for a mile or so into the hills, but they only carry off the surface drainage in wet weather. A few miles to the westward is the drainage basin of Big Muddy lake.

The underlying rock is mantled almost everywhere by boulder clay, most of which is stony. About one mile north of the western lake (No. 12), on the east side of the northerly trail, in sec. 36, tp. 1, range 20, west of the 2nd meridian, is an outcrop of shale. This outcrop extends for 75 feet north and south and has a 6-foot face. It is approximately 140 feet (barometer reading) above the lake level. The dip is apparently about 1 degree north. The rock is a fine-grained yellow-brown shale and contains numerous fossil leaves.[1]

---

[1] Samples taken from this outcrop were submitted to the Geological Survey of Canada for identification and W. A. Bell reported on them as follows:—
"Accession 574.

Samples of fossiliferous shale from outcrop in Sec. 36, Tp. 1, R. 20, W. 2nd Mer , Saskatchewan.
Submitted by L. H. Cole, Mines Branch; collected by M. F. Goudge.

Determination: Collection comprises a dozen fragments of shale which carry entire and fragmentary specimens of fossil dicotyledonous leaves. Amongst these the following were identified,—

Populus arctica Heer, Lesquereux.
Ficus sp.
Tilia sp.

Populus arctica of authors probably includes more than one specific type. The leaves here referable to the species are closely comparable to those figured by Lesquereux from the Bad Lands of Dakota (U.S.G.S. Terr., Vol 8, pl. 46), but similar forms are included in those figured by Heer from the so-called Arctic Miocene floras. The age of the latter floras is now generally conceded to be Eocene.

The species of *Ficus* resembles *Ficus ratonensis* Knowlton in its nervation but its secondary veins are much more markedly arched upwardly. The Raton flora is stated by Knowlton to be Eocene and to be allied to that of the Wilcox and Fort Union floras.

The *Tilia* is evidently a new species. As a genus *Tilia* has not been reported from pre-Eocene floras.

The conclusion follows that the beds from which the leaves were derived are most probably of Eocene age."

There is a possibility of coal seams being found at shallow depth in this district as the local farmers state that in places near the lake (No. 12) they have found bits of lignite at the mouth of badger holes. No seams of coal have been opened up in this locality, but 15 miles westward there is a seam under the bed of Big Muddy lake, from which, during the winter, lignite of good grade is dug out from under 2 feet of mud.

Deposit No. 12—(Sybouts Lake No. 2)

LOCATION

The deposit occupies the western third of the bed of the largest and most western lake in the Sybouts drainage basin. The lake is about 5 miles in length and 1 mile wide at its widest part.

TOPOGRAPHY

The country around the lake is much more level than the country around lake No. 42 and except in the eastern end the mounds of boulder clay that characterize lake No. 42 are not so pronounced, neither is the boulder clay so stony. The banks of the lake rise precipitously, in places to a height of from 50 to 60 feet, but for the most part the banks are low and shelving. On the low shelving banks are remnants of a raised beach, about 8 feet above the present brine level.

There are two small streams entering the lake. The larger stream, named Reserve creek, enters at a place on the north shore about ¾ mile from the east end, and the other, a tiny stream, enters from the south near the west end of the lake. Except in the spring and during wet weather, the amount of water brought in by these creeks is negligible. On the north bank of the lake near the western end is a small freshwater slough, separated from the saline lake by only 150 feet.

There is only about 3,000 yards between the western end of this lake (No. 12) and a valley leading into Big Muddy lake, but though the land is low for the most of the distance, there is no connecting valley between the two.

The underlying rock is covered with a veneer of boulder clay, the boulders in which are mainly granite and gneiss with a few of dolomite or limestone.

SPRINGS

There are two springs on the south shore of this lake, and one, an unusually large spring, on the north shore. A sample of the water from this spring was analysed with the following results:—

Na	380
Mg	260
Cl	trace
SO_4	910
HCO_3	1,200
Total	2,750
Sp. Gr. at 15° C.	1·000

(Results expressed in parts per million.)

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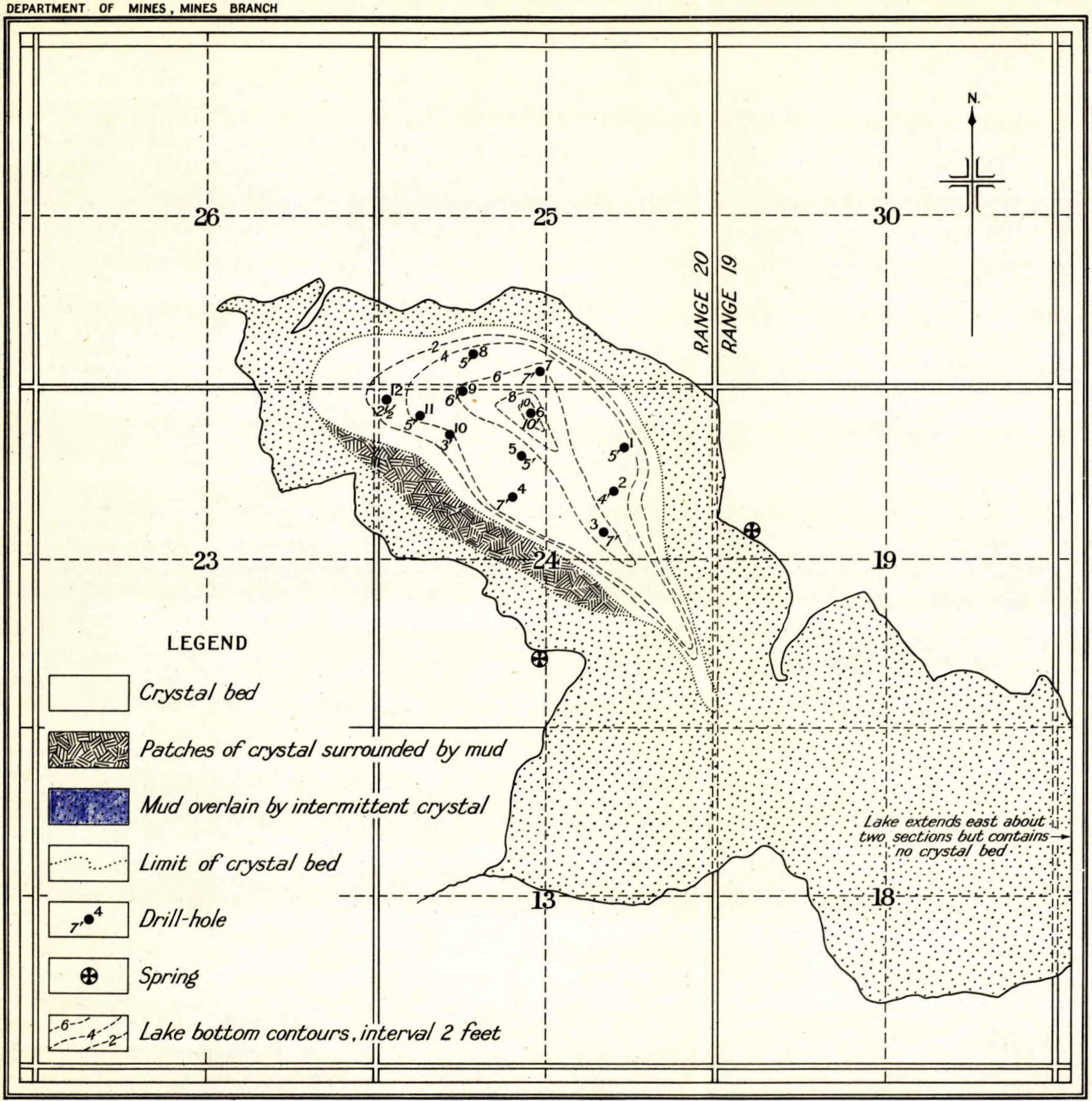

665

DEPOSIT No. 12

SYBOUTS SODIUM SULPHATE DEPOSIT No. 2

Secs 18, 19, Tp. 1, R. 19, and
Secs 13, 23, 24, 25, 26, Tp. 1, R. 20
West of the 2nd. Meridian
SASKATCHEWAN

Scale of Feet
1000 0 1000 2000 3000

All of these are freshwater springs and they issue from the ground only a foot or more above the brine level. No springs were observed coming through the crystal bed and no cones of crystal are reported as being built up during the winter.

THE BRINE

The brine is separated from the solid crystal by a layer of mud varying in thickness from 8 to 18 inches, and is usually a chocolate colour due to the waves stirring up the mud. On a calm day the brine covers the mud to a depth of from 6 to 12 inches over the whole lake, but if the wind blows strongly and consistently from either the east or the west, the brine is driven completely from one-third of the lake area and piled up in the other two-thirds. For example, on June 10, 1924, there was brine to a depth of 10 inches over the western end of the lake. On June 20th a strong wind came up from the west and by noon the western end of the lake was devoid of brine for a distance of 1½ mile from the end. The wind continuing for three days, the brine was driven altogether from the western third of the lake and remained piled up in the eastern part until the 22nd when the wind dropped and the brine flowed back to its normal level.

An analysis of the settled brine from this lake gave the following results:—

Na	22,760
Mg	1,480
Cl	2,530
SO_4	49,100
HCO_3	990
Total	76,860
Sp. Gr. at 15° C	1·066

(Results expressed in parts per million.)

The amount of intermittent crystal is small since the brine is so dilute. A thin crust of from ½ inch to 1 inch in thickness is deposited in the autumn.

PERMANENT CRYSTAL

The permanent crystal bed is present only, to any extent, in the western third of the lake bed. The middle segment of the lake contains some few scattered patches, about 2 feet in depth. The eastern segment contains only mud. Some parts of the middle and eastern parts could not be reached owing to the depth and softness of the mud, but it may be safely assumed that there is no solid crystal there. The deposit of crystal lies only in parts of sections 23, 24, 25, and 26, township 1, range 20, west of the 2nd meridian.

The depth of the bed varies from 5 to 7 feet and is fairly uniform over its whole extent. The edges of the bed are in most places 400 to 500 feet from the shore of the lake, the intervening space being filled with a brownish mud.

Twelve drill holes were put down and the drilling showed that the crystal under its thick coating of surface mud is fairly clear and free from mud layers. The outline of the crystal bed as shown on the map is the outline of that portion which is 2 feet or more in thickness. There are some patches of crystal between the main part and the shore, in many places, but as a rule the depth is slight.

The following are the averages of all the analyses of samples taken from this deposit:—

		Average 0 to 5′	Average 5′ to 10′
Insoluble	Per cent	27·16	18·97
NaCl	"	0·12	0·09
$NaHCO_3$	"	0·76	0·67
$CaSO_4$	"	1·05	0·95
$MgSO_4$	"	0·62	0·58
Na_2SO_4	"	69·73	77·71

The amount of crude hydrous salts is approximately 2,457,000 tons.

Deposit No. 42—(Sybouts Lake No. 1)

LOCATION

The deposit is situated in sec. 18, tp. 1, range 18, and secs. 10, 11, 13, 14 and 15, tp. 1, range 19, west of the 2nd meridian.

The lake has been staked by a number of local men, who have formed the Gladmar Sodium Sulphate Company. The company has erected two small buildings near the eastern end of the deposit. Considerable harvest crystal has been piled up on the shore, on both sides of the lake, near the buildings. No active work has been attempted.

TOPOGRAPHY

The lake occupies the eastern depression in the bottom of the large undrained basin referred to under regional topography. The banks of the lake are for the most part steep and are dotted with a series of knolls of boulder clay 40 to 80 feet high. These features are shown by the contours on the accompanying map. The lake has its greater axis in an easterly and westerly direction and is slightly over 3 miles long, with a width of 3,000 to 4,000 feet throughout the greater part of its length. There is no direct valley connecting this lake with the larger lake to the west, though there are several low-lying freshwater sloughs between the two lakes.

The surface soil is boulder clay, which for the most part is very stony and gravelly. This feature is especially noticeable on the faces of the glacial mounds on the banks where the finer material has been washed down the slopes, leaving the larger pebbles and rocks prominently displayed. The rocks are all well rounded, and the crystalline rocks, such as granites, gneisses and schists, are more numerous than are the boulders of limestone. In places the lake bed is composed of a gravel instead of the usual mud.

SPRINGS

The springs are mostly sub-crystal springs, there being only two seepages worthy of note along the shore, both of which are fresh water. There is practically no flow of water from either of these seepages, one of which is on the shore at the southwestern end, and the other on the shore at the head of a large inlet on the northern shore of the lake. About 700 feet west of the tip of the large cove in the northwest end of the lake is another small spring.

The sub-crystal springs are found all over the crystal bed, but are more plentiful in the western half of the deposit. With two exceptions the individual flow of these springs is small. These small springs have the appearance of being true brine springs, as small cones of crystal exist around their orifices. The channels in the crystal bed up through which the springs rise are very small, and the walls are of hard crystal, there being no trace of mud, except for a very little bit brought up by the water and deposited in a small circle around the outlet.

The two large sub-crystal springs are situated just south of the centre of the western half of the lake. Very probably they are both freshwater springs, as they have large mud chimneys. The brine in the vicinity of these two springs was over 2 feet deep, being more than twice as deep as in other parts of the lake and considerably less dense than the brine over the rest of the deposit.

In the neighbourhood of the large springs is a large brine spring which in the winter builds up a cone of pure crystal 6 to 8 feet high and 100 feet in diameter.

THE BRINE

The brine covering is very clear and colourless. During the month of June, 1924, the brine was from 4 inches to 1 foot deep. Baumé readings were taken on this brine from June 5th to June 16th, 1924, as follows:—

Date	Time	Temp. air	Temp. brine	Baumé
		°C.	°C.	°
June 5	Noon	....	15	17
" 6	"	....	18	17
" 7	"	....	9	15
" 9	"	11	10·75	14·5
" 10	7.30 a.m.	12·5	10	14
" 10	Noon	20	18·5	13
" 10	5.00 p.m.	23	22	14
" 11	7.30 a.m.	11	13	14
" 11	Noon	20	19	15
" 11	5.00 p.m.	11	20	16
" 12	7.30 a.m.	12·5	14·5	17·5
" 12	Noon	21	21·5	18
" 12	5.00 p.m.	21·5	26	18
" 13	7.30 a.m.	12·5	17	19
" 13	Noon	20·5	23	18
" 13	5.00 p.m.	15	21	19·5
" 14	7.30 a.m.	15	17	19
" 14	Noon	18·5	19	19
" 14	5.00 p.m.	21	21	20
" 15	7.30 a.m.	15	17	19
" 15	Noon	17·5	18·5	19·5
" 15	5.00 p.m.	15	17	21
" 16	7.30 a.m.	18	19	21
" 16	Noon	No readings		
" 16	5.00 p.m.	26	24	21

As might be expected from the fact that the brine was in direct contact with the crystal bed, the brine was very concentrated for so early in the season, and this concentration increased steadily during the month of June as the weather became warmer, in spite of the fact that there were frequent heavy rains.

An analysis of this brine gave the following:—

Na	39,880
Ca	690
Mg	4,720
Cl	1,970
SO_4	101,200
HCO_3	1,050
CO_3	50
Total	149,560
Sp. Gr. at 15°C	1·139

(Results expressed in parts per million.)

THE INTERMITTENT CRYSTAL

When the deposit was examined in June, 1924, there was very little intermittent crystal, but according to good authority there is generally from 3 to 4 inches formed each year.

The crystal, being deposited directly on top of a clean crystal surface instead of on mud, is capable of being harvested in a very pure condition.

THE CRYSTAL BED

The permanent crystal bed occupies practically all of the bed of the lake except in the eastern end, where there are only a few thin patches of crystal. It has an average depth of 5½ feet and covers an area of over 630 acres.

The solid bed is from 200 to 500 feet from the shore on the north side of the lake, and from 100 to 200 feet from the south shore except in the southwest end, where there are large stretches of mud between the crystal and the shore.

Thirty-nine drill holes put down showed that the crystal is deeper in the western end of the deposit (where a depth of 32 feet was found in one place) than it is in the central and eastern parts, where 12 feet was the greatest depth discovered.

The bottom of the crystal bed conforms to the shape of the basin, and as this is probably hummocky, it would be very difficult to outline exactly the sub-crystal topography.

The crystal is free from mud on the surface, is very smooth, and, as a rule, is hard and compact from top to bottom. In some few places near the edges, mud layers 1 to 3 feet thick were encountered interbedded with the crystal, but for the most part the crystal is free from mud layers and contains only the usual amount of included insoluble material. Samples were taken from all the cores obtained and averages of the analyses made with the following results:—

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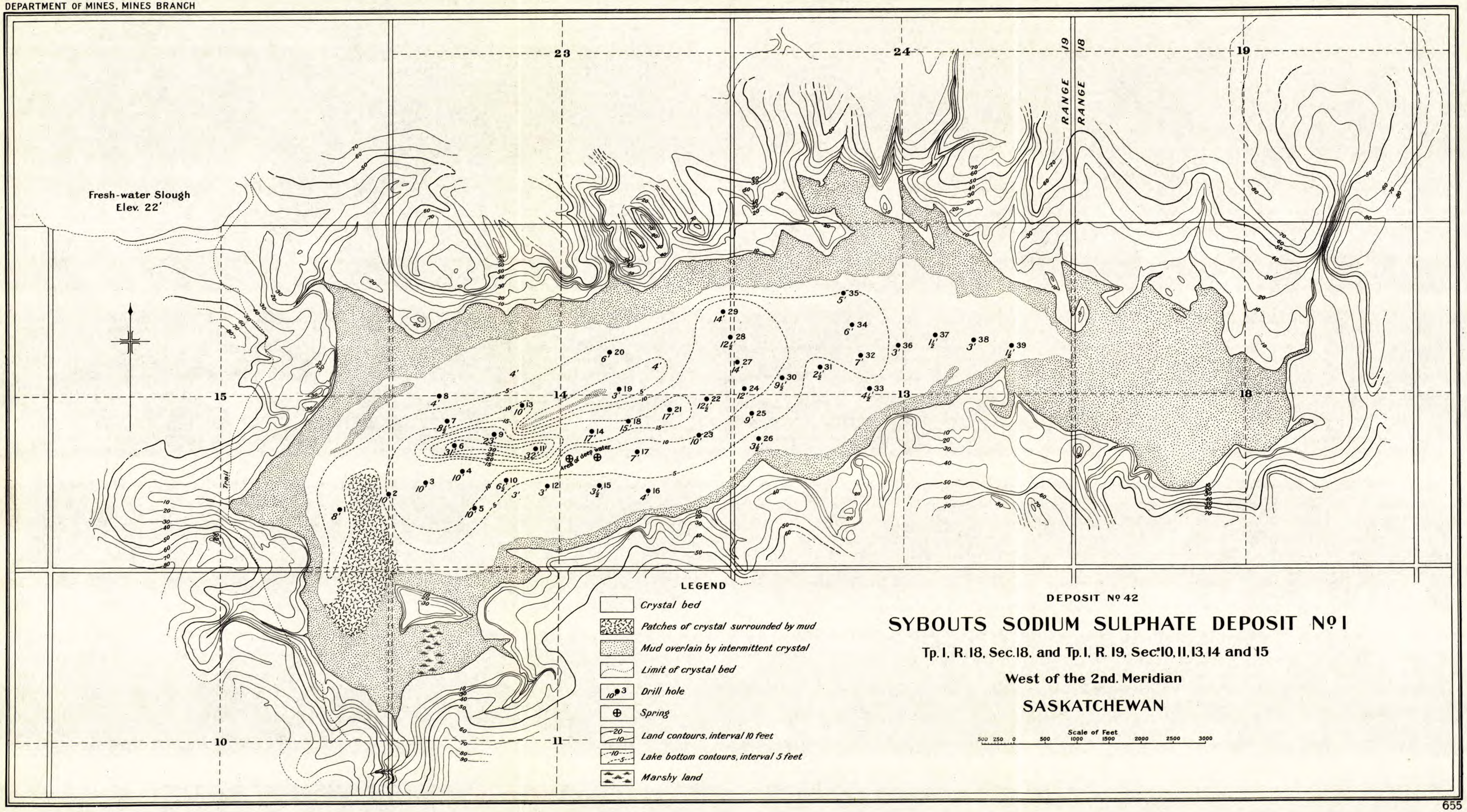

LEGEND

☐	*Crystal bed*
▨	*Patches of crystal surrounded by mud*
░	*Mud overlain by intermittent crystal*
┈	*Limit of crystal bed*
10' ● 3	*Drill hole*
⊕	*Spring*
20 / 10	*Land contours, interval 10 feet*
10 / 5	*Lake bottom contours, interval 5 feet*
⁂	*Marshy land*

DEPOSIT Nº 42

SYBOUTS SODIUM SULPHATE DEPOSIT Nº I

Tp. I, R. 18, Sec. 18, and Tp. I, R. 19, Secs. 10, 11, 13, 14 and 15

West of the 2nd. Meridian

SASKATCHEWAN

Scale of Feet
500 250 0 500 1000 1500 2000 2500 3000

—	0 to 5′	5′ to 10′	10′ to 15′	15′ to 20′	20′ to 25′	25′ to 30′	30′ to 35′
Insoluble.....Per cent	12·31	14·24	14·91	11·37	8·98	4·85	4·43
$NaCl$......... "	0·29	0·30	0·38	0·23	0·22	0·22	0·33
$NaHCO_3$..... "	0·76	0·71	0·71	0·59	0·64	0·54	0·34
$CaSO_4$........ "	1·77	2·22	2·33	1·38	2·39	2·18	2·74
$MgSO_4$........ "	1·76	1·78	2·04	1·60	1·67	1·65	1·78
Na_2SO_4....... "	82·46	79·91	78·78	84·16	86·17	89·91	90·89

The amount of hydrous salts available is approximately 8,800,000 tons.

Deposit No. 13—(Ceylon Lake)

LOCATION AND TRANSPORTATION

This lake, or rather series of four lakes joined by narrow channels is situated in secs. 1, 12, 13, and 24, tp. 4, range 21, west of the 2nd meridian. The nearest shipping point is 15 miles to the northeast, at Ceylon, a station on the Radville-Bengough branch of the Canadian National railway. Hardy, another station on the same line, is about the same distance to the northwest. The roads for part of the way are mere trails and are hilly and rough.

TOPOGRAPHY

The lakes lie in a deep depression running approximately north and south and are several miles in extent. They are surrounded, except at the south end, by steeply sloping morainic hills which rise in most places from 150 to 200 feet above the level of the crystal bed. Many coulees enter the depression from both sides but they are of small extent. The hills are composed of very stony boulder clay, which in some places is almost a gravel. Boulder patches are quite numerous.

At the south end of the lake the ground gradually rises but the depression continues for a considerable distance to the south. The drainage basin is long but of no great width. The depression was evidently at one time an old drainage channel and probably connected up with Big Muddy lake.

SPRINGS

A few marginal springs or seepages were noted around the shores of these lakes but none are of any great size.

THE BRINE

The brine is generally very clear since there is little mud on top of the permanent crystal. In the spring it is as a rule 1 foot or more in depth but when near concentration it will average only 6 inches. A sample was obtained for analysis.

$NaCl$....................................	5,148
$Ca(HCO_3)_2$....................................	689
$CaSO_4$....................................	184
$MgSO_4$....................................	26,000
Na_2SO_4....................................	49,882
Total..................................	81,903

(Results expressed in parts per million).

THE INTERMITTENT CRYSTAL

The intermittent crystal bed extends over the whole four lakes and in the fall of 1923 averaged 12 inches in depth. Harvesting and shipping of the intermittent crystal has been carried on in a small way each fall for a number of years, and a very pure crystal is obtained. An analysis of this crystal follows:—

Insoluble	Per cent	0·15
$NaCl$	"	trace
$NaHCO_3$	"	"
$CaSO_4$	"	"
$Al_2(SO_4)_3$	"	"
$MgSO_4$	"	1·25
Na_2SO_4	"	98·30
Total	"	99·70

THE PERMANENT CRYSTAL

The three southern lakes all contain crystal beds which practically cover their total areas.

Twelve holes were drilled in the two southern lakes and crystal varying from 2 to 8½ feet in depth was encountered, exclusive of the intermittent crystal. The third lake was tested with a bar and showed depths of from 3 to 4 feet including the intermittent crystal. The northern lake contained no permanent bed. The permanent bed carried considerable mud inclusions. The following analyses were made on samples obtained.

Hole No.		1	2	3	4	9	10	11	12
Insoluble	Per cent	24·50	6·87	15·87	7·02	32·41	6·73	12·93	13·21
$NaCl$	"	0·08	tr.	none	tr.	0·81	tr.	tr.	0·17
$NaHCO_3$	"	0·83	0·94	0·68	0·94	1·18	0·94	0·68	0·59
$Al_2(SO_4)_3$	"	2·25	1·17	1·00	1·17	2·61	1·00	2·08	....
$CaSO_4$	"	0·67	0·86	0·94	0·83	1·36	0·90	0·70	1·26
$MgSO_4$	"	....	....	....	....	....	....	....	1·10
Na_2SO_4	"	68·63	89·41	77·97	89·18	57·96	89·02	79·18	83·42
		97·34	99·64	97·30	99·50	96·93	98·95	97·42	99·75

A flame test revealed a trace of potassium.

The quantity of hydrous salts available, including the intermittent crystal, is approximately 2,400,000 tons.

Deposit No. 14—(Wiseton)

There are two lakes 21 miles south of Wiseton, Saskatchewan, situated in sec. 32, tp. 23, range 12, west of the 3rd meridian. The lakes cover approximately 270 acres. The brine was, in places, over 3 feet deep. There was no crystal bed visible, but the lakes are of interest on account of the high magnesium sulphate content.

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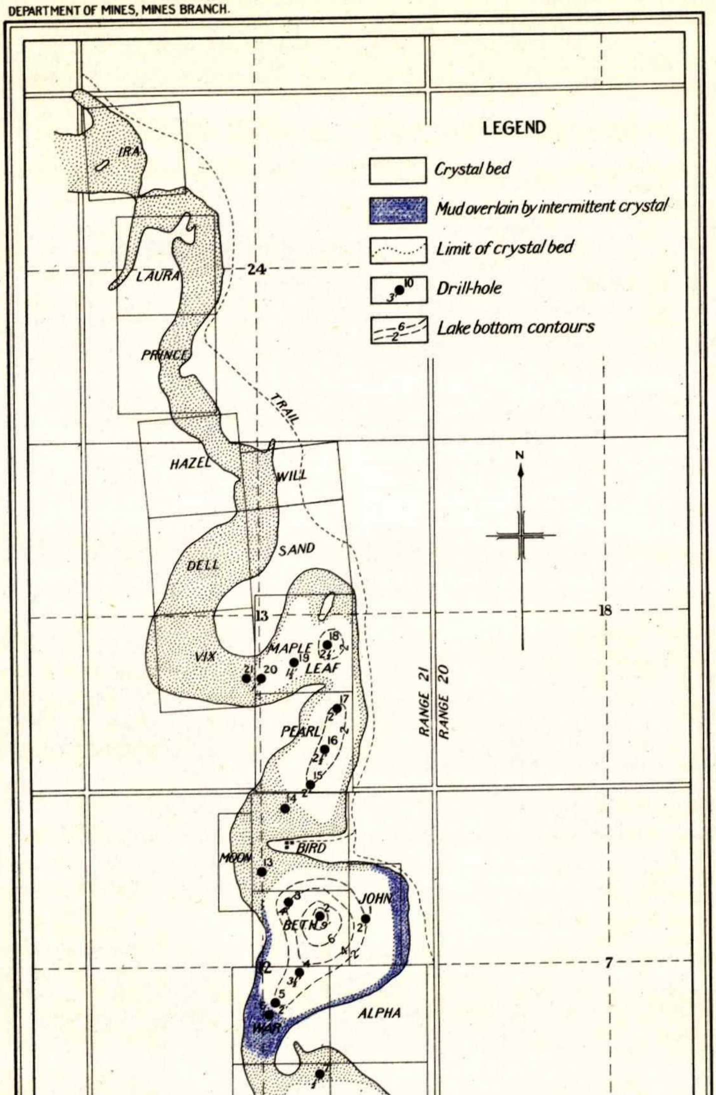


DEPOSIT No.13

CEYLON LAKE SODIUM SULPHATE DEPOSIT

Secs, 1, 12, 13 and 24, Tp. 4, R. 21

West of 2nd. Meridian

SASKATCHEWAN

Scale of Feet

1000 500 0 1000 2000

An analysis of an average sample of the brine gave the following results:—

Insoluble	20
$CaSO_4$	20
$MgSO_4$	200,000
$NaCl$	9,500
Na_2SO_4	80,000

(Results expressed in parts per million).

Taking the depth of brine as 2 feet, there is approximately 500,000 tons of hydrous salts in these two lakes.

Deposit No. 15—(Whiteshore Lake)

LOCATION AND TRANSPORTATION

The Whiteshore deposit occupies parts of the bed of Whiteshore lake. The lake is 62 miles due west of Saskatoon, in tp. 36, ranges 16 and 17, west of the 3rd meridian.

The deposit is well situated with respect to shipping facilities, as it lies parallel to, and only 2 miles south of the main line of the Canadian National railway. A spur could be easily laid to the deposit from either Palo or Oban. The Winnipeg-Edmonton line of the Canadian Pacific railway is about 2½ miles north of the eastern end of the deposit, Naseby being the nearest station on this line.

TOPOGRAPHY

The lake which is 10½ miles long and 1¾ mile wide at the widest part, with an average width of half a mile, covers an area of about 1,860 acres, and occupies the western part of a long, narrow valley. The banks are, for the most part, low and shelving, but in some places they rise quite steeply to a height of 10 or 15 feet. The southeasterly prolongation of the valley contains several smaller lakes of varying degrees of salinity. There are also several small sloughs near the western end of the lake, in some of which the water is quite fresh.

No rock outcrops were observed in the vicinity of the deposit, bedrock being covered everywhere by glacial drift. The soil is a rather sandy boulder clay. In some places around the lake there are patches of boulder clay, the boulders being schist, gneiss and granite with a small number of cream-coloured limestone or dolomite boulders. The beaches of the lake are, in places, quite stony and in some parts of the lake itself, there are large boulders of schist and gneiss far out from the shore.

SPRINGS

There are both freshwater and brine springs at this deposit.

Freshwater Springs

Several freshwater springs exist around the margin of the lake and they vary in size from tiny seepages to one with an estimated flow of 100 to 150 gallons per minute.

With the exception of three seepages on the north shore in the southern half of section 35, range 17, all the springs are on the southern shore at the eastern end of the lake.

There are only two freshwater springs of any size. Spring No. 1 is located in the low, grassy mud patch 500 feet or more out in that part of the lake which lies in the S.E. ¼ of sec. 23, range 16. The temperature of this spring was 6·5°C. in July, 1924. The flow was estimated at from 5 to 10 gallons per minute. The analysis of the water is as follows:—

Na	290
Ca	trace
Mg	90
Cl	trace
SO_4	520
HCO_3	570
Total	1,470

(Results expressed in parts per million).

Spring No. 2 which has the largest flow of any in the vicinity, is located on the southern shore, just on the dividing line between the S.W. ¼ and S.E. ¼ of sec. 23, range 16. The temperature of this spring in July, 1924, was 3°C and it had a flow of between 100 and 150 gallons per minute. The analysis of the water is as follows:—

Na	2,660
Ca	2
Mg	20
Cl	10
SO_4	4,580
HCO_3	840
CO_3	230
Total	8,342

(Results expressed in parts per million).

In addition to the freshwater marginal springs there appear to be several in the crystal bed, as in the eastern end of the lake there are several large mud and water-filled basins 10 to 80 feet in diameter. These basins had mud at the bottom and the appearance was as if a freshwater spring were issuing from the bottom of the lake.

Brine Springs

There are other springs which in all probability are brine springs since they issue from the top of the crystal bed through a very small orifice an inch or less in diameter instead of through a large mud chimney as do the freshwater springs. There is also, in many cases, a small cone of crystal or an elevation in the crystal bed around each orifice.

These springs are quite numerous, especially in the eastern end of the deposit. In the central part, the permanent crystal bed was covered at the time of examination by a thick layer of intermittent crystal, which hid the orifices of the tiny springs if any were present. In the western end of the lake, where the permanent crystal was patchy, the spring orifices were noticed in each patch of crystal. The crystal was deepest in the vicinity of these springs.

A sample was taken from one of the largest of these springs (No. 3 on the map) near the mud island in S.E. ¼ of sec. 23, range 16, and the chemical analysis is given below. The analysis may be compared with the analysis of the lake brine at the same time. The sample was taken with a pipette, but, due to the crystal bed being porous, the brine issuing from these tiny springs would probably be more or less mixed with the brine on the crystal bed, as well as with solution from the crystal as it passed through.

	No. 3 Spring
Na	180
Ca	trace
Mg	8,620
Cl	8,570
SO_4	22,200
HCO_3	1,640
Total	41,210

(Results expressed in parts per million.)

THE BRINE

When the deposit was examined during the period from July 23 to August 9, 1924, the brine was variable in amount. The previous month having been dry and hot, the brine had become very concentrated, and in consequence was just at that critical point when a few degrees drop in temperature would cause the salts to crystallize out. The only part of the lake that always contained brine during this period was the narrow part in sections 34 and 35, range 17. Here the brine was from 10 inches to 2 feet deep and very clear.

In general, the brine is deepest in the vicinity of the narrows, (sec. 35, range 17), where the road crosses, and shallows out to the east and west.

The chemical analyses of two samples of brine taken, one in the eastern half and the other in the western half of the lake, are as follows:—

	Eastern half	Western half
Na	28,930	36,890
Mg	6,820	11,120
Cl	6,700	10,220
SO_4	77,700	106,200
HCO_3	1,010	1,940
Totals	121,160	166,370
Sp. Gr. at 15°C	1·112	1·158

(Results expressed in parts per million.)

THE INTERMITTENT CRYSTAL

The intermittent crystal was not completely formed over the whole extent of the lake bed. The crystal varied greatly in depth over different parts of the lake, being thickest where the brine was deepest. It has its greatest depth along the centre line of the lake and shallows out towards the shores. It overlies mud and permanent crystal alike.

In the eastern end of the lake in section 23, range 16, there was an inch or less of intermittent crystal over the permanent bed, and, due to the shallowness of the brine there would be little, if any, more intermittent crystal formed during the autumn.

Over that part of the lake bed in sections 28, 29, and 30, range 16, the intermittent crystal had a depth of 14 inches in the middle of the lake. The depth lessened towards both shores and, at a distance of 1,000 feet from shore, was only about 4 inches.

The lake, in sections 34, 35, and 36, range 17, was brine covered and very little intermittent crystal had formed by August 8. However, a depth of at least from 12 to 18 inches can reasonably be expected to form over this part of the lake, due to the depth of brine. In the western end of the lake there was from 2 to 4 inches of intermittent crystal.

The intermittent crystal is very clear and free from mud, and could be easily harvested in a clean state.

The analysis of a sample of intermittent crystal from the lake is as follows:—

Insoluble	Per cent	0·18
$NaCl$	"	0·78
$NaHCO_3$	"	0·33
$CaSO_4$	"	0·24
$MgSO_4$	"	1·70
Na_2SO_4	"	96·76
Total	"	99·99

THE PERMANENT CRYSTAL

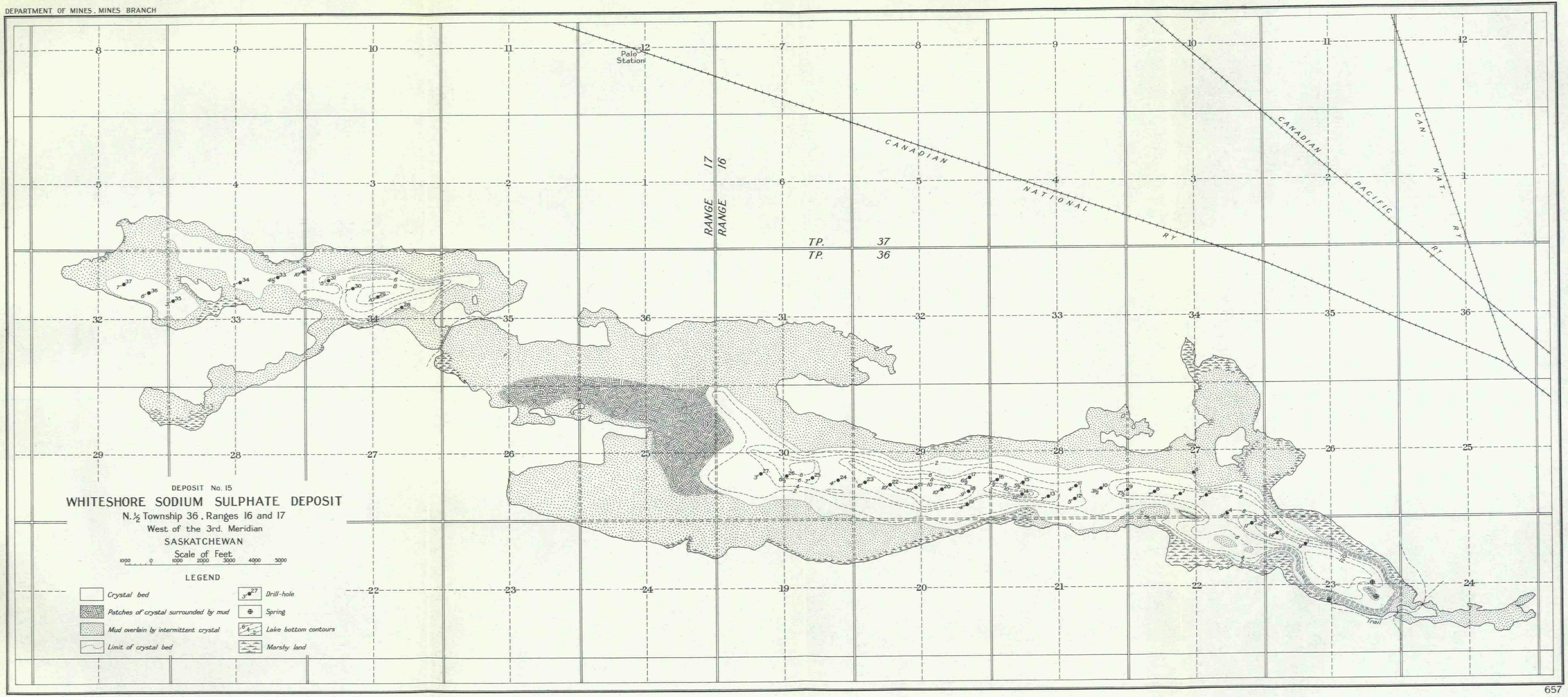
The permanent deposit exists as a large bed in the eastern half and as a series of smaller beds in the western end.

The main bed extends westward for a distance of 5 miles from section 24, range 16, to section 25, range 17. The average width of this bed is from $\frac{1}{4}$ to $\frac{1}{2}$ mile, and the depth is fairly uniform throughout this length, varying from 3 to 7 feet, with an occasional depth of from 10 to 14 feet.

The most consistently deep part is the extreme eastern end, where the crystal has a general depth of about 10 feet, and is very clear and hard. This end of the deposit is, however, covered with a mud layer from 4 inches to 3 feet deep and the surface of the crystal is very hummocky: so much so that it was not possible to drill any holes in the extreme eastern end.

The crystal in the large bed varies in physical composition from almost clear crystal to very muddy crystal. In some places mud layers 1 to 2 feet thick were found interbanded with the crystal. In general, the crystal to a depth of 5 feet is rather soft and muddy, but below that depth is harder and clearer. There is a layer of mud over the top of the whole of the crystal area, from $\frac{1}{2}$ inch to 1 foot or more, the greater depth of the mud being near the shore.

Twenty-seven drill holes were put down in the main crystal bed and the cores sampled. At the western end of this large bed, is a considerable area of the lake in which isolated patches of crystal exist. These crystal patches, irregular in outline, and varying in size from 10 to 100 feet in diameter, are separated from one another by mud. No drill holes were put down in these patches, but their depths were tested with iron bars, and none over 10 feet in depth were found. The quality of the crystal is similar to that in the main crystal bed.



DEPOSIT No. 15

WHITESHORE SODIUM SULPHATE DEPOSIT

N. ½ Township 36, Ranges 16 and 17
West of the 3rd. Meridian
SASKATCHEWAN

In the western part of the lake, just west of where the wagon road crosses at the narrows in section 35, range 17, there is a large patch of permanent crystal. The crystal bed varies from 7 to 10 feet in depth and is rather muddy. There is also a heavy surface deposit of mud, especially at the eastern end, where the mud covering was 3 feet or more deep. Four holes were drilled in this bed.

In the extreme western end of the lake are several large patches of crystal and numerous small ones. Six drill holes put down in these patches showed the crystal to be very muddy and also to contain relatively thick mud layers.

The analyses of all the samples taken from this deposit were averaged and the results follow:—

—		0 to 5′	5′ to 10′	10′+
Insoluble	Per cent	8·73	6·77	11·10
NaCl	"	0·86	0·69	0·72
$NaHCO_3$	"	0·81	0·69	0·83
$CaSO_4$	"	4·50	3·04	4·31
$MgSO_4$	"	6·99	7·78	11·57
Na_2SO_4	"	77·66	80·62	71·02
Totals	"	99·55	99·59	99·55

The amount of hydrous salts present is approximately 19,760,000 tons.

Deposit No. 18—(Minburn, Alberta)

LOCATION

Two small lakes situated in the south half of sec. 12, tp. 50, range 11, west of the 4th meridian, contain salts in the form of brine and intermittent crystal. The lakes are about 100 miles east of Edmonton and 6 miles southwest of Minburn, a town on the Humboldt-Edmonton branch of the Canadian National railway.

The lakes cover an area of about 25 acres and for the greater part of the year are brine covered. When examined in 1924 there was no intermittent crystal visible but, according to Allan[1], there is an intermittent crystal formed in some seasons.

A sample of brine taken from these lakes analysed:—

Na	31,100
Ca	140
Mg	1,810
Cl	1,270
SO_4	70,100
HCO_3	1,140
Total	105,560

(Results expressed in parts per million).

Several tons of crystal have been harvested from this deposit and piled on the shores.

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[1] Allan, J. A. Second Annual Report Research Council of Alberta, Edmonton, 1922, p. 40.

Deposit No. 19—(Vincent Lake)

LOCATION AND TRANSPORTATION

This deposit is situated in secs. 3 and 4, tp. 15, range 22, and secs. 33 and 34, tp. 14, range 22, west of the 3rd meridian. It is 14 miles by road north of Sidewood, a station on the main line of the Canadian Pacific railway. The road runs through parts of the Sand hills and is, in consequence, very hilly and where it winds down the coulee into the depression in which the lake is situated, it is very rough and stony.

TOPOGRAPHY

The deposit which is in the shape of an S, is situated in a deep depression, the banks of which slope rather steeply but in no place are they precipitous. There is a small, low island of morainic material close to the western shore at the centre of the deposit. At the northwest end there is a gently rising, broad valley extending back from the deposit for about a mile before it reaches the general level of the surrounding prairie. At the southeast end there are two more similar valleys, one running east and the other trending to the southeast. In places in these valleys the ground is quite marshy.

The deposit is about 200 feet below the general level of the surrounding country. The drainage basin is quite large. The drift is, in most cases, very sandy but contains numerous pebbles and in places is quite gravelly. Boulder patches are quite frequent and there are a great many large Archæan erratics dotted over the slopes in the drainage basin as well as on the surrounding prairie.

SPRINGS

In only one place was a marginal spring noted and it had only a very tiny flow. It was situated at the head of the small cove on the west shore just south of the island. A few small springs were observed in the crystal bed, all of which came up through the characteristic mud chimneys typical of freshwater springs.

THE BRINE

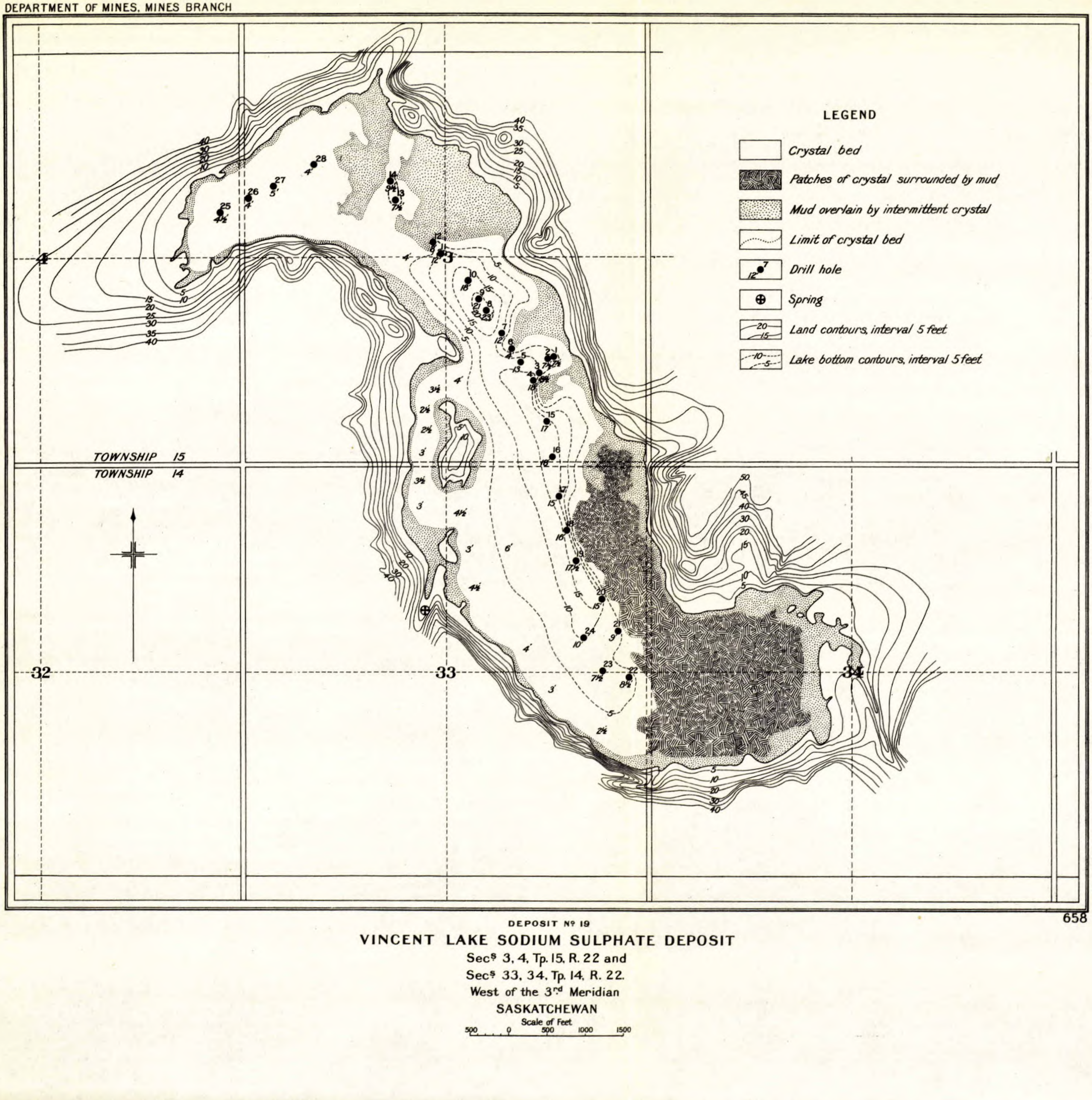
On account of the large drainage basin there is generally a considerable depth of water on the deposit each spring. When examined in July, 1922, there was still 2 feet of brine in some parts of the lake. The brine was very clear and by the end of July was near its saturation point. A sample of this brine analysed as follows:—

$CaCO_3$	1,410
$MgSO_4$	14,700
$NaCl$	18,720
Na_2SO_4	134,300
Total	169,120

(Results expressed in parts per million).

THE INTERMITTENT CRYSTAL

Intermittent crystal forms on top of the permanent bed and mud alike, and, as might be expected from the depth of brine, it is rather deeper than is usual, running from 7 to 12 inches. There is only a thin film of mud



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DEPOSIT No 19

VINCENT LAKE SODIUM SULPHATE DEPOSIT

Sec^s 3, 4, Tp. 15, R. 22 and
Sec^s 33, 34, Tp. 14, R. 22.
West of the 3rd Meridian
SASKATCHEWAN

Scale of Feet
500 0 500 1000 1500

between the crystal and the permanent bed, so that a very clean crystal could be harvested. Two analyses of the intermittent crystal follow:—

		1	2
Insoluble........................	Per cent	0·40	0·57
NaCl...........................	"	0·50	0·20
$NaHCO_3$........................	"	0·33	0·33
$MgSO_4$.........................	"	0·76	....
Na_2SO_4........................	"	97·46	98·67
Totals..............	"	99·45	99·77

THE PERMANENT BED

The permanent crystal covers approximately 325 acres and has an average depth of from 6 to 10 feet. At one place a depth of 30 feet was encountered but the extent was extremely small. The crystal carries the usual mud inclusion as well as mud partings, but on the whole the crystal bed is very compact and hard.

At the southwest end of the lake the crystal occurs in patches with mud between and in no place was a depth greater than 2 feet found. The area has, therefore, been marked as patchy crystal on the map.

An interesting feature is the irregularity of the limit of the permanent crystal bed along the northern half of the eastern shore. It will be noticed that wherever a point juts out into the lake that the crystal bed comes close to the shore and where there is a bay or recession in the shoreline that there is a corresponding bay in the outline of the crystal bed. In other words, wherever there is a bay and a long gradual slope running back from the shore there is an extensive mud area opposite it in the lake bed. It is probable that the permanent crystal bed has been dissolved by the large amount of surface waters entering the lake down the slopes into the bays.

Analyses were made on the material from each hole giving the average of each hole and the results obtained are as follows:—

Hole No.		1	2	3	4	5	6	7	8
Insoluble...........	Per cent	2·05	5·52	1·94	0·63	5·23	4·55	6·00	9·23
Al_2O_3, Fc_2O_3........	"	0·61	0·70	0·55	0·30	0·70	0·50	0·70	1·73
$CaCO_3$............	"	....	....	....	....	....	....	....	....
$CaSO_4$............	"	1·04	1·91	0·91	0·36	1·92	1·45	1·94	2·42
$MgCO_3$............	"	....	....	....	....	....	....	....	....
$MgSO_4$............	"	1·96	2·71	1·36	0·99	3·13	2·10	2·92	1·62
NaCl.............	"	....	....	0·29	0·60	0·92	0·74	0·74	1·09
Na_2SO_4............	"	93·82	88·40	94·54	97·68	87·85	89·30	86·51	83·46
Totals.....	"	99·48	99·24	99·59	100·53	99·85	98·64	98·81	99·55

Hole No.		9	10	11	12	13	14	15	16
Insoluble	Per cent	13·55	8·90	6·00	0·20	3·20	6·20	3·90	5·10
Al_2O_3, Fe_2O_3........	"	2·30	2·05	0·60	0·18	0·50	0·50	1·00	0·60
$CaCO_3$............	"	1·69	....	....	....	1·38	1·28	1·07	1·16
$CaSO_4$............	"	1·16	2·05	1·57	0·30	....	....	....	....
$MgCO_3$............	"	....	....	....	....	....	....	....	....
$MgSO_4$............	"	2·62	2·25	2·29	0·25	2·27	2·16	1·78	2·11
NaCl.............	"	1·38	1·21	0·77	0·61	0·77	0·86	0·80	0·82
Na_2SO_4............	"	76·72	83·72	87·71	99·18	91·70	88·37	91·35	90·10
Totals.....	"	99·42	100·18	98·94	100·72	99·82	99·37	99·90	99·89

Hole No.		17	18	19	20	21	22	23	24
Insoluble..........	Per cent	11·00	8·20	11·00	10·20	11·24	10·07	18·46	19·80
Al_2O_3, Fe_2O_3........	"	1·23	0·55	1·20	1·20	1·05	1·22	3·53	4·88
$CaCO_3$............	"	2·76	1·38	2·04	2·58	3·11	2·54	3·82	5·60
$CaSO_4$............	"	....	....	....	....	....	....	....	....
$MgCO_3$............	"	1·55	....	0·85	0·98	1·94	1·43	0·83	0·91
$MgSO_4$............	"	....	2·21	3·63	1·39	1·39	2·05	1·20	1·29
NaCl............	"	0·80	0·80	0·80	0·80	0·80	0·80	0·95	0·95
Na_2SO_4............	"	82·08	86·94	80·18	83·06	80·09	81·42	70·79	64·36
Totals.....	"	99·42	100·08	99·26	100·21	99·62	99·53	99·58	97·79

The quantity of hydrous salts, including the intermittent crystal, is approximately 5,640,000 tons.

Deposit No. 28—(Regina Beach No. 1)

LOCATION AND TRANSPORTATION

This deposit is situated in the northeast corner of sec. 25, tp. 20, range 22, west of the 2nd meridian. The nearest shipping point is 11 miles distant at Regina Beach, a station on the Canadian National railway. The roads are fairly good and with the exception of the rise to the prairie level at the deposit, are quite level.

TOPOGRAPHY

The lake is rectangular in shape being about 1,600 feet long and its greatest width is 600 feet. Notwithstanding its small size, compared with many other similar deposits in Saskatchewan and Alberta, the deposit was one of the earliest to be operated, and shipments of natural Glauber's salt have been made from it for a number of years.

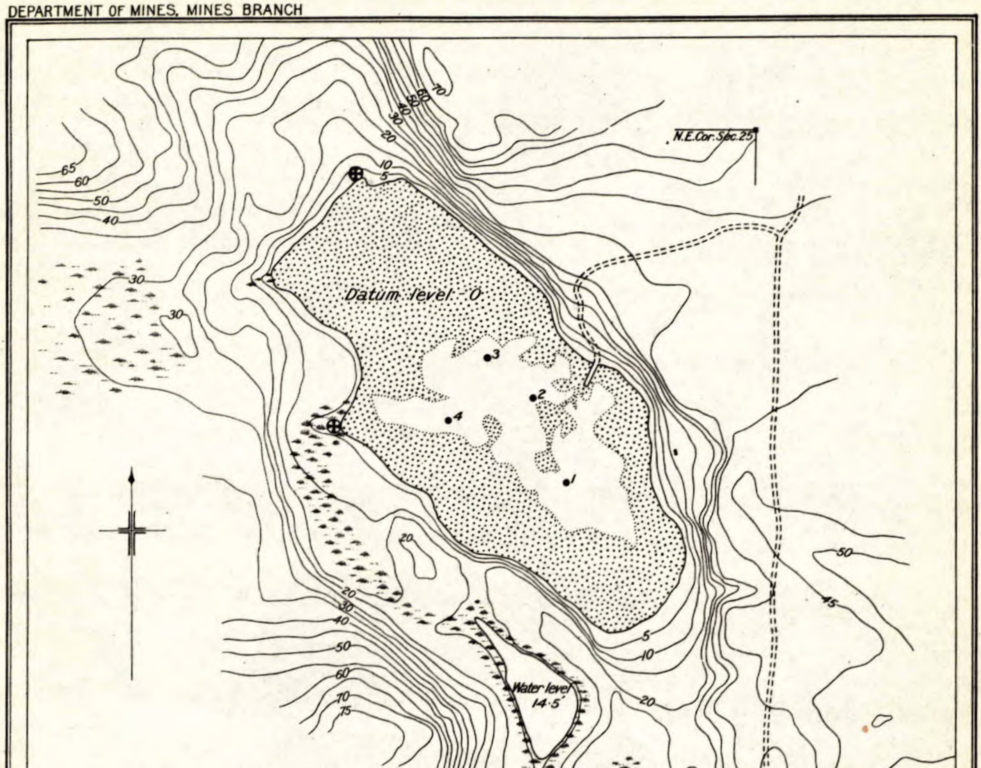
The deposit occupies a basin in a long, narrow depression, traceable for several miles, which was probably at one time an old drainage channel leading into the south end of Last Mountain lake. The Arm river, which has cut a deep valley into the prairie one mile to the west of the deposit, is considerably lower than the level of this lake and therefore the drainage basin is small. Lying to the east and in the same depression as the deposit are two small sloughs, in which the water is only slightly alkaline. Along the northwest shore the banks of the deposit rise abruptly, the lake being some 60 to 80 feet below the general level of the surrounding prairie. On the south shore the banks are not so abrupt and there is a considerable area of comparatively level ground running back for a quarter of a mile at an elevation 10 to 15 feet above the level of the lake.

The banks are composed of sandy boulder clay with considerable stretches of a gravelly nature.

SPRINGS

There are several marginal springs or seepages around the shore, but on account of the depth of the brine no information could be obtained as to whether there were any springs in the bed of the lake itself.

DEPARTMENT OF MINES, MINES BRANCH



DEPOSIT Nº 28

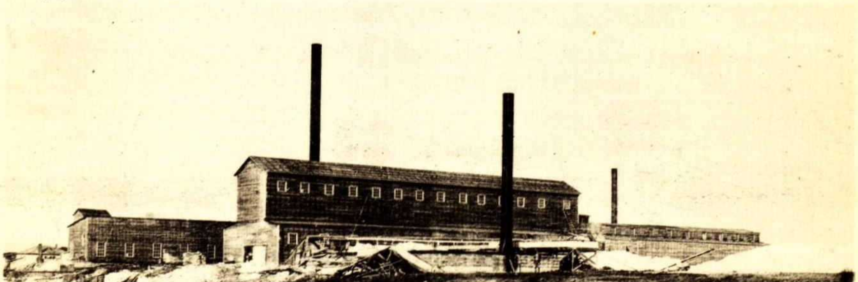
REGINA BEACH SODIUM SULPHATE DEPOSIT Nº1

N.E ¼ Sec.25, Tp.20, R.23
West of the 2nd Meridian
SASKATCHEWAN
Scale of Feet
200 100 0 200 400 600 800

#1705

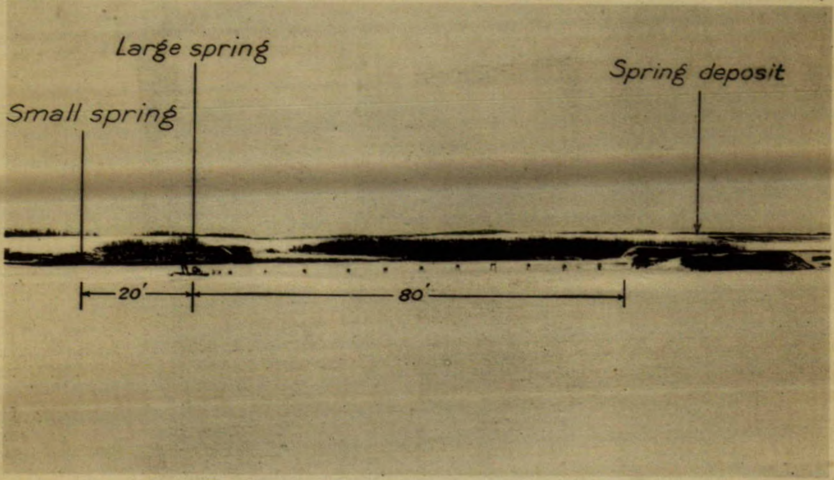
A. Flowing spring from depth of 70 feet, Muskiki lake, Sask.

#1706



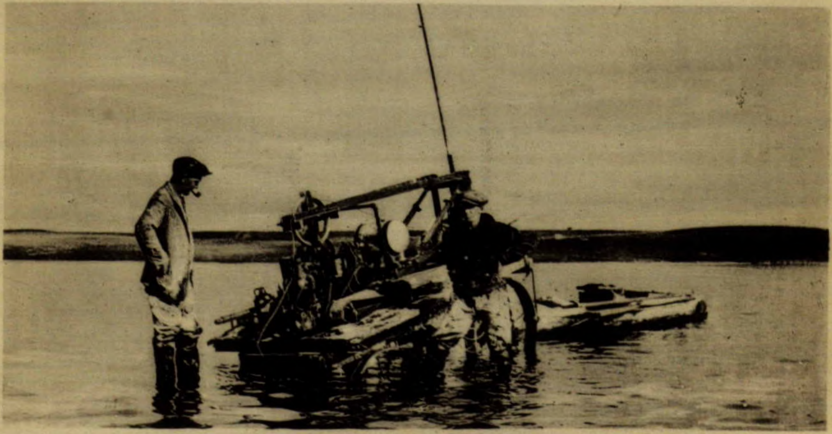
B. Plant of the Salts and Chemicals, Ltd., showing stock pile of crystals, Muskiki lake, Sask.

\# 1708



A. Springs in crystal bed, Muskiki lake, Sask.

\# 1720



B. Drill sunk in mud hole, Snakehole lake, Sask.

THE BRINE

The brine is unusually deep, being sometimes in the early spring as much as 4 feet deep over the whole deposit. When the deposit was examined in July, 1923, the depth varied from 3 feet to 3 feet 8 inches.

THE INTERMITTENT CRYSTAL

The lake seldom dries up, but at the lower temperatures of the late summer and fall, the Glauber's salt crystallizes in large quantities and sinks to the bottom, and is then harvested. This operation is performed entirely by manual labour, the men standing in the brine and lifting or shovelling the crystals on to scows, from which they are unloaded on to a wharf. After thoroughly draining, the salts are bagged and shipped by wagon to Regina Beach station.

There is probably from 18 inches to 2 feet of harvest crystal formed each year.

THE PERMANENT CRYSTAL BED

The permanent crystal bed is irregular and intersected with a chain of large mud holes, so that the crystal bed covers less than a quarter of the whole lake area. Mud covers the bed, ranging in thickness from 6 inches to 1 foot. A few mud lenses interbanded with crystal were encountered.

Four holes were sunk in the crystal bed: No. 1 in the southeast end with 10 feet of crystals; No. 2 in the centre with 9 feet 6 inches of crystals; No. 3 in the north end of the bed with a crystal depth of 12 feet 6 inches; and No. 4 in the northwest end with a depth of 5 feet 6 inches of crystals. The crystal in the permanent bed is of a bluish white colour, clear and hard and comparatively free from foreign substances.

Analyses of crystal from this deposit are as follows:—

—	Hole 1	Hole 2		Hole 3			Hole 4
	5 'to 10′	0 to 5′	5′ to 9½′	0 to 5′	5′ to 10′	10′ to 12½′	0 to 5½′
Insoluble.....Per cent.	5·03	5·70	9·10	1·67	6·90	5·17	6·00
$NaCl$......... “	0·29	0·07	0·45	0·10	1·62	1·50	0·20
$NaHCO_3$..... “	1·62	0·89	1·05	1·09	0·72	0·92	1·51
Al_2O_3, Fe_2O_3.. “	0·73	....	....	....	....	....	....
$CaSO_4$........ “	3·40	3·00	5·92	2·55	4·93	4·08	1·87
$MgSO_4$........ “	2·20	2·15	3·35	1·25	2·20	1·50	2·13
Na_2SO_4....... “	83·80	88·80	73·14	92·89	82·84	86·80	85·80
Totals...........	97·07	100·61	93·01	99·55	99·21	98·47	97·51

The total amount of hydrous salts available is about 100,000 tons.

Deposit No. 29—(Regina Beach No. 2)

An alkali lake situated in sec. 21, tp. 20, range 22, west of the 2nd meridian, was reported to contain a crystal bed of considerable area and depth. However, detailed examination revealed only a narrow strip of permanent crystal about 2,000 feet in length and 100 feet wide following the east shore, and two smaller beds, one on the west shore opposite the south end of the main bed, the other between the two beds. The crystal beds were covered with 3 feet of mud, and the depth of the brine was about 2 feet when the deposit was examined in August, 1923. The crystal beds above mentioned are free from mud holes as far as could be ascertained. There was no possibility of getting the drill on the deposit on account of the nature of the mud bottom, but sufficient bar tests were made to delimit the permanent crystal beds. The depth of crystal could not be obtained, owing to the heavy covering of mud. A road runs close to the lake at the north end.

Deposit No. 30—(Horseshoe Lake, Horizon Deposit)[1]

LOCATION AND TRANSPORTATION

There is a large lake containing a bedded deposit of sodium sulphate situated in secs. 5, 7, 8, 9, 16, 17, 20, and 21, tp. 9, range 25, west of the 3rd meridian. The deposit is about 16 miles south of Spring Valley station on the Avonlea-Gravelbourg branch of the Canadian National railway, and 16 miles north of Viceroy station on the Assiniboia-Weyburn branch of the Canadian Pacific railway. The road to Spring Valley runs through the Dirt hills and in consequence there are some steep grades.

TOPOGRAPHY

The deposit occupies the bottom of a deep, undrained depression surrounded by a series of morainic hills. Eight miles to the north are the Dirt hills, which extend northeasterly and southwesterly for about 20 miles, forming a ridge of morainic hills on their northern slope, which rise abruptly to a height of 600 feet or more above the level of the extremely flat country to the north. These hills are part of the northern extension of the Missouri coteau, and towards the south they slope more gradually down to an elevated plateau which in this district forms part of the watershed between Canada and the United States. It is in this plateau that the deposit is located.

The banks of the deposits slope gently from the edge of the crystal bed and rise gradually from 70 to 100 feet to the general level of the country. They are composed of a sandy, gravelly boulder clay containing many small granite and limestone boulders. An interesting feature of this occurrence is the many deposits of glacio-fluviatile material. For example, there is an eskar, running continuously for over a mile east and west along the south end of the deposit, the crest of which is about 20 feet in width and about 50 feet above the level of the crystal bed; the slopes on each side are about 30 degrees and very uniform. The northern slope forms the southern bank of the deposit.

There are 14 islands in the lake, varying in size from 20 feet in diameter to one which is 1,000 feet long by 500 feet wide. There are a number of small sloughs in the district, most of which contain fresh water.

The lake is approximately 2¼ miles long and its greatest width is nearly one mile.

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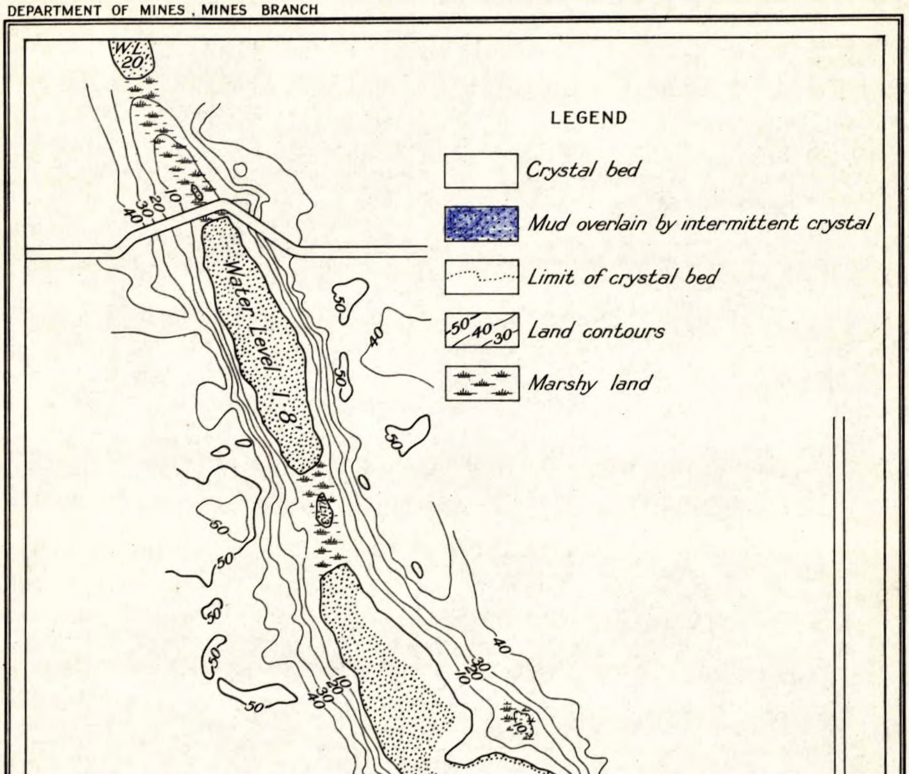
[1] Since the manuscript for this report was written the Canadian Pacific Railway has run a branch line from Amulet to Dunkirk, and this branch line passes the north end of the deposit.

DEPARTMENT OF MINES, MINES BRANCH



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DEPOSIT No. 29

REGINA BEACH SODIUM SULPHATE DEPOSIT No. 2

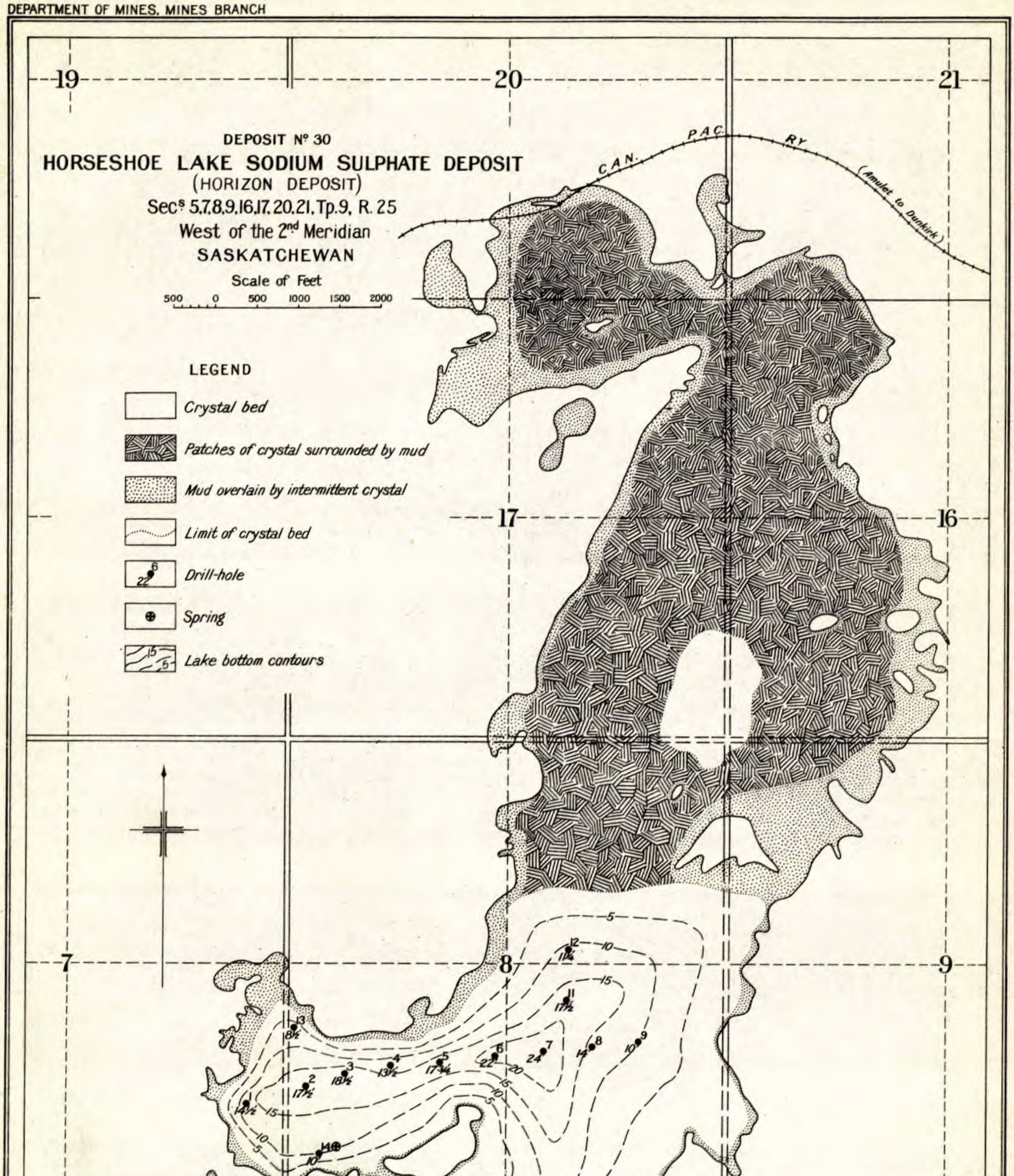
Sec. 21, Tp. 20, R. 22, West of the 2nd. Meridian

SASKATCHEWAN

Scale of Feet

500 0 500 1000

DEPARTMENT OF MINES, MINES BRANCH



DEPOSIT Nº 30

HORSESHOE LAKE SODIUM SULPHATE DEPOSIT

(HORIZON DEPOSIT)

Secs 5,7,8,9,16,17,20,21, Tp.9, R.25

West of the 2nd Meridian

SASKATCHEWAN

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SPRINGS

With the exception of a few small seepages there are no marginal springs worthy of note.

One sub-crystal spring was noted in the southwest part when the deposit was dry in the winter. The opening was about 6 feet in diameter and was surrounded by a mound of mud and ice 2 feet high and 50 feet in diameter. The water level in the spring was 2 feet below the edge of the ice crater and the spring did not seem to have overflowed recently. The temperature of the water was 5° C. An analysis of a sample of the water follows:—

$NaCl$	33,163
$Ca(HCO_3)_2$	1,700
$MgSO_4$	47,185
$MgCO_3$	420
$Mg(HCO_3)_2$	144
$MgCl_2$	269
Total	82,881
Sp. Gr. at 15°C	1·076

(Results expressed in parts per million.)

Between the low, grassy island in the southern part of the lake and the western shore, water seepages occur on top of the crystal bed, but no spring orifices were noted.

Similar seepages were noticed 1,500 feet north of the large island, 300 feet out from the east shore, but no definite spring orifice was visible.

THE BRINE

The brine in the early part of the summer is 8 to 10 inches deep, but soon becomes concentrated. The deposit usually becomes dry by the middle of July.

THE INTERMITTENT CRYSTAL

Intermittent crystal forms in the early summer and accumulates to a depth of about 5 inches. It rests on mud which, in the southern end of the deposit, is rarely more than 6 inches deep. The mud becomes deeper in the north end, especially near the islands, where a depth of 3 feet is quite common.

THE PERMANENT CRYSTAL

The permanent crystal covers practically the whole of the lake, and in general runs close to the shore. In the southern end near the large island, the bed is solid with very few mud holes and is fairly uniform in depth. In this part of the lake 14 drill holes were sunk.

In the northern half of the lake, although the crystal bed is present, as shown on the map, it is full of mud holes and occurs as isolated patches rather than as a continuous bed. One area just north of the large island is the only patch that has any continuity, and the depth of this patch in places is over 10 feet. Over the rest of this part of the lake the patches are so numerous and small in area that it was impossible to delimit them separately. It was impossible to get the drill on any part of the lake north of the large island, but a number of tests were made with a bar to determine the nature of the bed. In many places a depth of from only 2 to 3 feet was encountered.

Samples were taken from the cores obtained from the drill holes in the southern part of the deposit, and these were averaged as follows:—

—		0 to 5′	5′ to 10′	10′ to 15′	15′ to 20′	20′ to 25′
Insoluble	Per cent	4·46	4·19	3·96	6·92	1·20
NaCl	"	0·46	0·46	0·63	0·79	0·56
$NaHCO_3$	"	0·69	0·80	0·66	0·79	0·62
Na_2CO_3	"	0·06	0·07	0·11	....	....
$CaSO_4$	"	0·44	0·64	0·74	1·93	1·36
$MgSO_4$	"	1·01	0·88	1·05	1·53	1·02
Na_2SO_4	"	92·35	92·40	92·16	87·64	95·71
Totals	"	99·47	99·44	99·31	99·60	100·47

The quantity of hydrous salts, including intermittent crystal, is 9,000,000 tons.

Deposit No. 35—(Boot Lake)

LOCATION AND TRANSPORTATION

A small alkaline lake occurs in secs. 20 and 21, tp. 15, range 20, west of the 3rd meridian. It lies 20 miles north of Tompkins, a station on the main line of the Canadian Pacific railway, which is the nearest shipping point. The road to Tompkins runs through a part of the Great Sand hills and is very sandy and hilly.

TOPOGRAPHY

The lake lies in a deep depression in the morainic hills forming part of the Great Sand hills. The sides of the depression are steep, but no cliffs are present. The drift material is a sandy boulder till with considerable gravel. Glacial erratics are quite common.

SPRINGS

Several marginal springs were noted, but none had any considerable flow. A few surface seepages were also noticed on the crystal bed, but no definite spring orifices could be found.

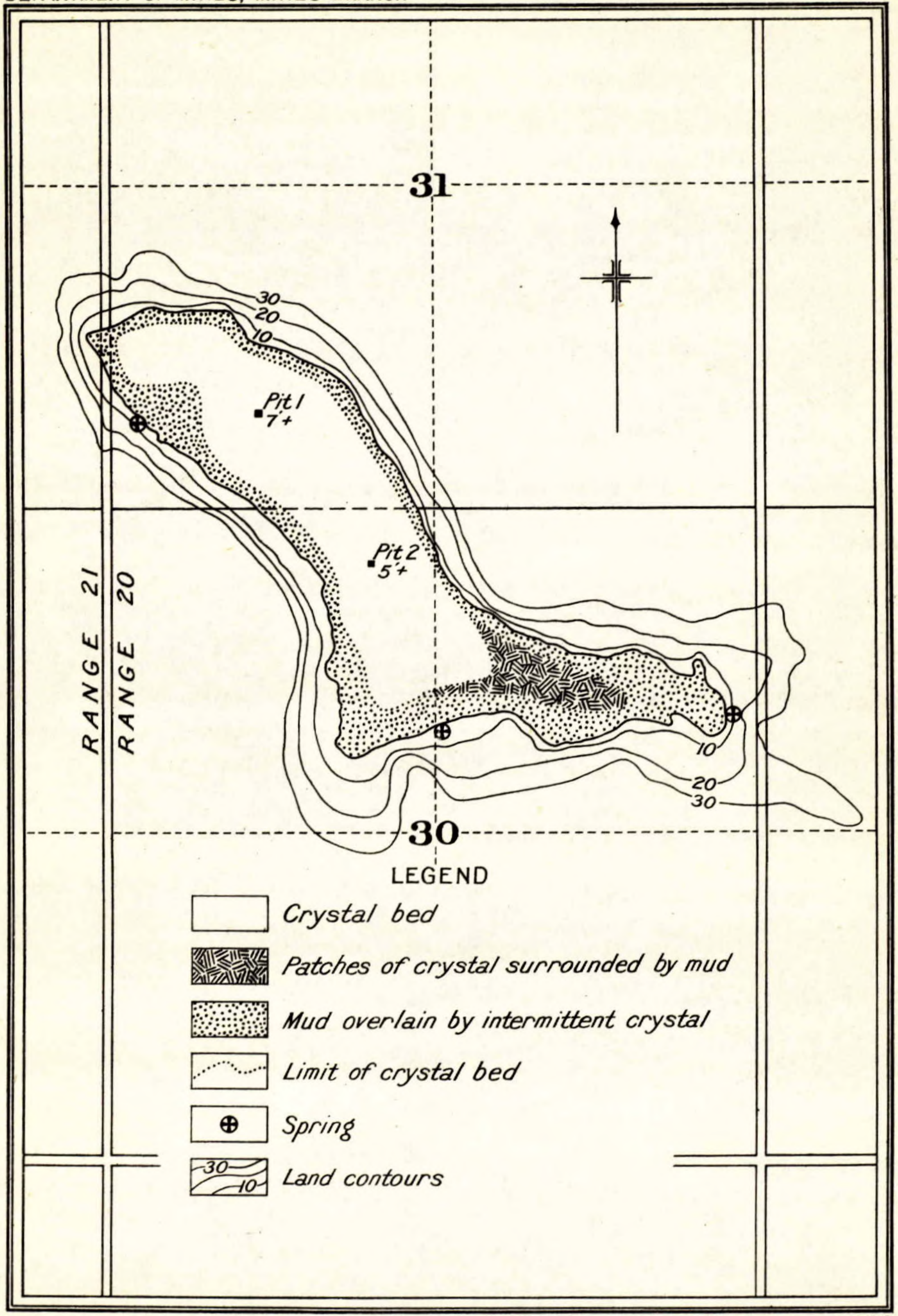
THE BRINE

The brine lies on top of the deposit for only a short time in the spring since the drainage basin is small.

THE INTERMITTENT CRYSTAL

Intermittent crystal, to a depth of 4 inches, had formed over the whole surface in October, 1924, and there was no brine present. The crystal rested directly on the top of the permanent crystal, there being very little, if any, mud separating the two beds.

DEPARTMENT OF MINES, MINES BRANCH



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DEPOSIT No 35

BOOT LAKE SODIUM SULPHATE DEPOSIT

Secs 30, 31, Tp. 15, R. 20
West of the 3rd Meridian
SASKATCHEWAN

Scale of Feet
1000 500 0 1000 2000

THE PERMANENT BED

There is a hard, permanent bed over 7 feet deep in places in the northern half of the lake. In the southern part the crystal is patchy and there are numerous mud holes. Two pits were sunk, but 7 feet was the greatest depth that could be excavated without being flooded out by water.

Samples were taken for the first 3 feet in depth in pit No. 1 to determine the character of crystal. The analysis follows:—

		1st foot	2nd foot	3rd foot
Insoluble	Per cent	3·00	1·87	3·67
NaCl	"	0·79	0·70	0·60
Al_2O_3, Fe_2O_3	"	0·40	0·70	1·00
$CaCO_3$	"	1·25	1·09	2·55
$CaSO_4$	"	1·89	....	....
$MgCO_3$	"	....	1·55	....
$MgSO_4$	"	3·44	2·21	4·81
Na_2SO_4	"	88·38	91·74	87·27
Totals	"	99·15	99·84	99·90

Approximately 750,000 tons of hydrous salts are available.

Deposit No. 37—(Grandora Lake No. 1)

LOCATION AND TRANSPORTATION

The Grandora deposit occupies the bed of a small lake, about 130 acres in area, located in secs. 29 and 30, tp. 36, range 7; and sec. 25, tp. 36, range 8, west of the 3rd meridian. The deposit is situated about half a mile north of Grandora, a small station 14 miles west of Saskatoon, on the main line of the Canadian National railway. The Winnipeg-Edmonton branch of the Canadian Pacific railway is less than half a mile to the north of the deposit, the station of Naseby being the nearest shipping point.

TOPOGRAPHY

The lake occupies a shallow depression in the sandy soil of the district. It is nearly 1½ mile long but is very narrow, being only 1,500 feet wide at the widest part, and the average width does not exceed 900 feet. It is divided into two parts by a long peninsula which juts out from the southern shore. The channel connecting the two parts is 2,000 feet long but only 150 feet wide. Around parts of the lake is an elevated beach about 3½ feet above the present shoreline.

The surrounding country is very flat and sandy and is dotted with clumps of poplar and willow. The general elevation of the country to the west of the deposit is less than 10 feet above the lake level. The soil in the vicinity of the deposit is a sandy, stoneless loam. No outcrops of bedrock were visible.

There are many small alkali and freshwater sloughs in the district, nearly all of which have the remains of an old shore-line 2 to 3 feet above the present water level.

The lake in which the deposit is situated, as well as the others in the vicinity, very probably represent depressions in the bed of a large lake that at one time covered the whole district.

SPRINGS

No springs were observed either on the margin of the lake or in the crystal bed, although there were numerous holes in the crystal suggestive of ancient spring holes.

THE BRINE

The brine did not exceed 2 inches in depth during the period in which the deposit was examined (July 10–21, 1924). The brine was separated from the crystal bed by a layer of mud and sand varying in thickness from 4 inches to 1½ foot. The brine was not so concentrated as were the brines on the deposits where no mud layer intervened between the brine and crystal.

THE INTERMITTENT CRYSTAL

There is scarcely any intermittent crystal formed, owing to the dilute nature of the brine. A crust of from one-quarter to one-half inch thick is the maximum deposited where the brine has completely crystallized.

THE PERMANENT CRYSTAL

The crystal occupies almost the whole bed of the lake and maintains its depth of from 6 to 10 feet right up to the shore, and in some places extends for a short distance under the present grass line. In such places, however, the crystal was mixed with about 50 per cent of sand, and graded into a sand cemented by crystal.

The deposit is composed of a dark-coloured, compact crystal, free from mud layers and quite free from included mud. The depth is uniform over most of the deposit and averages about 8 feet in the eastern and larger part, and 5 feet in the western part.

Underlying the major part of the deposit is a dark-coloured mud of rather firm texture. Near the shore the crystal is quite sandy and is underlain by sand instead of mud.

There are many small mud-filled holes in the hard crystal floor of the lake, which are possibly the outlets of former springs.

Thirty-two drill holes were put down. The analyses of the samples taken were averaged as follows:—

—		0 to 5′	5′ to 10′	10′ to 15′
Insoluble	Per cent	17·01	24·94	20·60
NaCl	"	0·45	0·44	0·53
$NaHCO_3$	"	0·89	0·91	0·86
$CaSO_4$	"	0·97	1·00	0·53
$MgSO_4$	"	1·25	1·14	0·63
Na_2SO_4	"	79·32	71·31	76·43
Totals	"	99·89	99·74	99·58

The available quantity of hydrous salts is approximately 1,126,000 tons.

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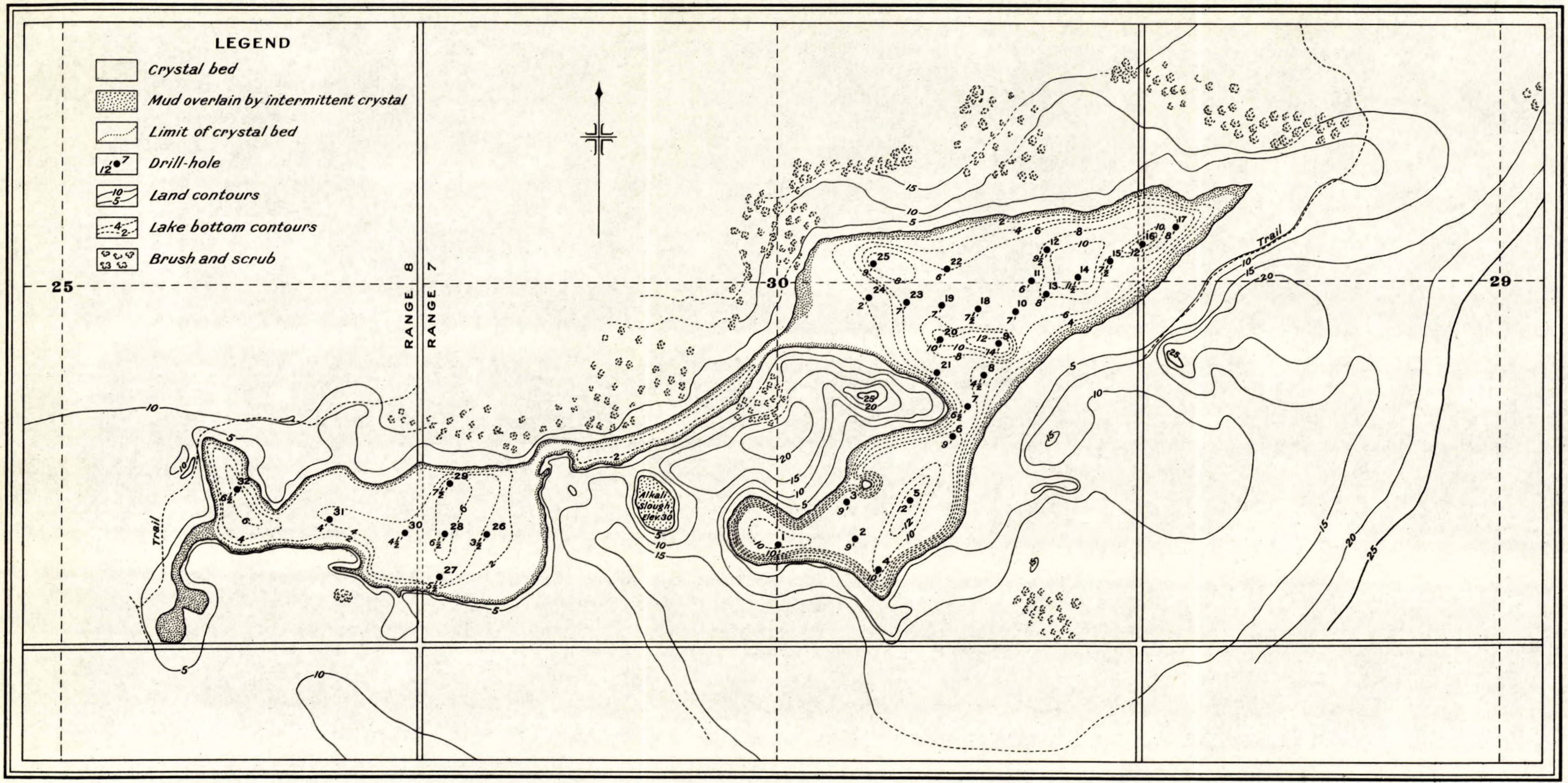

DEPOSIT Nº 37

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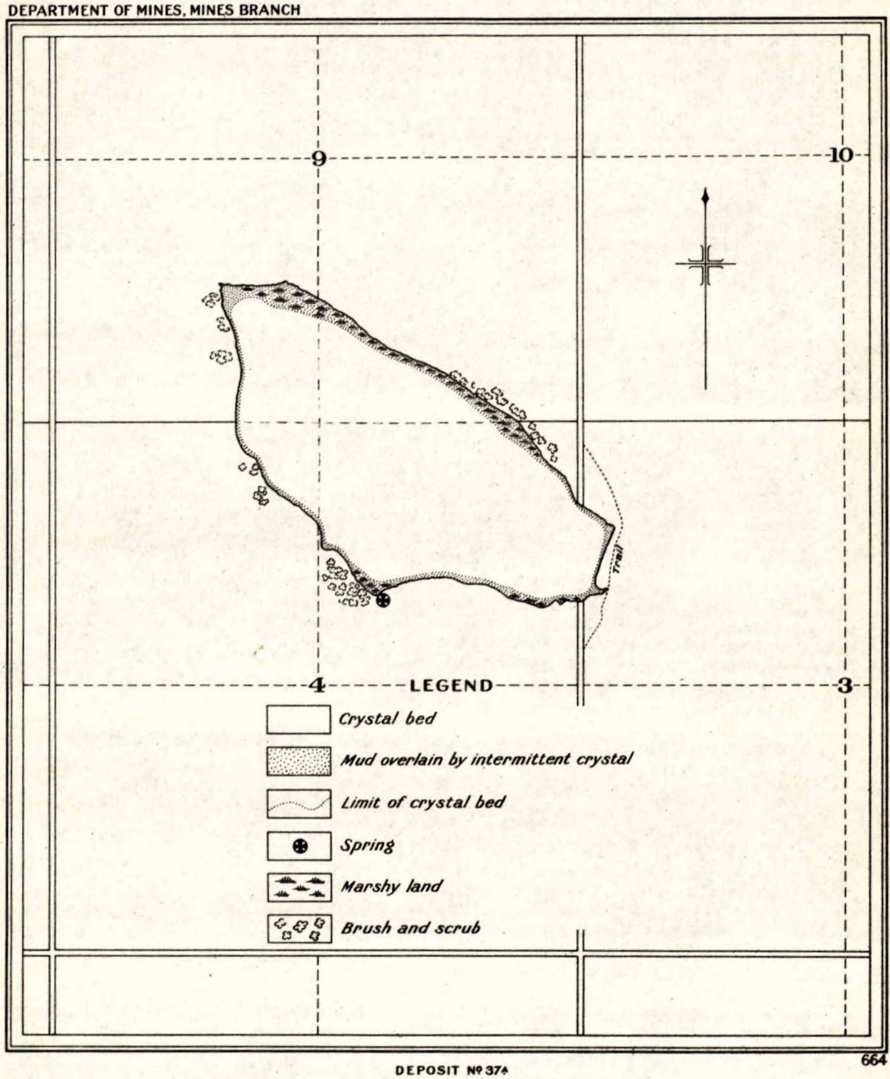
GRANDORA SODIUM SULPHATE DEPOSIT Nº I

Secˢ 29, 30, Tp. 36, R. 7 and
Sec. 25, Tp. 36, R. 8
West of the 3rd Meridian
SASKATCHEWAN

Scale of Feet
500 0 500 1000 1500

DEPARTMENT OF MINES, MINES BRANCH



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DEPOSIT Nº 37^{A}

GRANDORA SODIUM SULPHATE DEPOSIT Nº 2

Sec^{s} 3, 4, 9, Tp. 37, R. 8
West of the 3rd Meridian
SASKATCHEWAN

Scale of Feet
500 0 500 1000 1500 2000

Deposit No. 37A—(Grandora Lake No. 2)

LOCATION AND TRANSPORTATION

In parts of secs. 3, 4, 9 and 10, tp. 37, range 8, west of the 3rd meridian, is another lake containing a crystal bed. This lake is oval-shaped, being 5,000 feet long by 2,000 feet at its widest part, the greater axis running northwesterly and southeasterly. The area of the lake is about 140 acres.

A very dilute brine over 2 feet deep was present and under this brine was a layer of sand about 2 feet thick. This depth of sand and water precluded the possibility of drilling the deposit and also made it very difficult to gain an idea of the crystal bed by using a long iron bar. The sand would fill in the hole made by the bar and thus cushion the bottom of the hole and prevent further progress.

TOPOGRAPHY

The topography of the surrounding country is similar to that around Grandora Deposit No. 1.

SPRINGS

One small flow, more in the nature of a seepage than of a spring, was found on the south shore.

THE BRINE

The brine was only 2 feet deep a short distance out from shore but became deeper towards the middle of the lake. The brine was very dilute when the deposit was examined. According to the farmers of the district, the lake does not dry up in the autumn, but freezes over in winter.

THE INTERMITTENT CRYSTAL

No trace of intermittent crystal was observed on the sand.

THE PERMANENT CRYSTAL

The depth of brine and sand prevented any detailed examination of the crystal bed, but where it was tested out by means of a long iron bar it seemed solid and compact. The crystal extended in close to shore along the southwestern edge but was not examined around the remainder of the deposit. The middle of the lake could not be reached. Wherever it was tested the bed was 4 feet or more in thickness.

The sand covering the crystal was in places stained a rusty red and contained gypsum crystals. The gypsum crystals were also seen on the sandy beach around the deposit. In some other places there was a thin layer of sand underlain by a white marl.

Assuming that the deposit has a depth of 4 feet of crystal over its whole extent, there are 880,000 tons of crude hydrous crystal.

Deposit No. 48—(Alsask Deposit)

LOCATION AND TRANSPORTATION

The Alsask deposit occupies a depression 7 miles southeast of the town of Alsask, Saskatchewan. The deposit extends over parts of secs. 21, 27, 28, 33, and 34 of tp. 27, range 28, west of the 3rd meridian.

The flag station of Hardene, on the Alsask-Delisle branch of the Canadian National railway, is 2 miles west; Alsask, on the Winnipeg-Calgary line of the Canadian National railway, is 7 miles distant.

TOPOGRAPHY

The depression containing the deposit occupies the lowest part of a large, shallow drainage basin. The drainage basin has very sandy soil, especially in its southern part, and is dotted with low hills. There is a series of sand hills to the south and east, consisting of low dunes with only a sparse vegetation. Several lakes, the water in which varies from a dilute brine to practically fresh, occur in the same drainage basin as the deposit. The elevation of the deposit is approximately 2,100 feet above sea-level.

The lake bed is, roughly, crescent-shaped in outline, approximately 2 miles in length and from 2,000 to 2,500 feet wide in the centre. The area is 545 acres. The immediate drainage basin of the lake is about 2 miles in diameter and the banks slope gradually down to the lake in all places except at a high, broad point which juts out from the eastern shore, where the bank rises steeply to a height of 30 feet.

Opposite the middle of the deposit, and 1,500 feet to the eastward, is another and smaller lake which also contains crystal. However, the crystal is very patchy, shallow, and dirty, and is covered with mud. The general depth of the patches is 3 to 4 feet, with an occasional depth of 9 feet. This lake is 16·5 feet above the brine level of the main lake.

There are no streams feeding either of the lakes and there are no visible outlets. At the southern end of the large lake is a drainage channel leading from a freshwater lake, but the channel is dry except in wet weather. The water level in the upper lake would have to rise 3 or 4 feet before it would be drained by this channel. At the northeastern end of the lake is another dry channel leading back into the hills.

The underlying rock is everywhere covered to an unknown depth by glacial drift which varies from a sand to a stony boulder clay. The only outcrop of stony boulder clay in the immediate vicinity of the lake is on the sides of the steep promontory which juts out into the lake from the eastern shore. Around the major part of the lake the soil varies from a sandy loam to a pure sand. The sand is most noticeable at the southern end of the deposit, where it extends far back from the lake toward the Sand hills. The shore of the lake is composed of sand and sandy mud.

Along the margin of the southern end of the lake is a considerable stretch of low land with delta-like formations jutting out into the lake, the largest of which is composed of gravel.

SPRINGS

There are no freshwater springs of any size around the margin of the deposit. In the bay immediately south of the promontory on the eastern shore are two very small seepages.

Near Hardene, on the branch line of the Canadian National railway, 2 miles or so westward, is a very large freshwater spring, and this could be considered as a source of water supply for any industrial plant operating at the deposit.

In the crystal bed are several large spring holes in the crystal, presumably caused by freshwater springs.

THE BRINE

The deposit is covered with brine from the early spring until the late summer. In dry seasons the brine will disappear in July, due to solar evaporation, but in normal years it remains until August or September. In March, 1924, there was 5 inches of brine over the whole of the northern end of the deposit and about 3 inches over the southern end. Probably the maximum depth in years of normal rainfall would not exceed one foot.

The brine is separated from the crystal bed by a mud layer varying in depth from a thin film to 11 inches, 4 inches being the general depth over the greater part of the deposit, and this mud becomes the mud layer between the permanent and intermittent crystal when the latter forms.

The brine is very clear and free from organic matter. The chemical analyses of three samples of brine taken at different seasons in different years is given. An interesting feature of the three analyses of brine is the remarkably high sodium chloride content. It is probably due to this fact that at times there is deposited a thin layer of anhydrous sodium sulphate, in some cases one inch or more in thickness. The presence of the sodium chloride in the brine disturbs the equilibrium under which the sodium sulphate would normally be deposited in the hydrous form, and produces the phase in which the anhydrous material is precipitated. Naturally the composition of the brine is constantly changing, so that the proportions of sodium chloride vary and, therefore, the conditions are not always favourable for the maximum deposition of the salt in its anhydrous form. In some seasons, however, it is possible that sufficient of the anhydrous salt may be formed to enable it to be harvested and shipped without further treatment. Baumé readings as taken on the brine during the period from August 16 to August 30, 1924, are also given below.

Analyses of Brine, Alsask Deposit

—	Sample No. 1	Sample No. 2	Sample No. 3
Na_2SO_4	39,000	24,600	47,500
$NaCl$	35,000	37,100	77,200
$NaHCO_3$	3,840	2,940	840
Na_2CO_3	7,100	4,700	1,060
$Ca(HCO_3)_2$	202	486	....
$MgSO_4$	1,615	600	4,300
Totals	86,157	70,426	130,900
Sp. Gr. at 15° C	1·060	1·056	1·166

(Results expressed in parts per million.)

Sample No. 1 collected Sept. 20, 1923, by L. H. Cole, brine 5 inches deep.
Sample No. 2 collected March 1924, by M. F. Goudge, brine 5 inches deep.
Sample No. 3 collected August 1924, by M. F. Goudge, brine 2 inches deep.

Baumé Readings on Brine Deposit No. 48.

Date	Time	Temp. air	Temp. brine	Baumé
		°C.	°C.	°
Aug. 16	Noon	21	20	19
" 17	7.30 a.m.	16	17	18
	Noon	19·5	19	16
	5 p.m.	20	22	24 Drying rapidly.
" 18	7.30 a.m.	15	16	17 Very heavy rain.
	Noon	20	24	17
	5 p.m.	22	25	17
" 19	7.30 a.m.	16	17	17
	Noon	23	24	24 Drying up.
	5 p.m.	20·5	24·5	25
" 20	7.30 a.m.	15	15·5	15 Heavy rain, early a.m.
	Noon	18	20·5	16
" 21	7.30 a.m.	13·5	13	19
	Noon	18	19	18
" 22		No	readings.	
" 23	5 p.m.	22	27	21
" 24	7.30 a.m.	21	18	17
	Noon	23	27	19
	5 p.m.	23·5	27	28
" 25	7.30 a.m.	17	18·5	22
	Noon	24·5	22	21
	5 p.m.	20	21	24
" 26	7.30 a.m.	15	15	16
	Noon	26	24	21
	5 p.m.	21	26	20
" 27	7.30 a.m.	18·5	19·5	23
	Noon	27	24·5	26
	5 p.m.	23·5	27	22
" 28	7.30 a.m.	12	14	20 Lake drying.
	Noon	25·5	22	26 "
	5 p.m.	19	23	26 "
" 29	7.30 a.m.	13	14·5	23 "
	Noon	29·5	22	21 "
	5 p.m.	16·5	20	22 "
" 30	7.30 a.m.	12	11	17 Cold wind and rain.
	Noon	14·5	15·5	23 Lake drying.
	5 p.m.	16·5	16	21 "

After this date, lake too dry for readings.

THE INTERMITTENT CRYSTAL

The intermittent crystal varied in depth from 3 to 6 inches in August, 1924. It is very clean and free from mud, although it is separated from the crystal bed by a mud layer. Around most of the lake the intermittent crystal also overlies the mud between the edge of the crystal bed and the shore.

The analyses of two samples of this top crystal taken from different parts of the lake are given below.

		Sample No. 1	Sample No. 2
Insoluble	Per cent	0·50	0·50
Na_2SO_4	"	97·64	96·09
NaCl	"	0·97	1·30
$NaHCO_3$	"	0·68	1·50
$CaSO_4$	"	......	trace
$MgSO_4$	"	......	0·24
Total	"	99·89	100·53

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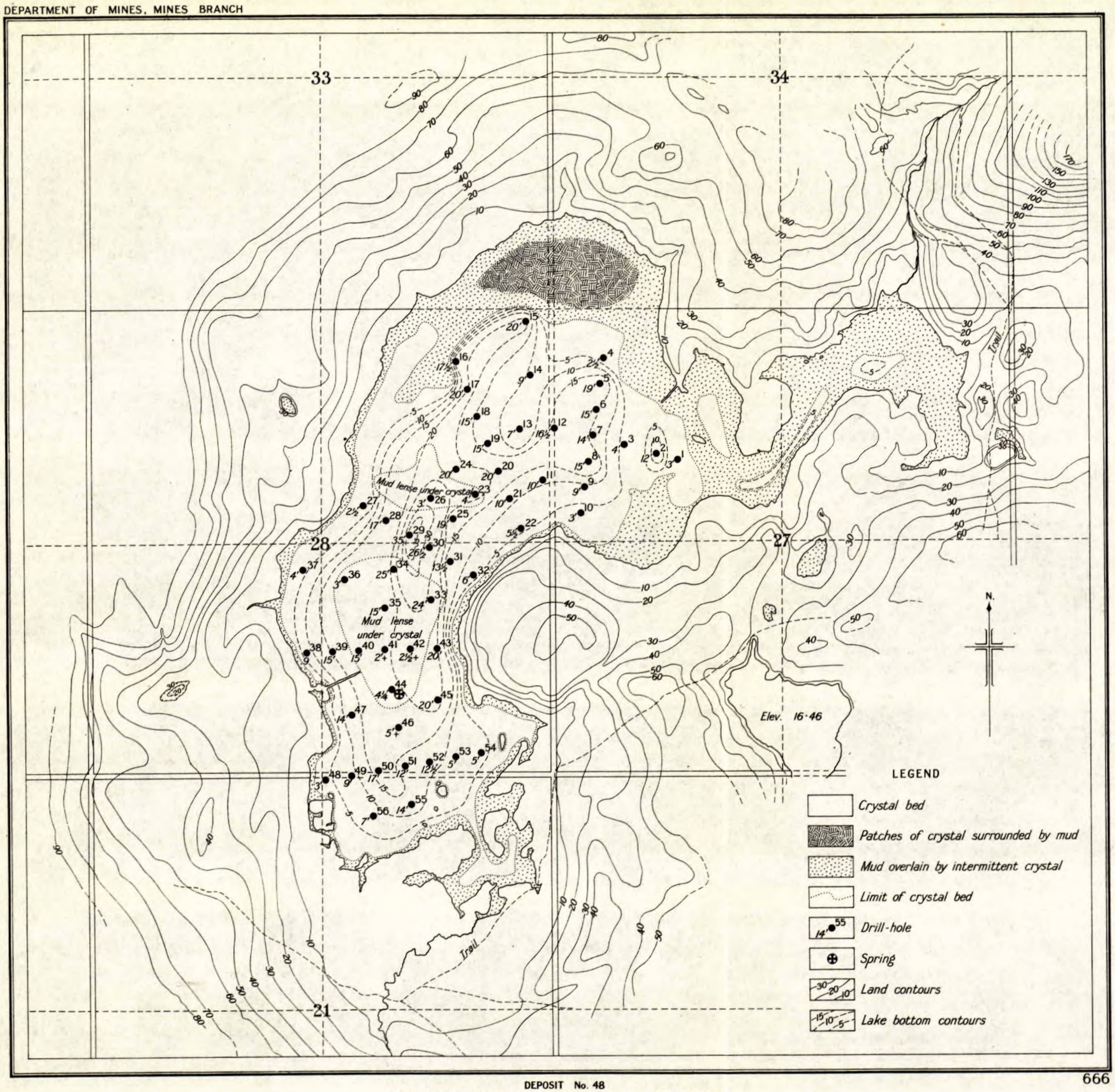

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DEPOSIT No. 48

ALSASK SODIUM SULPHATE DEPOSIT

Sec^s 21, 27, 28, 33, 34, Tp. 27, R. 28
West of the 3rd. Meridian
SASKATCHEWAN

Scale of Feet
500 0 500 1000 1500

Sample No. 1 was taken from the north end of the deposit in March, 1924; the deposit was covered with brine to a depth of 5 inches.

Sample No. 2 was taken from the middle of the deposit in August, 1924. There was 3 inches of brine on the deposit.

THE PERMANENT CRYSTAL

The permanent crystal bed covers an area of 345 acres. Fifty-six drill holes put down over the whole extent of the deposit showed that the crystal is compact and of good quality.

In the central part the crystal is exceptionally clear throughout its thickness of from 12 to 35 feet. The chemical analyses of every 5-foot section of the drill holes show that the crystal is very pure chemically.

In some parts of the deposit quite extensive lenses of mud exist both on top of and interbedded with the crystal. The most extensive of these mud lenses is in the southern central part of the déposit (see Map No. 664), where in drilling holes 33, 34, 35, 36, 40, 41, 42, and 44 a mud layer 3 to 8 feet in thickness was encountered beneath 2 to 3 feet of hard, permanent crystal. The mud is underlain by solid crystal from 7 to 19 feet thick. In the central part of the deposit is a smaller mud patch, which lies mainly on top of the crystal bed to a varying depth of from 3 to 9 feet. In all probability it extends under the crystal at the locations of drill holes 23 and 26, as the crystal at these holes was only 4 feet and 3 feet deep respectively, while all around this area the crystal was from 15 to 35 feet deep. In the vicinity of drill hole No. 14 there is an overburden of mud 2 to 3 feet in thickness.

These mud lenses would not greatly interfere with the working of the deposit, as the greater part of the crystal bed is comparatively free from mud.

Samples were taken from all cores for each 5 feet and averages taken of the analyses with the following results:—

—		0–5′	5′–10′	10′–15′	15′–20′	20′–25′	25′–30′	30′–35′
Insoluble	Per cent	10·44	8·65	7·38	7·29	7·76	5·74	6·39
NaCl	"	1·17	0·97	1·00	1·09	1·67	1·31	2·07
$NaHCO_3$	"	1·57	1·39	1·44	1·47	2·11	1·54	1·38
Na_2CO_3	"	0·72	0·55	0·64	0·59	0·82	0·35	0·20
$CaSO_4$	"	0·29	0·21	0·21	0·21	0·30	1·26	0·42
$MgSO_4$	"	0·63	0·41	0·35	0·30	0·36	0·48	0·36
Na_2SO_4	"	84·69	87·70	88·76	88·55	86·92	88·82	87·16
Totals	"	99·51	99·88	99·78	99·50	99·94	99·50	97·98

The estimated quantity of hydrous salts is approximately 6,986,000 tons.

Deposit No. 69—(Metiskow Lake)

LOCATION AND TRANSPORTATION

Seven miles southwest of the town of Metiskow, Alberta, is a deposit of hydrous sodium sulphate which differs in some respects from the usual type of deposit in western Canada.

The deposit occupies the bed of a crescent-shaped depression located in parts of secs. 11, 12, 13, 14, and 24, tp. 39, range 6, west of the 4th meridian.

The nearest shipping point is the town of Metiskow, situated on the Winnipeg-Edmonton branch of the Canadian Pacific railway. The seven miles of road between the lake and the railway is in poor condition, being both hilly and sandy.

TOPOGRAPHY

The lake occupies the lowest depression in a large drainage basin. The surrounding country is very hilly, and wooded with poplar and willow. The general elevation of the country above sea-level is from 2,200 to 2,300 feet. The elevation of the lake is 2,157 feet.

The banks are in general very steep, rising to a height of from 60 to 120 feet, except at the north end, from where a broad valley extends northeasterly, in which valley, 2½ miles distant, is a large shallow lake known as Sunken lake. The water in this lake is comparatively fresh.

There are many other lakes and sloughs around the lake, but all, save Sunken lake, are at a greater elevation. Three and a half miles to the west is Boucher lake (fresh water) with an elevation of 2,214 feet. Ribstone creek, flowing northeasterly to Battle river, flows through Boucher lake.

The survey of the outline of the lake is accurate, but the contours of the banks of the lake are only approximate as regards detail.

To the northeast of the lake are sand hills, and the soil is very sandy. Around most of the lake the soil is a boulder clay with small patches of stony boulder clay on some of the hillsides. The beaches are composed of sand. No exposures of the country rock were observed in the vicinity.

SPRINGS

There are no springs around the northern part of the lake, but at the southern end there are four fairly large freshwater springs, two of which are on the shore, the other two being at a considerable distance from the lake. The analyses of water from the two largest of these are given below.

	No. 1	No. 2
$NaCl$	660	330
$NaHCO_3$	230	320
$MgSO_4$	650	650
Na_2SO_4	....	1,880
Totals	1,540	3,180
Sp. Gr. at 15°C	1·000	1·000

(Results expressed in parts per million.)

BRINE SPRINGS

There were no brine springs observed in the lake, the turbid nature of the surface brine preventing the crystal bed from being seen. Near the middle of the N.E. ¼ of sec. 12, tp. 39, range 6, are two springs about 100 feet from shore. These are springs of the carbonate class, and there is formed around their orifice quite a deposit of tufa. The flow from the west spring had apparently ceased and the flow from the other was not large. The temperature was 7° C.

Farther east from the carbonate springs and also near the north shore is a place where the brine is over 5 feet deep. This may mark the location of a spring. In no other places than the above were evidences of springs in the lake bed noticed.

The sodium sulphate occurs as brine and permanent crystal.

THE BRINE

The brine was about 8 inches deep in September, 1924. It differs from the brine on the other deposits both in its large carbonate content and in its physical properties. In colour it is greenish yellow and is opaque.

According to farmers who live within sight of the lake, the brine never crystallizes solidly until late in the winter, when it freezes over. Until recently there was a depth of several feet of brine on the lake. Certainly the lake has shallowed very considerably during the past few years, as now there is a sandy beach from 100 to 300 feet in width between the present water level and the former shore.

The analysis of the brine is given below.

NaCl	15,480
Na_2CO_3	122,000
$MgSO_4$	8,100
Na_2SO_4	112,000
Total	257,580
Sp. Gr. at 15° C	1·212

(Results expressed in parts per million).

Baumé readings on the brine were taken from September 9 to September 24, 1924, inclusive, as follows:—

Baumé Readings on Brine—Metiskow (Deposit No. 69)

Date	Time	Temp. air	Temp. brine	Baumé
		°F.	°F.	°
Sept. 9	5 p.m.	55	59	25
“ 10	7.30 a.m.	52	50	24
“ 10	Noon	58	55	22
“ 10	5 p.m.	57	56	21
“ 11	7.30 a.m.	44	45	21
“ 11	Noon	59	58	21
“ 11	5 p.m.	No reading		
“ 12	7.30 a.m.	52	50	20
“ 12	Noon	69	72	22
“ 12	5 p.m.	62	68	23
“ 13	7.30 a.m.	46	52	22
“ 13	Noon			
“ 13	5 p.m.	62	66	23
“ 14		No readings		
“ 15	7.30 a.m	54	50	25
“ 15	Noon	72	74	23
“ 15	5 p.m.	70	76	23
“ 16	7.30 a.m.	58	52	24
“ 16	Noon	80	74	25

Baumé Readings on Brine—Metiskow (Deposit No. 69)—Concluded

Date	Time	Temp. air	Temp. brine	Baumé
		°F.	°F.	°
Sept. 16	5 p.m.	72	78	23
“ 17	7.30 a.m.	56	52	24
“ 17	Noon	73	70	23
“ 17	5 p.m.	69	72	25
“ 18	7.30 a.m.	57	54	25
“ 18	Noon	60	56	16
“ 18	5 p.m.	57	55	21
	(5 a.m.—12.30 p.m. heavy rain)			
“ 19	7.30 a.m.	40	44	23
“ 19	Noon	44	46	23
“ 19	5 p.m.	46	47	23
“ 20	7.30 a.m.	39	42	20
“ 20	Noon	45	47	21
“ 20	5 p.m.	50	50	21
	Rain from 5.30 p.m. till 5 a.m. Light rain			
“ 21	7.30 a.m.	44	45	20 (frost during night)
“ 21	Noon	54	56	20
“ 21	5 p.m.	58	59	19
“ 22	7.30 a.m.	44	45	20
“ 22	Noon	No reading		
“ 22	5 p.m.	68	58	21
“ 23	7.30 a.m.	44	46	21
“ 23	Noon	No reading		
“ 23	5 p.m.	58	54	25
“ 24	7.30 a.m.	42	42	21
“ 24	Noon	56	57	21·50

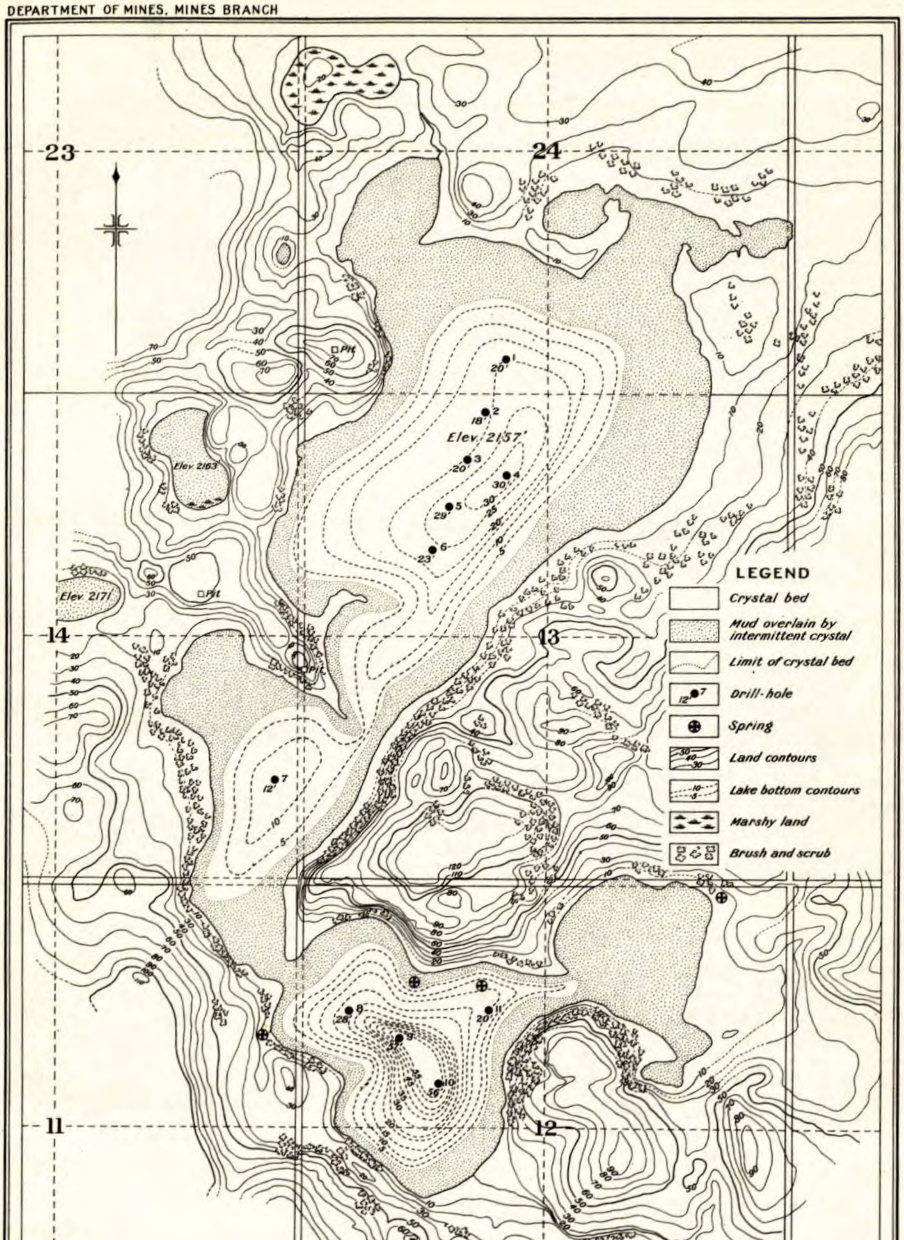
THE CRYSTAL BED

The crystal bed is being built up very rapidly as the lake annually decreases in depth and apparently there is no intermittent crystal, unless it is formed late in the autumn or in the early winter. There was no sign of intermittent crystal in the Metiskow lake on September 25, 1924.

The permanent crystal bed extends over the major part of the lake as may be seen by referring to the map. The crystal bed, however, is not solid crystal from top to bottom, but is in a more or less unconsolidated state. The deposit in the main part of the lake bed consists of alternate layers of pure crystal and of mud and crystal to a depth of 20 to 30 feet. In the extreme southern part of the deposit, however, 57 feet of crystal and mud was drilled through in two places. The first 20 feet was composed of layers of crystal and mud, but below this was hard compact crystal 37 feet thick.

To generalize, a typical hole through the deposit in the northern end of the lake would show 2½ to 3 feet of soft crystal, this was made up of a hard surface crust 3 inches thick underlain by 4 inches of pure slushy crystal, then alternate hard and soft crystal layers to 2½ or 3 feet, with some mud intermixed (this crystal shallows out towards the shore); 3 to 6 feet of mud and crystal, and then alternate thin layers of crystal and thick layers of mud to 18 feet, the crystal layers being from 2 to 6 inches thick and the mud layers from 1 to 2 feet thick. At a depth of 18 feet a layer of very hard consolidated mud almost approaching a shale in degree of hardness is encountered. The hard mud varies from 6 inches to 1 foot in thickness.

DEPARTMENT OF MINES, MINES BRANCH



DEPOSIT No 69

METISKOW SODIUM SULPHATE DEPOSIT

Secs 11, 12, 13, 14 and 24. Tp. 39. R. 6

West of the 4th. Meridian

ALBERTA

Scale of Feet

500 0 500 1000 1500 2000

Under this layer, which seems to extend over the whole lake bed, is muddy consolidated crystal to a variable depth, 10 feet being the greatest depth found in the northern part of the lake, whereas 37 feet of solid crystal was discovered under this mud in the southern part of the lake.

In the soft mud between the hard thin layers are numerous crystals, some of almost perfect form, others of irregular shape, but all glassy-clear and free from included mud.

Considering the deposit from top to bottom, possibly the crystal would not exceed more than 50 per cent of the whole. The samples obtained by drilling do not give an exact idea of the proportion between mud and crystal. The mud between the crystal layers being soft would not remain in the core barrel and hence the samples as obtained for analysis do not show so great a proportion of mud (or insoluble matter) as is probably present. The crystal bed as outlined on the map is that part of the deposit where the layers of crystal could be felt beneath the mud.

In drilling, the drill could be moved only to certain places on the crystal bed, owing to the softness of the top crystal. The top crystal, although 2½ feet thick in the centre of the deposit, shallowed out to a depth of only a few inches near the shore. Hence, the drill had to be kept in the centre of the deposit. Owing to the extremely muddy nature of the crystal bed, which will possibly prevent its ever being mined in competition with the purer deposits of Saskatchewan, only the number of drill holes required to give an idea of the extent of the deposit were put down. The location of the holes may be seen by referring to the map.

In estimating the tonnage of the deposit, the cubic content of the crystal bed was determined and then halved on the supposition that 50 per cent was crystal and 50 per cent was mud. The estimate thus arrived at was approximately 5,150,000 tons.

The averages of all analyses of samples taken from the deposit follow.

Averages of all Analyses of Samples from Deposit No. 69

—		0-5′	5′-10′	10′-15′	15′-20′	20′-25′	25′-30′	30′-35′	35′-40′	40′-45′	45′-50′	50′-55′
Insoluble.......	Per cent	13·91	22·03	21·77	23·79	25·72	7·99	12·85	6·83	11·88	5·96	3·46
NaCl..........	"	0·78	0·77	1·05	0·78	0·67	0·37	0·14	0·18	0·34	0·08	0·50
$NaHCO_3$.......	"	4·60	3·72	4·19	2·90	2·75	2·29	3·06	1·77	2·44	1·40	1·16
Na_2CO_3........	"	4·69	3·24	3·80	2·21	2·18	1·90	3·10	1·00	1·05	1·80	0·60
$CaSO_4$..........	"	0·11	0·08	0·15	0·19	0·13	0·07	......	......	0·22	0·21	0·46
$MgSO_4$.........	"	0·27	0·30	0·33	0·45	0·29	0·29	0·24	0·27	0·23	0·17	0·18
Na_2SO_4.........	"	74·63	69·71	65·37	67·48	65·80	86·96	80·74	89·86	83·69	90·75	94·23
Totals......	"	98·99	99·85	96·66	97·80	97·54	99·87	100·13	99·91	99·85	100·37	100·59

Deposit No. 82—(Ingebright Lake No. 2)

LOCATION AND TRANSPORTATION

The lake is situated in parts of secs. 4 and 9, tp. 17, range 25, west of the 3rd meridian. The town of Leader, on the Empress branch of the Canadian Pacific railway, is the nearest shipping point, being about 34 miles by road.

TOPOGRAPHY

The general topography of the vicinity is similar to that of Ingebright No. 1.

The lake occupies a part of what appears to be the drift-filled channel of a pre-glacial valley. The presence of a sink hole in the bed of this deposit, the difference in elevation between the bottom of which and the top of the bank in the immediate vicinity is over 130 feet, further strengthens this theory. The sink hole is oval-shaped in plan and is of the same type as the two large sink holes discovered in deposit No. 9. It is located in the northern end of the deposit just north of the low, marshy point that juts out from the western shore. The shape and extent are shown on the map by contours.

The basin is about 8,000 feet long and relatively narrow, being only 1,500 feet wide at its widest place. In the southern part are 4 small islands, on the larger of which is a freshwater spring (Spring No. 1). The banks of the southern part of the basin above the crystal are gently sloping and the soil is sandy and almost free from boulders. In the northern part, however, the banks rise steeply to a height of 50 feet above the crystal, and stony boulder clay is predominant on the eastern shore, but not on the western slopes where the soil is sandy. At either end of the basin is a valley connecting it with other basin deposits of a similar nature, but there is no regular drainage channel in these valleys, they serve merely as overflow channels in wet weather. The deposit cannot have more than about 5 inches of water on it at any time, as there is only that difference in elevation between the filled basin level and the drainage level of the valley leaving the deposit at its southern end.

SPRINGS AND DRAINAGE

The drainage basin is relatively long and narrow and extends for a mile or so in width along both sides of the deposit. There is practically no drainage received from the north; the only water entering being from the side slopes. The surface of the deposit is about 100 feet below the general level of the hills on either side.

There are three springs along the margin: one on the broad, low point on the west shore opposite the narrowest part of the deposit, and two on the east shore about the middle of the deposit. There is also a spring of considerable size on the western extremity of the largest island.

In the crystal bed only one spring was observed, and that was located 100 feet due south of hole No. 5. The flow from this spring, which is a freshwater spring, seemed almost negligible, as it never overflowed on the crystal surface, but there was a hole, 15 feet in diameter, from top to bottom of the crystal bed, which at this place was 80 feet thick. This "chimney" increases in diameter in depth and was encountered at a depth of 50 to 70 feet when drilling hole No. 5, 100 feet distant. It appears to be a true solution cavity in the crystal and to be filled with nothing but water or very thin mud.

All of the marginal springs around are seepages, having no definite orifice visible. This is especially true of the spring (No. 4) on the low, flat point on the west shore of the deposit. No sample was obtained from

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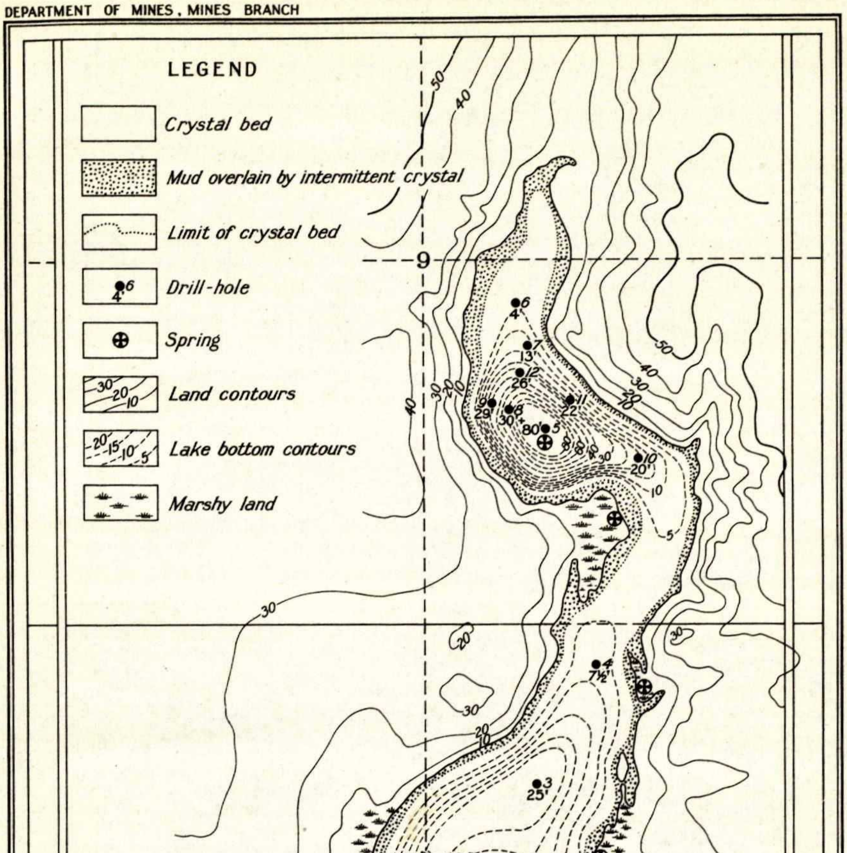


DEPOSIT No. 82

668

INGEBRIGHT SODIUM SULPHATE DEPOSIT No. 2

Tp. 17, R. 25, Sec. 4 and 9

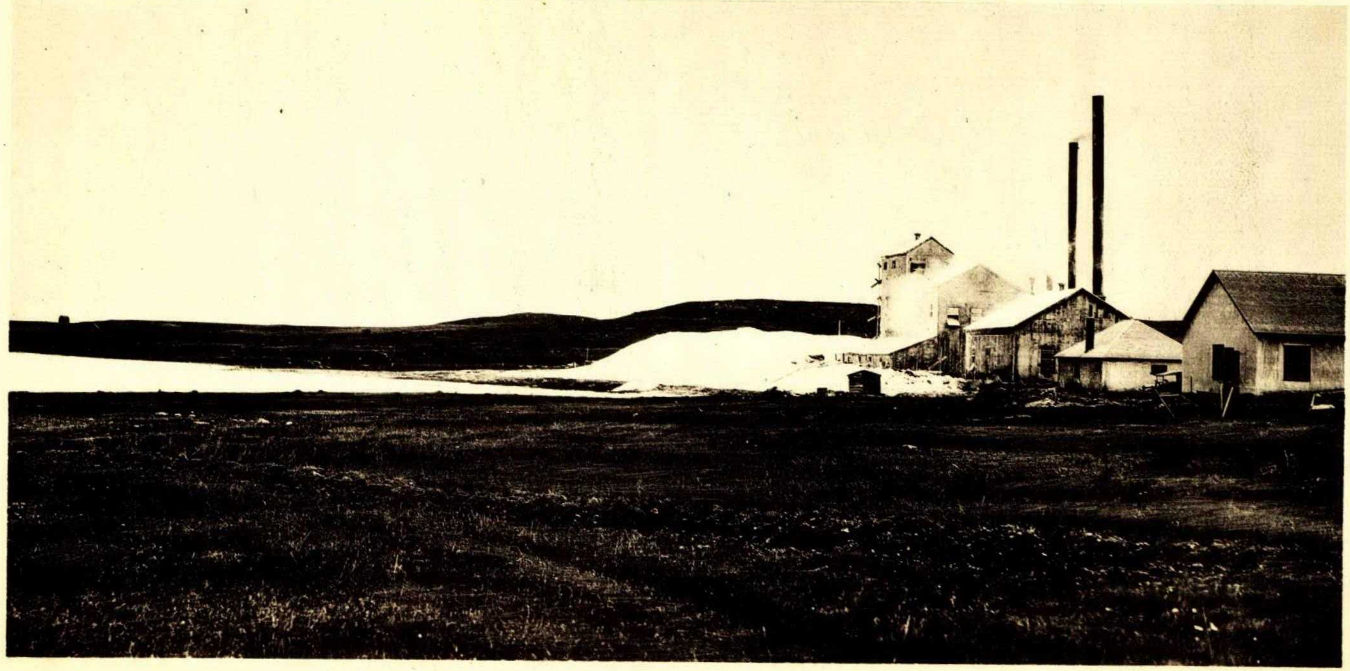
West of the 3rd. Meridian

SASKATCHEWAN

Scale of Feet

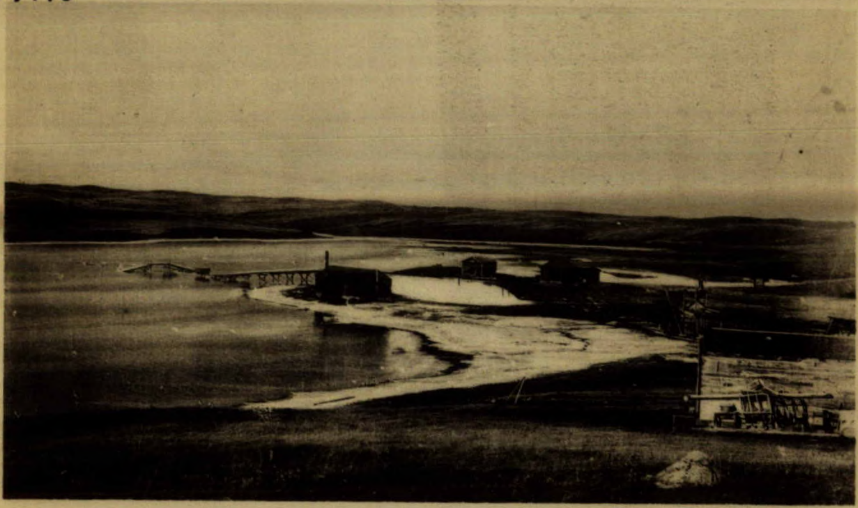
500 0 500 1000 1500

#2656



Plant of Bishopric and Lent Co., showing stock pile of salts in the foreground, Frederick lake, Sask.

#1715



A. Plant and lake at Fusilier, Sask.

#1716

B. General view looking north, Snakehole lake, Sask.

this spring, as in no place was there any decided flow to the water and it appeared to be somewhat stagnant.

The analyses of the water of the two springs (Nos. 1 and 2) from which samples were obtained, are given below:—

Constituents	Spring No. 1	Spring No. 2
Na_2SO_4	4,150	2,540
$NaCl$	590	590
$NaHCO_3$	535	......
$Mg(HCO_3)_2$	488	670
$MgSO_4$	......	1,320
$Ca(HCO_3)_2$	284	810
Totals	6,047	5,930
Sp. Gr. at 15°C	1·005	1·004

(Results expressed in parts per million.)

The temperature of the springs was 5° C.; this temperature prevailed on a cold day when there was about 3 inches of snow on the ground.

THE SODIUM SULPHATE

The sodium sulphate crystal occurs as a permanent crystal bed of varying thickness. The crystal is very hard, compact and quite free from mud strata and included mud. It is covered on the surface with a layer of black mud varying in thickness from 10 inches to over 2 feet.

The permanent crystal is the only commercial form of sodium sulphate, the brine and intermittent crystal occurring only in very limited quantities, since if the brine exceeds 5 inches in depth it runs out of the south end of the basin by the valley previously mentioned; thus, with the exception of an inch or two of clear brine on top of the mud there is no brine present. In the late summer a thin deposit of intermittent crystal, an inch or less in thickness, is deposited, which readily dissolves in wet weather.

The crystal bed almost fills the basin, extending to within about 50 feet of the shoreline, except at the ends of the basin, where it does not completely fill the narrow coves. The intervening space between the crystal edge and the shore is filled with a black mud reeking of hydrogen sulphide. It also underlies the crystal bed in its entirety and forms a cushion between the crystal and the boulder clay. In the southern end of the basin the mud underlying the crystal was in the nature of a soft, calcareous ooze, through which the drill rods, after the bottom of the crystal had been penetrated, would sink with their own weight until a hard, compact stratum was reached. In the northern part of the basin the oozy nature of the mud was not so pronounced.

The twelve drill holes put down showed that the crystal bed varied greatly in depth. In the southern part between the islands and the narrows, the depth of crystal varied between 7 and 25 feet in the places tested. South of the islands the crystal was not tested on account of the great depth of sticky mud on top of the bed. The mud was not firm enough to hold up the drill and was too sticky to allow the passage of the drill through it. In the northern parts, the crystal bed varied in depth from 4 to 80 feet. The depth of 80 feet was found only in what appears to be an oval-shaped sink hole. An idea of the location, shape, and extent of this sink hole can best be obtained from the map of the deposit. On the map the contours of the crystal bed are shown by means of dotted lines. The datum level is the top of the crystal bed (beneath the mud). The crystal contour interval is 5 feet from 0 to 30 feet, and then a 10-foot interval is used from 30 feet to 80 feet.

Samples were taken from this deposit and analysed, and from these analyses, averages for each 5 feet in depth were obtained as follows:—

Averages of all Analyses of Samples from Deposit No. 82.

—	0′-5′	5′-10′	10′-15′	15′-20′	20′-25′	25′-30′	30′-35′	35′-40′	40′-45′	45′-50′	70′-75′	75′-80′
Insoluble per cent	9·87	8·40	4·44	9·31	8·01	16·30	11·52	8·53	4·47	0·77	5·17	5·53
$NaCl$.... "	0·31	0·32	0·28	0·38	0·43	0·25	0·16	0·79	0·41	0·28	0·38	0·38
$NaHCO_3$ "	0·79	0·81	0·67	0·67	0·69	0·83	1·00	0·59	0·59	0·67	0·51	0·33
Na_2CO_3.. "	0·09	0·03	0·03	0·02	0·03	......	......	......	......	0·10	0·10	0·30
$CaSO_4$... "	0·73	1·13	0·87	1·32	1·60	1·75	3·00	4·56	4·15	1·29	1·02	0·88
$MgSO_4$... "	1·26	1·32	1·17	0·69	0·66	0·54	0·51	1·08	0·76	0·76	0·65	0·65
Na_2SO_4.. "	86·33	87·43	92·53	87·37	87·79	79·49	82·67	84·35	89·71	95·74	92·50	91·75
Totals.......	99·38	99·44	99·99	99·76	99·21	99·16	98·86	99·90	100·09	99·61	100·33	99·82

The quantity of hydrous salts is estimated to be 2,800,000 tons.

SUMMARY AND CONCLUSIONS

The production of sodium sulphate from the natural deposits of western Canada is still in its infancy. There is a fairly steady market for the material in the anhydrous form in the pulp and paper industry, but the main consuming centres are in eastern Canada, and the present high freight rates from the deposits to the markets are an important factor. Very little of the crude material, as such, can be marketed, and this necessitates the installation of refining plants. The product has to compete against that produced as a by-product from acid manufacture, but there are hopes that simple refining methods and lower freight rates will eventually benefit the natural product. Already great strides have been made in perfecting cheap and economical dehydrating processes, and the products produced are of a high grade.

The resources of sodium and magnesium sulphate of western Canada are among the few resources of which estimates of reserve material can be obtained with any degree of accuracy. The deposits of these materials are confined to well-defined areas, and it is only a matter of investigation to determine the tonnages. It should be observed in this connexion that, while this report gives only the detailed descriptions of those deposits that were investigated by the Mines Branch, it should not be supposed that they are the only deposits which have economic value. Many others were visited, and in a number of them crystal beds were noted, but it was not feasible to drill them all and only a few representative ones were drilled. Likewise, it is obvious that these other deposits could not be referred to in a report of this length without making it too bulky.

The work carried on by the Mines Branch on these deposits in western Canada has proven up the presence of hydrous salts, mainly sodium sulphate, to the extent of about one hundred and fifteen million tons (115,000,000).

It can, therefore, readily be seen that, although it may be a number of years before these deposits are worked to their fullest extent, Canada has in them a resource of great potential value.

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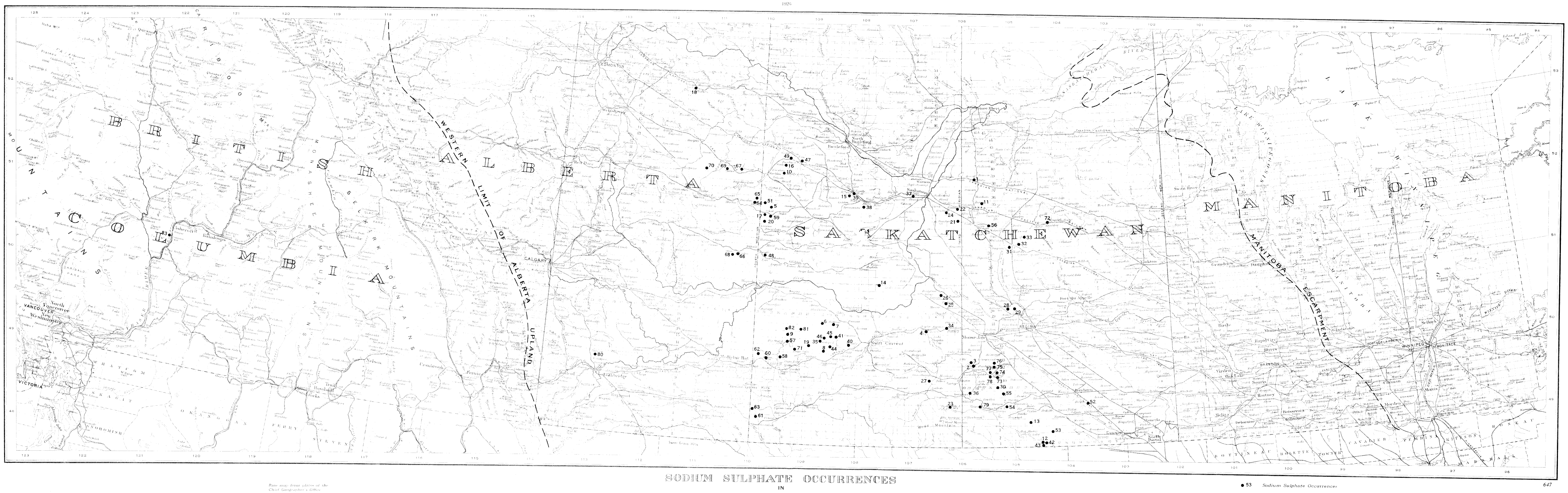
CANADA
DEPARTMENT OF MINES
Hon. Charles Stewart, Minister; Charles Camsell, Deputy Minister

MINES BRANCH
John McLeish, Director
1926



Base map from plates of the
Chief Geographer's Office
Department of the Interior

SODIUM SULPHATE OCCURRENCES
IN
WESTERN CANADA

Scale:- 35 miles to 1 inch
25 0 25 50

● 53 *Sodium Sulphate Occurrences*

Numbers on map correspond to numbers used in text.

Accompanying report No. 646 "Sodium Sulphate Deposits in western Canada" by L. H. Cole.

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