BRITISH COLUMBIA DEPARTMENT OF MINES
Hon. W. J. ASSELSTINE, *Minister* JOHN F. WALKER, *Deputy Minister*

BULLETIN No. 4

Saline and Hydromagnesite Deposits of British Columbia

by

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Introduction

Deposits of sodium and magnesium salts occur in various parts of the interior of British Columbia. Most of them have been known for many years and some commercially exploited on a small scale. The more important of these deposits were investigated by the writer during the summer and autumn of 1937. The present report brings together information based on this field work as well as previously published reports.

The deposits discussed herein are restricted to those of sodium carbonate, sodium sulphate, magnesium sulphate, and hydromagnesite. The last, although not commonly considered in the same category as the others, is sufficiently allied in origin to merit its inclusion in the present work.

Many compounds, related to the above are found in nature. Most important are common salt, potassium salts, salts of boron, marl, and gypsite. The first three are not known to occur in commercial quantities in British Columbia; the last two, although relatively abundant, have insufficient commercial value at present to merit their separate inclusion.

CHAPTER I

Occurrences of Sodium and Magnesium Salts in British Columbia

Saline Deposits

Small undrained lakes containing concentrated solutions of sodium and magnesium salts, are found in the Clinton, Chilcotin, Ashcroft, Kamloops and Okanagan areas. Three fairly distinct types of brine occur in these: the first is composed largely of sodium carbonate, the second contains both magnesium and sodium carbonate, and the third is composed predominantly of sodium sulphate. Lakes in which sodium carbonate is the important constituent rarely contain appreciable amounts of other constituents; the others, however, are more variable in composition.

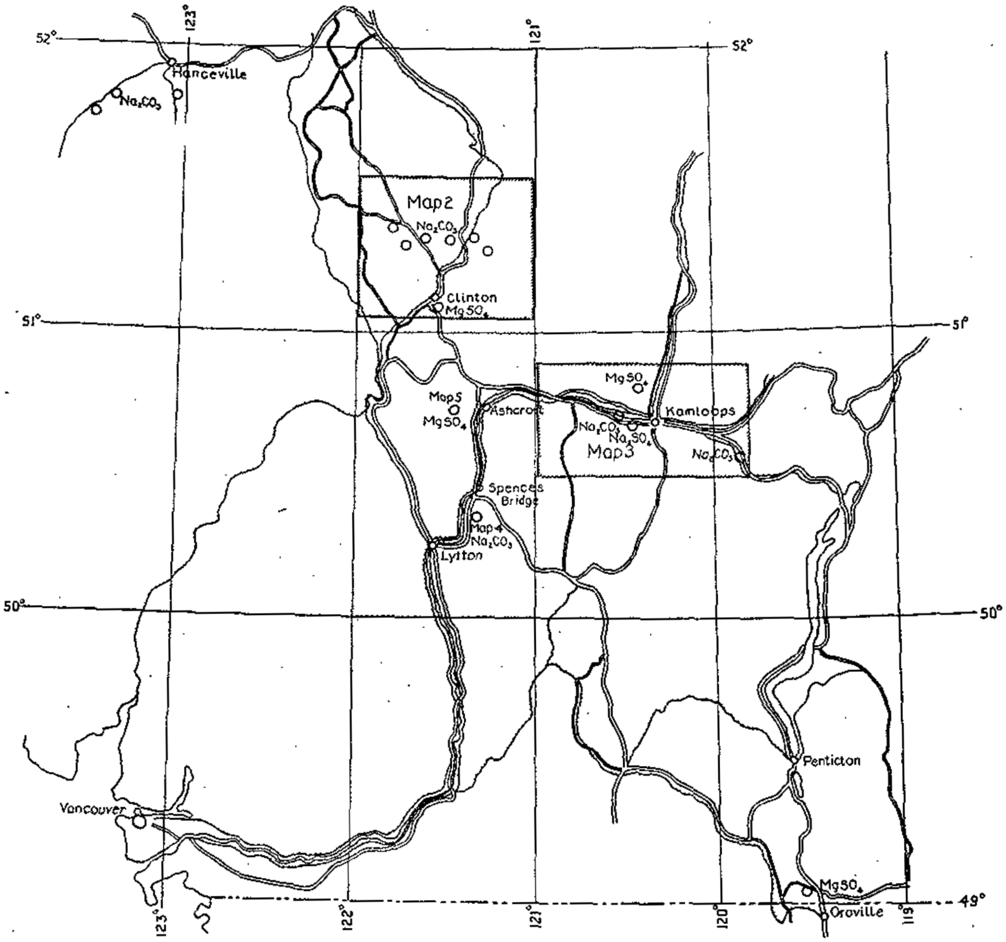
Sodium Carbonate Lakes

The best known sodium carbonate lakes in British Columbia are those of the Green Timber Plateau, north of Clinton. Several of these have yielded sal soda commercially for a number of years, and plants were erected at three in unsuccessful attempts to produce soda ash. Shipments of sal soda have likewise been made from a lake near Cherry Creek, 12 miles west of Kamloops. Unexploited lakes containing sodium carbonate brine lie along the Kamloops-Vernon road, east of the Thompson River and 7 miles south of Spences Bridge, and near the Nemaia valley road south of Hanceville.

Green Timber Plateau (See Map 2)

The Green Timber Plateau is bounded by the Marble Mountains on the south-west, the Fraser River on the west, Lac La Hache valley on the north-east, and the Bonaparte River on the south-east. It is flat or gently-rolling with an average elevation of 3700 feet, mantled with glacial drift, and forested largely with jackpine. Basaltic lava flows underlie the area but outcrops are rare, the type exposure being in the Chasm.

The climate of the region is severe with a range of temperature from 90 degrees or more in summer to a minimum of 30 to 40 degrees below zero in winter. Precipitation averages



MAP 1. (Key-map.)
Showing location of known saline deposits in British Columbia.

9 to 12 inches, with 3 or 4 inches represented by snow. For May, June, July, August and September, precipitation totals 5 to 6 inches; mean temperatures for these months range from 47 to 60 degrees.

Drainage lines are few, poorly developed and even non-existent over much of the area. Shallow undrained lakes abound, ranging in size from pools a few yards in diameter to fairly large bodies of water such as Green Lake and Meadow Lake. Nearly all contain alkaline brines of various degrees of concentration; in some, sodium carbonate is the only important constituent, in others, notably the larger lakes, minor amounts of different salts are present.

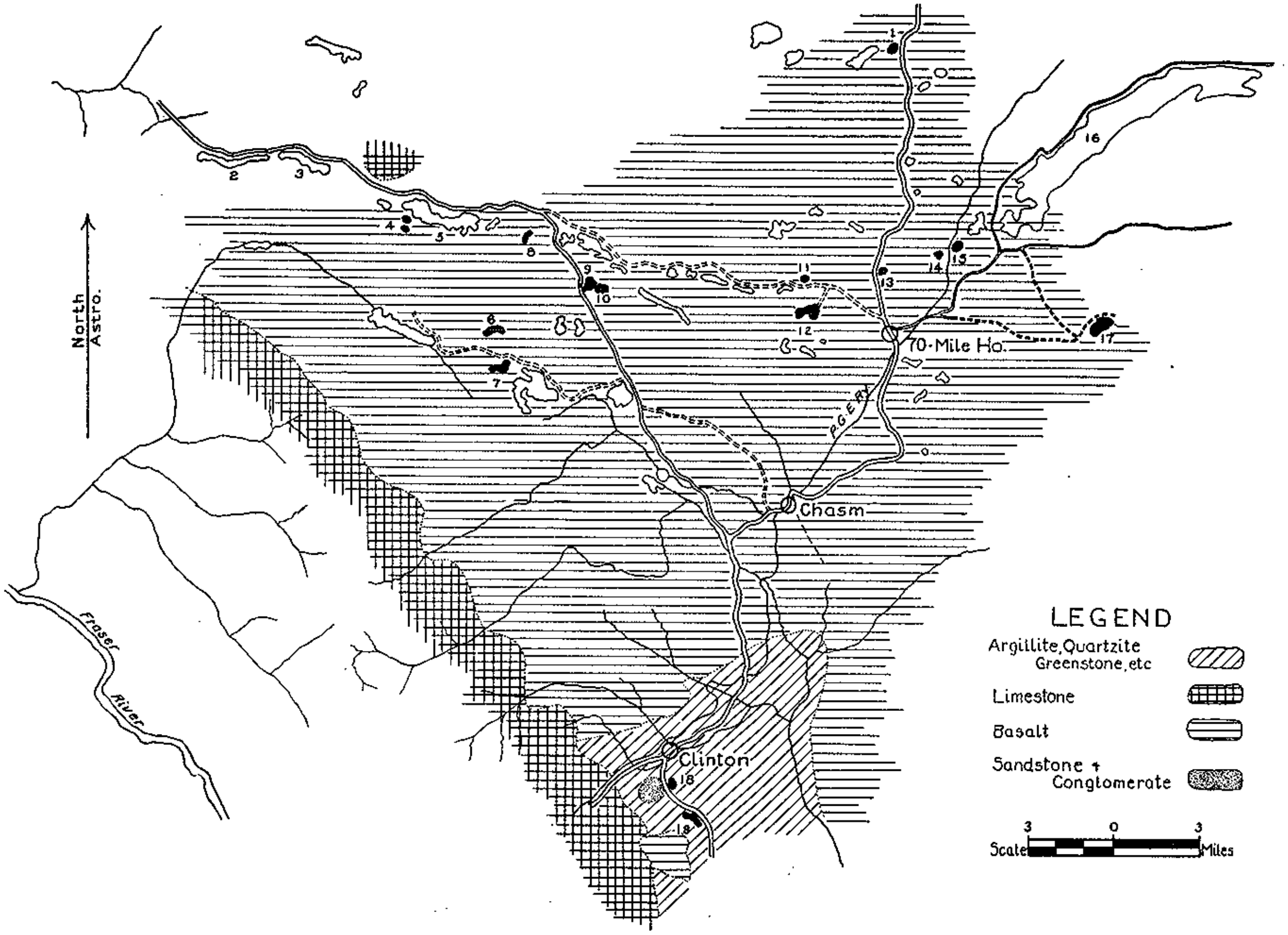
The writer spent several weeks in the autumn of 1937 examining the alkaline lakes of the Green Timber Plateau. Re-examinations were made of a number of lakes which have been, or are being worked and about which considerable information has been published. Others showing evidence of alkaline brines were sampled. Many of the less accessible lakes were not visited; some of these undoubtedly contain brines comparable with the more dilute brines analysed. On the other hand, the area has been carefully searched for lakes of possible commercial value by local inhabitants and it is unlikely that any of present economic interest have been overlooked.

General Description of Soda Lakes

The soda lakes under discussion are essentially similar with the exception of Last Chance Lake (Map 2, No. 10). All occupy gentle depressions in drift representing very restricted drainage basins, and are small, shallow, and without apparent outlets. The depth of brine varies in general with the season of the year, being greatest in the spring after run-off and least in the autumn; certain lakes are completely dry by the end of the summer. All lakes have, apparently, contained considerably more water at one time than they do at present.

Lake beds are composed of soft black mud several feet deep. The same mud, usually covered with a thin white efflorescence of dried sodium carbonate, surrounds the shorelines to a width of 20 feet or more. In most cases the forest edge extends practically to the mud line.

Apart from a species of small red crustacean, the lakes are apparently devoid of life. A most interesting feature, however, is the presence of swarms of black flies around the water line of the more concentrated lakes. These are usually



MAP 2.
Showing location of Soda Lakes on Green Timber Plateau.
Geology from Kamloops Sheet, Geological Survey of Canada, G. M. Dawson.

so numerous as to form a black ring around the lake, a foot or more in width. The flies are not found associated with dilute brines and hence are at least an indication of a high degree of soda concentration. A reddish-purple, spiky plant, commonly called the "salt plant," grows in the mud surrounding the lakes. Its ashes were a principal source of soda ash in Europe before the invention of the Leblanc process.

In general the various lake brines are dilute to concentrated solutions of sodium carbonate containing minor amounts of other salts. The soda lakes proper, however, contain brines with specific gravities ranging from 1.048 to 1.125, in which sodium carbonate constitutes 92 to 95 per cent. of total solids. In certain of these the concentration of sodium carbonate by the end of the dry season becomes such that the brines are super-saturated in respect to winter temperatures, and crystals of natron ($Na_2CO_3.10H_2O$) are precipitated.

In shallower lakes of high concentration, natron is deposited over the entire lake bed, forming a clean solid layer up to 9 inches thick of interlocking crystals. In lakes of lower concentration large branching discrete crystals may form, whereas in deeper lakes exposed to a prevailing wind, a layer of natron is commonly deposited only on the windward shore. Under normal conditions the natron, known as winter-crystal, is re-dissolved in the spring with increase in temperature and influx of more water. If, however, the deposit is buried or covered with mud so that dissolution is inhibited, at least a part may remain through the summer to be augmented during the following winter. In this way a bed of permanent crystal may accumulate.

In general, sodium carbonate is present in the soda lakes either in solution, or as winter crystal, or permanent crystal. Only one lake (Last Chance Lake, Map 2, No. 10) on the Green Timber Plateau is known to contain a deposit of permanent crystal, although another (Goodenough Lake, Map 2, No. 4) has a high proportion of disseminated crystals in its muddy bed. In the autumn of 1937 ten lakes contained brines of specific gravity greater than 1.040, but in only three of these (Map 2, Nos. 7, 11 and 12) did crystals form during the winters of 1936-37 and 1937-38. Of the others examined six had specific gravities greater than 1.010, the remaining seven ranging down to 1.002.

Eighty-Three Mile Lake (Map 2, No. 1)

Eighty-Three Mile Lake lies several hundred feet west of the Cariboo Highway near 83 mile. In October, 1937, it covered approximately 30 acres and contained brine to a maximum depth of about 2 feet. A brine sample had the following composition:

(1) Specific Gravity at 16 degrees C. - 1.0485.
Per cent. solids - 4.85%.

Composition of Solids

(2) Na_2CO_3 - 97.2%
$NaCl$ - 2.8
Na_2SO_4 - trace
$MgSO_4$ - trace
$CaSO_4$ - trace

(1) Chief Assayer, Victoria.

(2) All carbonate and bicarbonate expressed as carbonate.

No winter-crystal was forming at the time of examination, and it is understood that none has occurred in recent years.

A sample of brine obtained in the autumn of 1924 (Ref. 6, p. 95) had a specific gravity of 1.040 at 22 deg. C., equivalent to 1.0412 at 16 deg. C.

Assuming an average depth of 6 inches to one foot, the amount of sodium carbonate in solution would be from 1000 to 2000 tons.

Goodenough and Safety Lake (Map 2, No. 4)

Goodenough Lake lies about 500 feet, and Safety Lake about 1400 feet south of the west end of Meadow Lake. Both were completely dry in October, 1937, and it is understood that they have been for several years. In each lake the surface was covered with a white encrustation from one-quarter to 1 inch thick. The area of the encrustation in Goodenough Lake was roughly 16 acres, and that of Safety Lake 5 acres.

The extreme softness of the lake beds made detailed investigation impossible. However, a pit about 40 feet from the shore at the northern end of Goodenough Lake showed the surface efflorescence to be underlain by 8 inches of greenish muddy material containing 50 to 75 per cent. natron crystals, beneath which was black oozy mud. About 1 inch of similar crystal-charged material was noted under the white surface layer of Safety Lake.

The following description of Goodenough Lake in October, 1924, is quoted from a report by Goudge, Department of Mines and Resources, Ottawa (Ref. 6, p. 86):

> "In October, 1924, there was a deposit of pure winter crystal, averaging about three inches in thickness, covering 14 acres of the bed of Goodenough Lake. This bed was composed of interlocking crystals of natron and was hard and compact. It rested directly on the level mud bottom of the lake. On top of the crystal was a thin film of brine one-quarter to 1 inch deep. In the western part of the lake there were several circular open spaces 2 to 8 inches in diameter in the crystal bed. These openings were fringed with perfectly-formed natron crystals and appeared to mark spring orifices but no flow was observed.
>
> "The mud beneath the winter crystal is, to a depth of 2 1/2 feet, impregnated with natron crystals. These crystals which occur individually, and the majority of which are very perfect in outline, comprise about 75 per cent. of the mixture of mud and crystal. These crystals do not dissolve with the winter crystal in the spring but remain as a permanent deposit of very muddy crystal."

The following analyses are quoted from the same report (Ref. 6, p. 87):

Analyses of Crystal, Goodenough Lake

	Winter Crystal or Natron from Surface	Muddy Permanent Crystal
Water Insoluble	0.44%	48.88%
Organic Matter	----	6.47
$MgCO_3$	0.35	trace
$MgSO_4$	----	1.07
$CaCO_3$	----	----
$CaSO_4$	----	0.39
Na_2SO_4	0.05	----
NaCl	0.81	----
$NaHCO_3$	0.70	----
Na_2CO_3	97.65	43.19

(These are recalculated on a 100 per cent. water free basis.)

Hypothetical Composition of Residual Brine

Specific Gravity at 22 degrees C - 1.108
Total per cent. solids - 13.35%

KCl - 6.54%
$Mg(HCO_3)_2$ - 2.08
Na_2SO_4 - 6.87
NaCl - 3.19
$NaHCO_3$ - 14.16
Na_2CO_3 - 67.16

Goudge describes Safety Lake as follows: (Ref. 6, p.88).

> "Safety Lake--is a small lake having an area of only 4 1/2 acres at water level (October 1924).
>
> "When the lake was examined there was no crystal of any kind visible, but it contained brine to an average depth of 6 inches. The chemical analysis of this brine is shown below.
>
> "The mud beneath the brine was very soft and deep."

Hypothetical Composition, Safety Lake Brine

Specific Gravity at 22 degrees C. - 1.091
Total per cent. solids 9.57%

KCl - 3.97%
$Mg\ (HCO_3)_2$ - 4.23
Na_2SO_4 - 0.39
NaCl - 3.96
$NaHCO_3$ - 4.94
Na_2CO_3 - 82.51

Hoffmann mentions the occurrence of natron in Goodenough Lake in the Geological Survey of Canada Annual Report for 1898 (Ref. 8, p. 11 R). The following is excerpted from his description:

> "The deposit at the time of its examination--the close of the dry season--was found to cover the whole of the bottom of the lake, which has an area of not less than twenty acres, up to 8 or 10 feet of its margin, and to have a fairly uniform thickness of from 7 1/2 to 8 1/2 inches, but to thin down at the edges to about 2 inches. It was covered by about 3 inches of water, but in the spring and early summer, after

the melting of the snow, it is said to be increased to a depth of some three feet more or less. The deposit would, it has been estimated, represent approximately twenty thousand tons of material."

The following analysis was made of fresh winter crystals:

Na_2CO_3	-	35.54%
$NaHCO_3$	-	1.34
Na_2SO_4	-	0.14
$NaCl$	-	0.02
H_2O	-	62.89

Hoffmann further refers to a dark greenish-grey stratum upon which the crystal bed rested and notes the numerous natron crystals distributed through it. The lake brine had a specific gravity of 1.1085 at 15.5 degrees C.

Reinecke (Ref. 9, p. 61), examined Goodenough Lake in September, 1919, at which time the area of the lake was roughly 15 acres. No mention is made of the depth of brine, but the following analysis represents a sample taken from the remains of an old stock-pile on the shore of the lake:

Na_2CO_3	-	53.21
Na_2SO_4	-	0.14
Water	-	46.47

At present the only sodium carbonate in Goodenough Lake occurs as muddy permanent crystal, the sodium carbonate content of which is probably between 3000 and 5000 tons. It is instructive to examine the following tonnage estimates for the years in which data are available:

Ref.	Date	Area of brine or winter crystal	Estimated tonnage of Na_2CO_3		
			Winter-Crystal	Brine	Permanent Crystal
Hoffmann	Autumn 1898	20 acres	7400	800	?
Reinecke	Autumn 1918	15 "	----	---	----
Goudge	Autumn 1924	14.5 "	2300	90)	
Writer	Autumn 1937	none	none	) none)	3000 to 5000

Unfortunately insufficient information is available to permit an intelligent estimate of the quantity of permanent crystal. Even allowing for a possible increment to this, however, through the years, there has been a definite diminution of the amount of sodium carbonate in the lake. Records show that not over 600 tons of natron, equal to 200 tons of sodium carbonate, has been removed for commercial purposes.

In 1924 the brine of Safety Lake contained about 300 tons of sodium carbonate. Today none is present other than that represented by a one-inch layer of greenish mud and crystal amounting to no more than 80 or 90 tons of sodium carbonate at best.

Goudge notes (Ref. 6, p. 86) that the elevation of the surface of the brine in Safety and Goodenough Lakes was approximately the same as that in Meadow Lake. This is worthy of mention insofar as the water now is apparently much lower in Meadow Lake than it was at the time of his examination.

Lake No. 6 (Map 2, No. 6)

Lake No. 6 is about 1 1/2 miles north-west of Little White Lake and one mile north of Liberty Lake. It is long and narrow, occupying a shallow depression in gently rolling country. When visited in October 1937 it contained an average of 15.24 6 inches of brine over an area of 3.6 9 acres. The surrounding mud was practically free of the typical alkaline efflorescence and soda flies were absent. No winter-crystal was present and none is known to have formed here in past years. The brine is a relatively weak solution of sodium carbonate as shown by the following analyses:

(1) Sp. Gr. at 16 deg. C. - 1.033
Total solids - 3.29%

Composition of Solids

(2)			
	Na_2CO_3	-	80.5%
	Na_2SO_4	-	14.0%
	NaCl	-	5.5%
	$MgSO_4$	-	tr.
	$CaSO_4$	-	tr.

(1) Analysed by Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

From the above analysis the quantity of sodium carbonate contained in the brine would be about 160 tons.

Reinecke (Ref. 9, p. 61), examined the lake in the early autumn of 1919 at which time brine, with a specific gravity of 1.085 (at 15 deg. C.), covered about 8 acres to a depth of 6 inches to one foot.

2 cm 6 cm 20 cm

Liberty Lake (Map 2, No. 7)

4.8 cm

Liberty Lake occupies part of the bed of what was once a much larger lake. When visited in October 1937, brine covered approximately 12 acres to a depth of 8 inches. The mud surrounding the lake was heavily encrusted with white efflorescence and winter-crystal was in the process of formation, a layer 1 inch thick and 20 feet wide having accumulated along the north shore. The original lake bed occupied a long narrow shallow depression. When visited by Reinecke (Ref. 9, p. 61) in 1919 two lakes were present, the larger covering 15.6 acres to a depth of 10 inches, the smaller covering 9.5 acres to a depth of 1 foot.

The following analyses were made of samples taken by the writer:

Brine Samples - Liberty Lake

(1) Sp. G. at 16 deg. C. - 1.1255
Total solids - 13.78%

Composition of Solids

(2) Na_2CO_3 - 81.5%
Na_2SO_4 - 11.7%
NaCl - 6.5%
$MgSO_4$ - tr.
$CaSO_4$ - tr.

(1) Sample of winter-crystal from stock pile on shore

(2) Na_2CO_3 - 88.79%
Na_2SO_4 - 11.02%
Insol - trace
$MgSO_4$ - trace
Ca, CO_2, Cl, Al, Fe, and PO_4 - absent

Note: Above analysis recalculated to 100% water-free basis. Sample as analysed contained 14.2% water.

(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

Goudge mentions that crystal was known to form in 1924 in the lake under discussion, although he made no examination. Records do not show the amount of natron harvested from Liberty Lake. Several hundred tons have been shipped, however, and stock piles along the shore contained in 1937, at least 400 tons. The slabs of winter crystal in the stock piles were 4 to 5 inches thick and were composed of clear crystals covered with a white powdery coating.

When visited the lake contained approximately 1500 tons of sodium carbonate in solution. No permanent crystal-bed is known to occur. In 1919 brine in the larger lake examined by Reinecke (Ref. 9, p. 61) had a specific gravity of 1.135, that in the smaller 1.160. On the basis of this, and assuming the composition to be the same as today, the amount of sodium carbonate in solution at that time would have been roughly 5000 tons.

Snow White Lake (Map 2. No. 8)

Snow White Lake, a shallow lake covering 9 acres, lies about one mile west of the Canoe Creek Road. In October 1937, it contained about 8 inches of brine, of which the following analysis is typical:

(1)	Sp. Gr. at 16 deg. C.	1.050
	Total solids	4.88%

Composition of Solids

(2)	Na_2CO_3	94.4%
	Na_2SO_4	2.3%
	NaCl	2.7%
	$MgSO_4$	tr.
	$CaSO_4$	tr.

(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

No deposit of winter-crystal was present when examined nor has any formed for several years. The remnants of a stock pile, however, were noted on the east shore, and it is understood that shipments have been made.

The following analysis (1) represents a sample from the old stock pile:

Analysis of crystals from old stock pile

(2)	Na_2CO_3	99.36%
	Insol	trace
	Na_2SO_4	nil
	NaCl	nil
	$MgSO_4$	nil

Note: analysis calculated to a 100% water free basis. Sample contained 16.3% water.

(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

The quantity of sodium carbonate contained in the lake brine when examined would approximate 400 tons.

Rob and Nan Lake (Map 2, No. 9)

Rob and Nan Lake is on the east side of the Canoe Creek Road about 12 miles from Chasm Station. Brine, covering little more than half of the former lake bed, averages 16 inches in depth over 25 acres. The bottom is muddy and no permanent crystal-bed occurs. A brine sample had the following composition (1):

40 cm

10 ha

Sp. Gr. at 16 deg. C.	-	1.065
Total solids	-	6.39%

Composition of Solids

(2)	Na_2CO_3	86.5%
	Na_2SO_4	6.5%
	NaCl	7.5%
	$MgSO_4$	tr.
	$CaSO_4$	tr.

(1) Chief Assayer.
(2) Both carbonate and bicarbonate expressed as carbonate.

In October 1924 (Ref. 6, p. 90) brine covered 29 1/2 acres to a depth of 18 inches. Its composition was as follows:

Sp. G. at 22 deg. C. - 1.104 (equivalent to 1.106
Total Solids - 11.29% at 16 deg. C.)

Composition of Solids

Na_2CO_3	-	72.18%
$NaHCO_3$	-	4.78%
NaCl	-	6.52%
Na_2SO_4	-	5.52%
$Mg(HCO_3)_2$	-	5.65%
KCl	-	5.35%

In the autumn of 1919 (Ref. 9, p. 61) brine covered 60 to 80 acres to a maximum depth of 2 to 4 feet; it had a specific gravity of 1.070 at 20 deg. C. (equivalent to 1.071 at 16 deg. C.)

There is no record of crystals having formed in Rob and Nan Lake. The quantity of sodium carbonate in solution was about 11,000 tons in 1919, 5700 tons in 1924, and 2600 tons in 1937.

Last Chance Lake (Map 2, No. 10)

Last Chance Lake lies to the east of Rob and Nan Lake, from which it is separated by a low ridge 450 feet wide. The lake is unique among the others of the region in containing a large bed of permanent crystal in the form of circular bowl-shaped masses separated by mud. The area of the bed in which "bowls" appear is 29 acres, of which about half is underlain by crystal.

The crystal areas are almost circular and range from 4 to 70 feet in diameter. They are separated by slightly raised ridges and areas of soft black mud, heavily encrusted with dried soda, and in places strewn with boulders, among which angular basaltic fragments are conspicuous. Very little brine was present when examined in October 1937, being confined to about one-half inch over the crystal bowls. In June of the same year the lake contained about 6 inches of brine over the entire surface.

The writer was not equipped to test the depth of crystal present. This, however, was done in some detail by Goudge in October 1924. From drilling and test pits on some 30 bowls he found them to range in depth from 1 to 10 feet, with an average of 3 1/2 feet for all. The following description is quoted from his report: (Ref. 6, p. 88)

"Some 30 of the crystal masses in all parts of the lake bed were investigated as to depth and shape by means of a long chisel-pointed iron bar. The results may be summarized by stating that all the masses are bowl-shaped, that these bowls are deeper along the centre line of the lake than near the shore and that they are deeper in the western end than in the eastern end of the lake. The average depth of bowls over the whole lake is 3 1/2 feet.

"Pits were dug in several of the crystal bowls but no depth over 4 feet was attained on account of the pits being flooded by the rapid infiltration of brine through the porous crystal. These pits proved, however, that the clean compact crystal showing on the surface is only a few inches deep and that below it the bowls are composed of very large interlocking crystals. The large crystals, presumably natron crystals, are darkened by included mud and the interstices between them are filled with fine silt. There are also irregularly-shaped masses of mud included within the bowls.

"In many cases there is in approximately the centre of each crystal bowl, a tiny solution channel extending from the bottom to the surface. No flow of brine was observed coming up through these channels.

"The amount of crude crystal in Last Chance lake is, on a preliminary estimate, placed at 70,000 tons."

The following analyses represent samples taken by the writer: (1)

	Top crtystals from pools 1 inch thick	Old Stock Pile
(2) Na_2CO_3	92.32%	84.50%
NaCl	tr.	tr.
Na_2SO_4	4.00	tr.
$MgSO_4$	tr.	tr.
$CaSO_4$	tr.	tr.
Insoluble	1.5	14.50%
CO_2, Al, Fe, PO_4	nil	nil

Note: analyses recalculated to a water free basis. The first sample contained 15 per cent combined water, the second 20%.

(1) Chief Assayer, Victoria.

(2) Both carbonate and bicarbonate expressed as carbonate.

The analyses below are from Goudge's report: (Ref. 6, p. 89)

Analyses of Crystal, Last Chance Lake

	Surface crystal 3" thick	Crystal at depth 1-2 ft.	Stock Pile
Na_2CO_3	96.28	63.41	49.65
$NaHCO_3$	0.70	0.63	0.65
NaCl	1.40	1.49	1.58
Na_2SO_4	0.10	1.39	2.13
$CaCO_3$	--	--	tr.
$MgCO_3$	1.11	8.59	tr.
Insol.	0.41	25.49	45.99

Note: Analyses calculated to 100% water free.

Analyses of brine samples taken by the writer and by Goudge are given below:

Writer (1)	Goudge (Ref. 6, p.89)
Sp. G. at 16 deg.C. - 1.1565 Total solids - 17.99%	Total solids - 14.38%

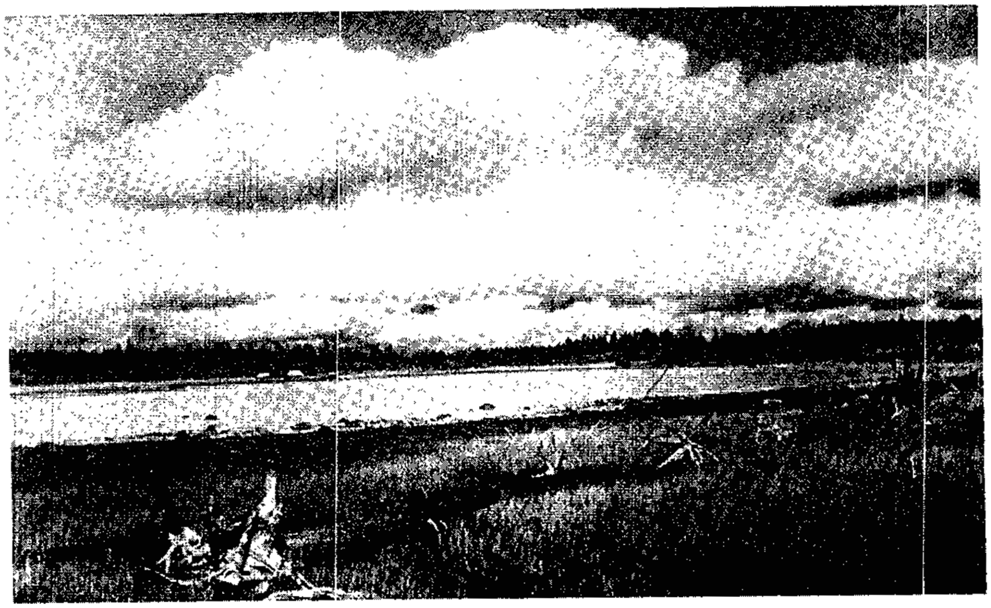
	Composition of Solids			Composition of Solids		
(2)	Na_2CO_3	-	63.0	Na_2CO_3	-	57.64%
	Na_2SO_4	-	22.5	$NaHCO_3$	-	3.78
	NaCl	-	15.0	NaCl	-	6.58
	$MgSO_4$	-	tr.	Na_2SO_4	-	26.05
	$CaSO_4$	-	tr.	$Mg(HCO_3)_2$	-	3.64
				KCl	-	2.31

Sp.G. at 22 deg.C.-1.146 (equivalent to 1.148 at 16 deg. C.)

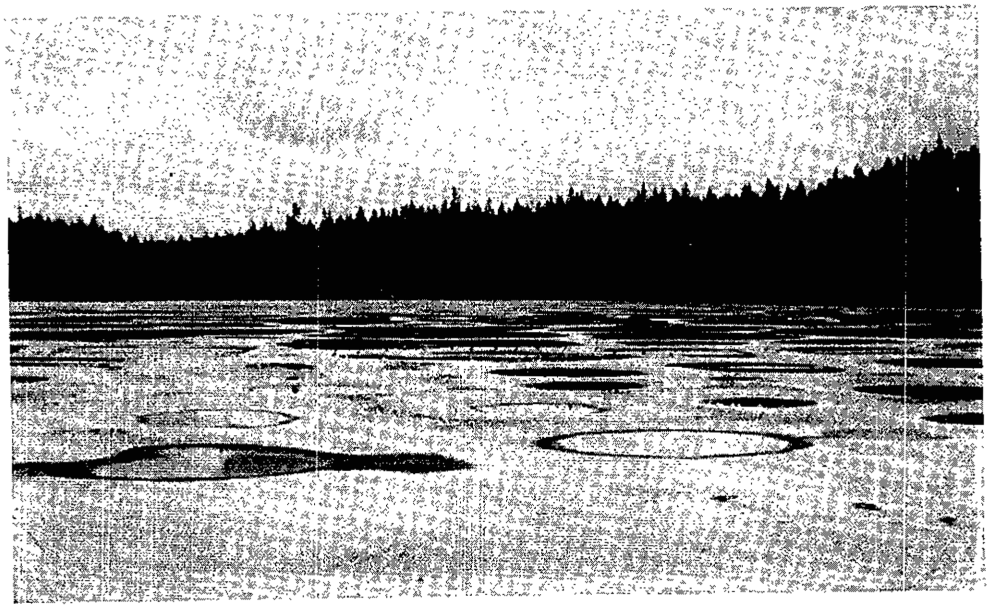
(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

Reinecke (Ref. 9, p. 61) gives a specific gravity of 1.170 for the brine in the autumn of 1919.

On the assumption that the lake contains 70,000 tons of crude crystal, as estimated by Goudge, the amount of sodium carbonate present would be about 17,500 tons.



ANITA LAKE. (Map 2, No. 12.)
Picture looking north-eastward. Note stock piles of winter crystal on far shore.



LAST CHANCE LAKE. (Map 2, No. 10.)
Picture looking eastward. Note typical "crystal bowls" covered by shallow brine with raised mud ridges between.

Margaret Lake (Map 2, No. 11)

Margaret Lake is a small shallow lake, roughly circular in shape, lying about one-half mile north of the old 70 Mile House-Meadow Lake road. In October 1937, brine covered 4 1/2 acres to an average depth of 1 foot. Winter-crystal was forming at the time of examination, a layer about half an inch thick already covering the eastern half of the lake bed. The bottom is fine black mud and no permanent crystal deposit is known to occur. Shipments of natron have been made from Margaret Lake at one time or another, but the total amount removed is unknown.

In October 1924, (Ref. 6, p. 92) brine covered 5 acres to a depth of 6 inches to 2 feet, and a rim of winter-crystal 8 to 10 inches thick and 15 feet wide occurred around most of the south-eastern shore. The central part of the lake was filled with large radiating clusters of crystals.

The following analyses represent samples of brine and crystals taken by the writer in 1937, and Goudge in 1924:

Writer (1) Brine		Goudge (Ref. 6, p. 93) Brine	
Total solids	- 13.38%	Total solids	- 11.07%
Sp.G. at 16 deg. C.	- 1.125	Sp.G. at 22 deg. C.	- 1.108

Composition of Solids		Composition of Solids	
(2) Na_2CO_3	- 95.5%	Na_2CO_3	- 77.28%
$NaCl$	- 4.2%	$NaHCO_3$	- 11.85
Na_2SO_4	- tr.	$NaCl$	- 4.57
$MgSO_4$	- tr.	Na_2SO_4	- 0.17
$CaSO_4$	- tr.	$Mg(HCO_3)_2$	- 3.01
		KCl	- 3.12

Winter Crystal		Winter Crystal	
Na_2CO_3	- 98.3%	Na_2CO_3	- 98.48
Na_2SO_4	- nil	$NaHCO_3$	- 0.62
$NaCl$	- tr.	$NaCl$	- 0.33
$MgSO_4$	- nil	Na_2SO_4	- 0.22
$MgCO_3$	- nil	$CaCO_3$	- nil
$CaCO_3$	- nil	$Mg(HCO_3)_2$	- nil
Insol.	- 1.7%	Insol.	- 0.35

Note: Both samples recalculated to a 100% water free basis. Writer's sample contained 15.8% combined water.

(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

The approximate amount of sodium carbonate, in solution and as winter-crystal, was 850 tons in 1937, and 1000 tons in 1924.

Anita and Lela Lakes (Map 2, No. 12)

Anita and Lela Lakes occupy parts of an original lake bed 65 to 70 acres in extent. The present lakes, covering about 26 acres and 6 acres respectively, are separated by 800 feet of dried mud strewn with boulders. Around the lakes the mud is heavily encrusted with dried soda.

Brine covered Anita lake to an average depth of 8 inches and Lela Lake to 1 foot when examined in October, 1937. It is interesting to note that in June of the same year brine stood about 1 foot higher in Anita Lake; in September 1938, however, even less was present than in the preceding autumn. Water-level is approximately the same in both lakes.

In October 1937, a thin layer of winter-crystal was in the process of formation over the muddy bottom of Anita Lake; none, however, was noted in Lela Lake. No deposit of permanent crystal is known to occur in either.

The following quotation is from Goudge's report: (Ref. 6, p. 90)

> "In October 1924, about 25 acres of Anita Lake was covered with winter crystal varying in thickness from 2 to 6 inches. On top of the crystal there was brine to an average depth of 2 inches. Numerous circular holes from 4 to 18 inches in diameter were noticed in the layer of winter crystal. These holes appeared to mark the orifices of tiny springs, but, as at Goodenough lake, no flow of water was observed. In the north-eastern part of the lake, just at the water line, is a small spring, around which a considerable deposit of calcareous tufa has accumulated. The water of this spring has a salinity of 2168 parts per million and it contains all the constituents present in the brine.
>
> "The mud in the bottom of the lake is very deep and soft and no crystals were observed in it.
>
> "In October 1924, there was a depth of brine in

the lake (Lela Lake) varying from 1 to 3 feet. Along the south-western shore and extending outwards for a distance of about 70 feet, was a shelving bed of winter crystal, which was 9 inches thick near the shore but gradually thinned out to nothing toward the centre of the lake. The crystal bed was steadily increasing both in thickness and extent when the lake was examined. A few clusters of crystals had formed in the central part of the lake."

Analyses of brine and crystals taken by both Goudge and the writer follow:

	Writer (1) Brine - Anita Lake		Goudge (Ref.6, p.91 and 92) Brine - Anita Lake	
	Total Solids	12.44%	Total Solids	12.52%
	Sp.Gr. at 16 deg. C.	1.117	Sp.G. at 22 deg.C.	1.104
	Composition of Solids		**Composition of Solids**	
(2)	Na_2CO_3	93.2%	Na_2CO_3	63.96%
	NaCl	6.0%	$NaHCO_3$	6.83
	Na_2SO_4	.5%	NaCl	16.23
	$MgSO_4$	tr.	Na_2SO_4	2.33
	$CaSO_4$	tr.	$Mg(HCO_3)_2$	7.42
			KCl	3.23

	Brine - Lela Lake		Brine - Lela Lake	
	Total Solids	7.02%	Total Solids	12.12%
	Sp.G. at 16 deg. C.	1.0675	Sp.G. at 22 deg.C.	1.115%
	Composition of Solids		**Composition of Solids**	
(2)	Na_2CO_3	93.2%	Na_2CO_3	70.55%
	NaCl	5.8	$NaHCO_3$	11.51
	Na_2SO_4	.8	NaCl	6.97
	$MgSO_4$	tr.	Na_2SO_4	2.23
	$CaSO_4$	tr.	$Mg(HCO_3)_2$	4.82
			KCl	3.92

	Winter Crystal - old stock pile - Anita Lake		Winter Crystal - Anita Lake	
(2)	Na_2CO_3	98.85%	Na_2CO_3	96.72%
	NaCl	tr.	$NaHCO_3$	0.73
	Na_2SO_4	tr.	NaCl	1.04
	$MgSO_4$	tr.	Na_2SO_4	0.73
	$CaCO_3$	nil	$CaCO_3$	nil
	$MgCO_3$	nil	$MgCO_3$	nil
	Insol.	tr.	Insol.	0.78

Winter Crystal - Lela Lake		
Na_2CO_3	-	98.17%
$NaHCO_3$	-	0.42
NaCl	-	0.77
Na_2SO_4	-	0.37
$CaCO_3$	-	nil
$MgCO_3$	-	nil
Insol.	-	0.27

(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

Note: Analyses of crystals recalculated to 100% water free basis. Writer's sample from Anita Lake contained 14.9% water.

In 1919 (Ref. 9, p. 61) one body of water 85 acres in extent covered both Anita and Lela Lakes. This lake contained brine to a depth of 4 feet in summer and 3 feet in winter. The Specific gravity of the brine was 1.055 at 15 deg. C. and the lake was estimated to contain 65,000 tons of sodium carbonate.

On the basis of Goudge's figures Anita Lake contained about 6000 tons of sodium carbonate in solution in 1924 and Lela Lake about 2100 tons. Corresponding amounts in 1937 would be 3000 tons and 550 tons.

Records are incomplete, but it seems probable that at least 3000 tons of winter-crystal, equivalent to 1000 tons of sodium carbonate, have been harvested from Anita and Lela Lakes since 1918. When examined in the autumn of 1937 there were several stock piles of natron on the north shore, harvested during the preceding winter; the crystal-slabs averaged 4 to 6 inches in thickness.

White Elephant Lake (Map 2, No. 14)

White Elephant Lake, in October 1937, contained brine to an average depth of 1 to 2 feet over an area of 14 acres. It lies about 1/4 mile south-west of Rose Lake, and 1/4 mile west of the Pacific Great Eastern Railway.

The lake-bed is soft mud and no permanent crystal deposit occurs. The muddy shoreline is heavily encrusted with dried soda. In the past winter-crystal has formed and shipments been made, but none has occurred within recent years.

The following brine analysis represents a sample taken by the writer: (1)

Brine - White Elephant Lake

Total Solids - 8.3%
Sp.G. at 16 deg. C. - 1.083

Composition of Solids

(2)	Na_2CO_3	97.5%
	NaCl	2.1
	Na_2SO_4	.4
	$MgSO_4$	tr.
	$CaSO_4$	tr.

(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

In 1937 White Elephant Lake contained about 2000 to 2500 tons of sodium carbonate in solution.

Rose Lake (Map 2, No. 15)

Rose Lake lies directly east of the Pacific Great Eastern Railway at Coulson's Siding. In October 1937, it contained about 2 feet of brine over an estimated area of 30 acres. No winter-crystal has formed in recent years, although several thousand tons were harvested from the lake between 1924 and 1929.

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When examined by Goudge in 1924 brine covered 32 acres to an average depth of 2 1/2 feet. The following description is quoted from his report: (Ref. 6, p. 93)

> "Along the southwestern shore a solid bed of winter crystal extended outwards for a varying distance of from 10 to 20 feet. Dotted over the whole lake were large clusters of soda crystals and these crystals were being gathered by means of boats. Later on in the season when the lake had crystallized over completely, the bed of crystal near the shore was worked exclusively."

Analyses of brine and crystals follow:

Writer (1) Brine - Rose Lake	Goudge (Ref. 6, p. 94) Brine - Rose Lake
Total Solids - 8.17%	Total Solids - 12.02
Sp.G. at 16 deg. C. - 1.0795	Sp.G. at 22 deg.C.-1.121

	Composition of Solids			Composition of Solids		
(2)	Na_2CO_3	-	95.8%	Na_2CO_3	-	88.99%
	NaCl	-	3.9%	NaCl	-	4.32
	Na_2SO_4	-	0.5	Na_2SO_4	-	0.98
	$MgSO_4$	-	tr.	$MgCO_3$	-	4.07
	$CaSO_4$	-	tr.	KCl	-	1.58

(2)	Crystal - Old Stock Pile			Crystal		
	Na_2CO_3	-	99.12	Na_2CO_3	-	98.33
	NaCl	-	tr.	$NaHCO_3$	-	0.62
	Na_2SO_4	-	tr.	NaCl	-	0.52
	$MgSO_4$	-	nil	Na_2SO_4	-	0.21
	$MgCO_3$	-	nil	$CaCO_3$	-	nil
	$CaCO_3$	-	nil	$MgCO_3$	-	nil
	Cl, PO_4, Fe and Al		nil	Insol.	-	0.32
	Insol.	-	.62			

1. Chief Assayer, Victoria.
2. Both carbonate and bicarbonate expressed as carbonate.

The amount of sodium carbonate in solution in Rose Lake was about 6500 tons in 1937 and 14,500 tons in 1924.

Hutchison Lake (Map 2, No. 17)

Hutchison Lake lies about 5 miles east of 70 Mile Station. It is long and narrow, occupying a depression with steeply sloping banks. The muddy shoreline is heavily encrusted with soda.

Brine covered an area of about 15 acres in October 1937, and had a depth of at least 10 feet in the middle of the lake. No winter-crystal was forming and none is known to have occurred.

From description (Ref. 6, p. 95) the lake has not changed materially in size since examined by Goudge in 1924. In 1919 Reinecke (Ref. 9, p. 62) states that brine covered 17 acres to an unknown depth.

Analyses of brine samples taken by Reinecke, Goudge, and the writer follow:

	Writer (1)		Goudge (Ref. 6, p. 95)		Reinecke (Ref. 9, p. 61)	
	Per cent Solids - 7%		Per cent Solids - 6.29%		Per cent Solids - 4.23%	
	Sp.G. at 16 deg.C. - 1.0685		Sp.G. at 22 deg.C. - 1.059		Sp.G. at 16 deg.C. - 1.044	
	Composition of Solids		Composition of Solids		Composition of Solids	
(2)	Na_2CO_3	96.3%	Na_2CO_3	85.69%	Na	18.38 pts./1000
	NaCl	3.3%	$NaHCO_3$	3.75	K	tr.
	Na_2SO_4	.1%	NaCl	nil	Ca	tr.
	$CaSO_4$	tr.	Na_2SO_4	nil	Mg	.026 "
	$MgSO_4$	tr.	$Mg(HCO_3)_2$	2.81	CO_3	22.66
			K_2CO_3	2.66	HCO_3	3.06
			KCl	5.09	SO_4	.082
					Cl	.859

(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

Insofar as the average depth is difficult to judge, the total amount of brine, hence the amount of sodium carbonate, can only be roughly estimated. It seems probable, however, that at least 12,000 to 13,000 tons of sodium carbonate is in solution in Hutchison Lake.

Other Lakes

In addition to those described, many lakes on the Green Timber Plateau contain dilute alkaline brines. The writer took samples from several of the larger or more concentrated of these. Analyses follow: (1)

Lake	Ref. Map 2	Sp. G.	% Solids	Composition of Solids					
				Na_2CO_3	NaCl	Na_2SO_4	$MgSO_4$	$CaSO_4$	$MgCO_3$
Long Lake	No. 2	1.022	2.2%	41.0	4.0	45.5	3.7	5.8	---
White "	No. 3	1.008	.76	82.5	3.7	5.6	8.2	tr.	
Meadow "	No. 5	1.004	.67	56.0	29.2	---	tr.	10.5	4.6
------ "	No. 13a	1.017	1.60	94.0	5.0	1.0	tr.	tr.	---
------ "	No. 13b	1.0175	1.63	92.2	6.4	1.1	tr.	tr.	---
Green "	No. 16	1.002	.42	79.5	---	---	tr.	tr.	18.1

(1) Chief Assayer, Victoria.

In a general way the above analyses may be taken as representative of most of the alkaline lakes of the region. Not only are these abundant but numerous dry lake beds are also to be found. The surface of these is commonly crusted and cracked; some show a faint alkaline efflorescence. The writer drilled a number of dry lakes to depths of 3 and 4 feet to determine whether permanent crystal-deposits occurred; in no case, however, was anything other than heavy black mud and bluish clay encountered.

Kamloops Area

A number of small undrained saline lakes, some dry, occur in the vicinity of Kamloops. Although most of these contain sodium sulphate as a major constituent, several contain relatively concentrated solutions or crystal-beds in which sodium carbonate predominates.

The climate of the region is severe with a temperature range from a maximum of 100 degrees or more in summer to a minimum of 20 or 30 degrees below zero in winter. Precipitation is variable from place to place, but in general is low, the average annual rainfall in Kamloops being 10 inches, of which at least half is contributed by snow.

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Lake No. 1 (Map 3, No. 1)

Lake No. 1 is about 1 mile east of the Kamloops-Cache Creek Highway, 12 miles from Kamloops, and three-quarters of a mile south, and 800 feet above the Canadian Pacific Railway along Kamloops Lake. It occupies a small, rather sharp, depression in rolling to hilly grass-covered country.

The lake lies close to the contact of an area of pinkish syenite to the north, and basic porphyritic volcanics to the south. Its drainage basin is about 450 acres in extent, of which about three-quarters is underlain by volcanic rocks.

The lake was nearly dry when examined October, 1937. The surface was covered by a heavy encrustation of dried soda, underlain by 2 to 4 feet of soft black mud, beneath which a solid crystal-bed occurred. In September, 1938, a thin layer of brine covered nearly half the lake. The area of the bed is between 3 and 4 acres, and it is understood that about 3 acres are underlain by permanent crystal. The writer was not adequately equipped to determine the depth and form of the crystal bed. However, in the Report of the Minister of Mines for British Columbia, 1930, the deposit is mentioned (Ref. 4, p. 196) and it is stated that holes drilled with a steam jet

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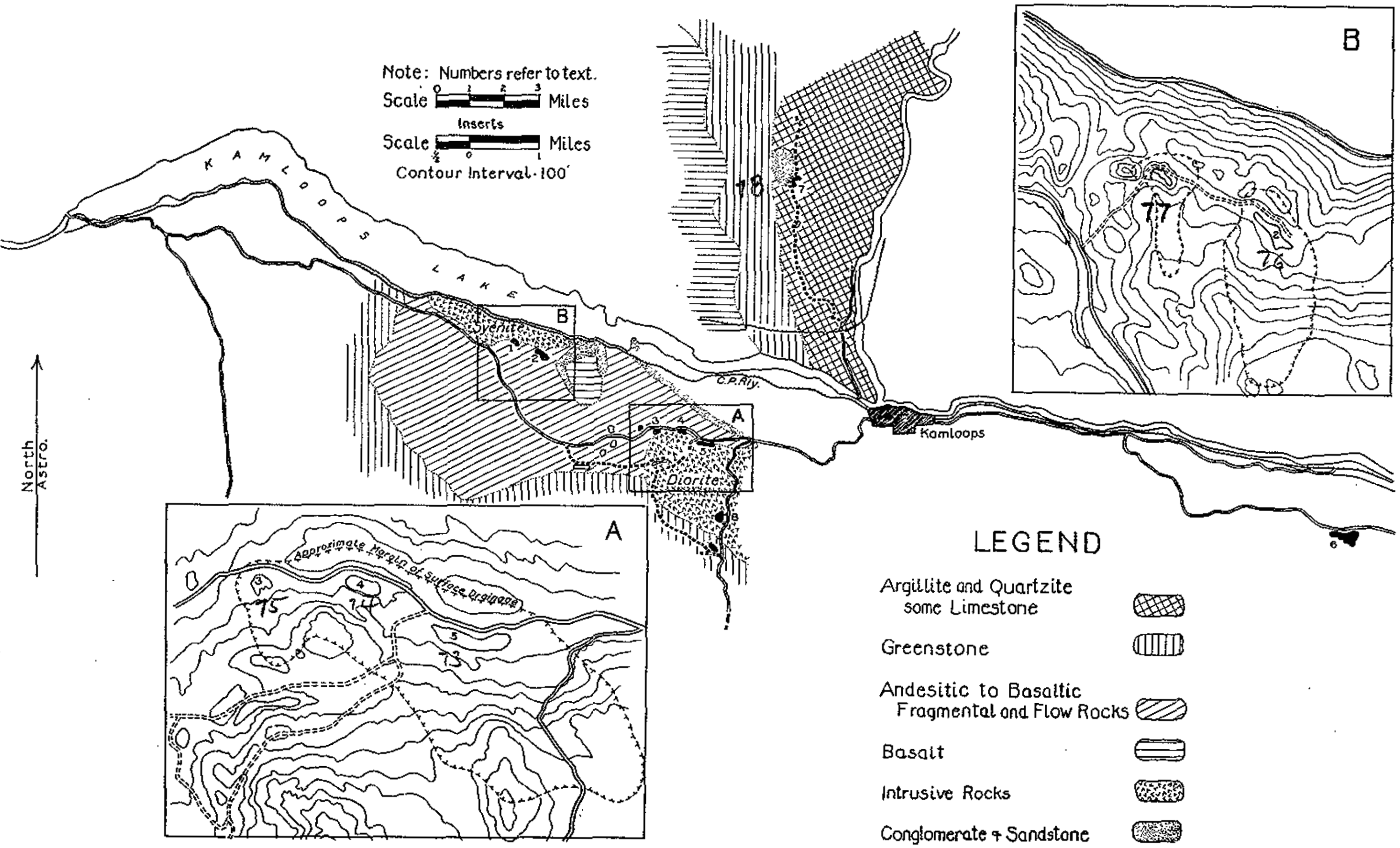


MAP 3.
Saline deposits in vicinity of Kamloops.
Geology from Kamloops Sheet, Geological Survey of Canada, G. M. Dawson.

encountered from 18 to 36 feet of solid crystal, without, in places, bottom being reached. If these figures are assumed as correct, the lake would contain approximately 100,000 tons of permanent crystals. In the same report the typical following analysis is given:

H_2O	-	63%
Insol	-	1 - 5%
Salts	-	26-22%

Composition of salts

Na_2CO_3	-	92%
Na_2SO_4	-	8%

It is understood from the owner that analyses vary in respect to the proportion of sodium carbonate and sodium sulphate in different parts of the bed. Unfortunately the soft surface and the depth of mud made it impossible for the writer to obtain samples of the crystal-deposit itself. Analyses of samples taken from the surface crust and settling tank follow: (1)

			Surface crust	Recrystallized material from settling tank
(2)	Na_2CO_3	-	57.9%	58.9%
	Na_2SO_4	-	39.8	40.6
	Insol	-	1.1	tr.
	CaO	-	nil	nil
	MgO	-	nil	nil
	PO_4	-	nil	nil

(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

Note: Analyses recalculated to 100% water free basis. Samples as analyzed contained 15.8% and 14.0% water respectively.

From these it appears probable that the proportion of sodium sulphate in the quoted analysis is too low to be truly representative.

The deposit was worked from 1931 to 1935 and about 1000 tons of impure natron or sal soda shipped to Vancouver and Calgary. The method of recovery was to liquefy the crystal by means of steam, pump the solution to a settling tank to remove insoluble impurities, and recover the sodium carbonate and sodium sulphate by recrystallization.

As mentioned on the basis of quoted thicknesses the lake may be assumed to contain about 100,000 tons of permanent crystals, or roughly 30,000 tons of sodium carbonate and sulphate.

Barnes Lake

Barnes Lake lies about a quarter of a mile west of the Kamloops-Vernon Highway, 17 miles from Kamloops. It has an area of 35 to 40 acres and when visited in October, 1937, contained brine to an average depth of 6 inches over a large part of the bed. The muddy shoreline and dry portions of the bed are heavily encrusted with dried soda. Owing to the soft bottom it was impossible to obtain a sample of the brine.

No winter-crystal was present in Barnes Lake when examined. It is understood, however, that the present water-level is considerably higher now than in the past, and that crystals have formed. In the autumn of 1932 a 3-inch layer of natron covered a large part of the lake, a sample of which, submitted to the Dept. of Mines for analysis showed the following composition: (1)

Na_2CO_3	-	97.50%
NaCl	-	.5%
Insol.	-	.9%
Fe_2O_3	-	.7%

(1) Chief Assayer, Victoria.

Note: recalculated to a 100% water free basis. Sample as assayed contained 58.9% water of composition.

The writer drilled several 4-foot holes at various points about 15 feet from the shore. No deposit of solid crystals was encountered but small natron crystals were noted in the mud. The lake has been drilled by several interested parties with conflicting results. Apparently, however, the muddy bottom contains a fairly high proportion of disseminated crystals and it is reported that a solid layer 3 to 6 inches thick was encountered at a depth of 6 feet. In view of the meagre data available it is impossible to estimate the tonnage of sodium carbonate present.

Other Lakes

Other lakes, containing sodium carbonate as a major brine

NE-47 constituent, occur in the area. Buse Lake (Map 3, No. 6), on the south side of the Kamloops-Vernon Highway, 14 miles from Kamloops, contains brine of the following composition: (1)

Total solids - 2.37%
Sp.G. at 16 deg. C. - 1.023

Composition of Solids

(2)	Na_2CO_3	-	75.5%
	NaCl	-	3.4%
	Na_2SO_4	-	18.9%
	$MgSO_4$	-	2.3%
	$CaSO_4$	-	tr.

(1) Chief Assayer, Victoria.
(2) Both carbonate and bicarbonate expressed as carbonate.

A lake in the vicinity of Savona is reported to contain a concentrated sodium carbonate brine. Others undoubtedly occur in the region.

Chilcotin Area (See Map 1)

Several alkaline lakes occur south-west of Hanceville, along or close to, the old Nemaia Valley Road; others, many dry, are common elsewhere in the Chilcotin area.

In general the country is flat to gently rolling, drift covered, and underlain by basaltic flow rocks. The climate is severe, maximum summer temperatures ranging from 80 to 90 degrees, and minimum winter temperatures from 30 to 40 degrees below zero. Precipitation averages 12 inches annually at Big Creek, 6 to 7 inches being contributed by rainfall during the months of May, June, July, August, and September. Snowfall represents an additional 3 to 4 inches.

As the writer has not examined the alkaline lakes of this region the following descriptions are quoted from Survey of Resources Report, Pacific Great Eastern Railway Lands (Part 2, Vol. 2, West Lillooet Block, pp. 55-58-R.M. Logie, 1929, Unpublished Manuscript).

Soap and Towdykin Lakes

"Soap lake is situated on the Nemaia Valley road, approximately 14 miles from the Chilco Ranch at Hanceville.

Towdykin lake is about half a mile in a north-westerly direction from Soap lake. These two lakes are not connected by a stream but Soap Lake is slightly lower than Towdykin lake and in the latter there is quite a noticeable current in the direction of Soap lake. This current is probably due to the circulation of ground waters towards Soap lake. Neither of these lakes has any apparent outlet, and Soap lake contains a more concentrated solution than Towdykin. The main salt present in the solution is sodium carbonate.

Analysis of Water from Soap lake

Constituents	Grains per gallon
Na_2CO_3	848.8
$MgSO_4$	Trace
$CaSO_4$	Trace
$CaCO_4$	Trace
$NaCl$	Trace

Collector, R. M. Logie; Analyst, D. E. Whittaker, B. C. Department of Mines.

"These lakes are situated in an area that is almost entirely drift covered, and the thickness of drift is at least 5 feet and more likely well over 100 feet. The rock underlying the drift is probably Miocene basalt as occurrences of rocks older than this are not known in the region.--Springs are not known in the drainage basin of these lakes, although springs may rise in the lake beds.

"No crystal was observed in association with these lakes, but scattered crystals of salts were noted in the bed of Soap Lake."

White Lake (Kiliyul Lake)

"An alkaline lake similar to Soap and Towdykin lakes occurs about one and a half miles from the Chilco Ranch at Hanceville. This lake contains salts similar to those of Soap lake but not as large a proportion is present. An efflorescence of salts was noted on the shore of the lake, but they were only sparsely disseminated through the mud. No crystal bed was observed in connection with this deposit.

> "The lake occurs in a region that has a very thick covering of glacial drift which is apparently underlain by Miocene basalts. There is no apparent outlet to the lake and the drainage basin of the lake does not appear to be very large."

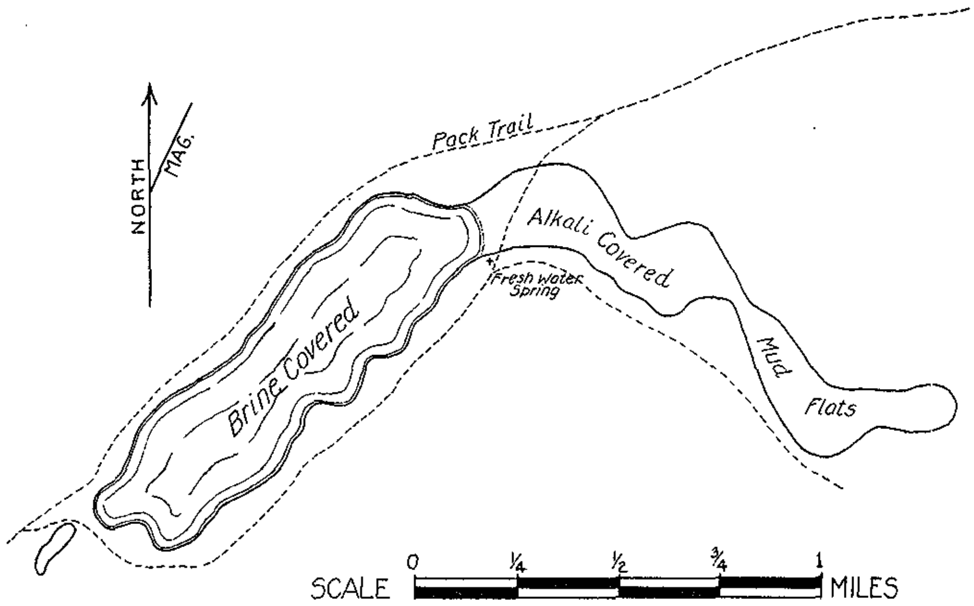
Two other dry lakes are mentioned specifically by Logie; in neither did permanent crystal beds occur. Speaking generally of the saline lakes of the region Logie says:

> "A number of saline deposits are scattered throughout the northern section of the block and are generally confined to areas underlain by basalt.....Poison lake (dry) differs from the rest of the deposits in that it is situated in an area where a greater part of the underlying formations belong to the Cache Creek series of Carboniferous age. The salts in these deposits, as determined by analysis, are mainly sodium carbonate, and sodium sulphate, with traces of magnesium sulphate, calcium sulphate, sodium chloride, and one deposit contains small quantities of potassium (Writer's note--in Poison lake sodium sulphate and calcium sulphate predominate).....The drainage basins of the lakes are not large and are confined in general to small areas in the immediate vicinity of the lakes."

Soap Lake, Spences Bridge (Map 4)

Soap lake lies south of Spences Bridge about 7 miles by pack trail, and approximately 2000 feet above the Canadian Pacific Railway tracks to the west. The writer has not examined this lake and the following description is quoted from a report by L. H. Cole (Ref. 5, p. 25).

> "The lake which lies in a depression in rolling plateau country is completely surrounded by gently sloping hills and has no apparent outlet. The country is sparsely wooded with bullpine and fir and the slopes are well covered with grass during certain seasons of the year.
>
> "According to Drysdale the rock formation of the surrounding hills belongs to the Kamloops Volcanic group of Lower Miocene age, and consist mainly of basaltic lavas and pyroclastics with younger mica andesites cutting them and forming coarse agglomerates in the andesitic matrix.
>
> "The lake is over one mile long and 1300 feet wide



MAP 4.
Soap Lake (after Cole).

"at its widest point, but in dry seasons it is rather a chain of lakes separated by alkali-covered mud flats, and when visited in August 1926, the eastern half of the lake was dry with a white incrustation of salts not more than an inch in thickness. Only the western end of the lake contained a greenish-colored brine to a depth of 3 feet, underneath which a soft oozy mud occurred which could be penetrated by a pole to a depth of 10 feet.

"The area of the western part of the lake in which brine occurred was approximately 60 acres. The tonnage of salts present in the brine will run 15,000 tons per foot of depth.

"A spring of potable water flows out of the hillside, 30 feet above the shore of the lake on the south side. As the season advances the shoreline recedes, leaving an incrustation of salts surrounding the lake. No crystal bed was encountered in any part of the lake. Information as to whether the lake ever becomes completely dry was not available.

"A sample of the brine from the centre of the western half of the lake was taken at a depth of 2 feet below the surface and analyzed with the following results:"

Total solids - 14.69%
Sp.G. at 22 deg. C. - 1.161

Composition of Solids

Na_2CO_3 - 81.42%
$NaHCO_3$ - 10.03%
$NaCl$ - 2.17
Na_2SO_4 - 5.93
$MgCl_2$ - 0.45
$MgSO_4$ - nil
KCl - nil
K_2CO_3 - nil

Sodium Sulphate Lakes

Lakes in which sodium sulphate is the major constituent are, as far as known, found only in the Kamloops area. They are similar in form and occurrence to the sodium carbonate lakes of the same region.

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Lake No. 2 (Map 3, No. 2)

Lake No. 2 lies about one mile to the south-east of Lake No. 1 and at approximately the same elevation. The surface of the ground is largely drift-covered, but outcrops are common; the lake and its drainage basin are underlain by basic porphyritic volcanics.

The lake is about 7 1/2 acres in area and occupies a sharp narrow depression. Its drainage basin covers approximately 900 acres. The lake was practically dry in October, 1937, except for a small moist area on the south-west shore suggestive of springs. In September 1938, 2 or 3 inches of brine covered half its surface.

In the autumn of 1937 most of the surface was covered by winter-crystal about 1 inch thick. Towards the south-east end of the lake the deposit was formed of circular areas separated by mud; even in the centre of the lake-bed a suggestion of this structure was preserved. The mud forming the remainder of the surface and surrounding the shore-line was heavily encrusted with white efflorescence of dried salts.

About 6 inches of soft black mud occurring beneath the surface layer contained tiny disseminated crystals and smelled strongly of hydrogen sulphide. Underlying this over at least three-quarters of the lake, was a deposit of hard massive permanent crystals. The writer was not equipped to investigate the depth of the crystal bed or its extent. In the Annual Report of the Minister of Mines, British Columbia, for 1930 (Ref. 4, p. 196) it is stated that 2 pits, 4 and 9 feet deep, were dug in solid permanent-crystal and that two holes were drilled, one showing 7 feet of crystal near the edge, the other 19 feet near the centre. On the basis of these figures alone an accurate estimate of the quantity of salts in the lake is impossible. On the other hand they do, in conjunction with the topography, suggest the presence of a large tonnage, probably from 100,000 to 200,000 tons.

The deposit is described in the Report of the Minister of Mines for British Columbia, 1922 (Ref. 2) and the following analyses given:

Composite sample of 6 Borings - (to depth 4')

Na_2SO_4	-	83.8%
MgO	-	.9%
Insol.	-	15.1
Fe and Al	-	tr.

Note: Recalculated to 100% water free basis. Sample contained 51% water of crystallization as analyzed.

Samples taken by the writer had the following analyses (1)

		Composite of 3 1-foot pits	Pure surface crystal
Na_2SO_4	-	79.2%	99.2%
$MgSO_4$	-	7.2	tr.
$CaSO_4$	-	2.8	nil
NaCl	-	---	.5
Insol	-	10.8	.3

(1) Chief Assayer, Victoria.

Note: Analyses recalculated to 100% water free basis. Samples as analyzed contained 36.7% and 51.2% water of crystallization respectively.

Assuming that some 100,000 to 200,000 tons of impure mirabilite is present in the lake, the sodium sulphate content would amount to 40,000 to 80,000 tons.

NE-73

Iron Mask Lake (Map 3, No. 5)

Iron Mask Lake is on the south side of the Kamloops-Cache Creek road about 6 miles from Kamloops. It is the first and largest of a series of small undrained lakes occurring at intervals along the road for nearly 4 miles to the west.

The lake is roughly half a mile long by 300 to 500 feet wide. The eastern end is covered with tailings from the old Iron Mask mine situated on the hillside above; the remainder was dry in October 1937, except for numerous shallow pools distributed over its central portion. The depression in which the lake lies is flanked on the north by a low hill underlain by greenstone and fresher porphyritic basic volcanics, and on the south by the slopes of Iron Mask Hill, underlain by diorite. The basin of the lake is closed at the west end by a low divide.

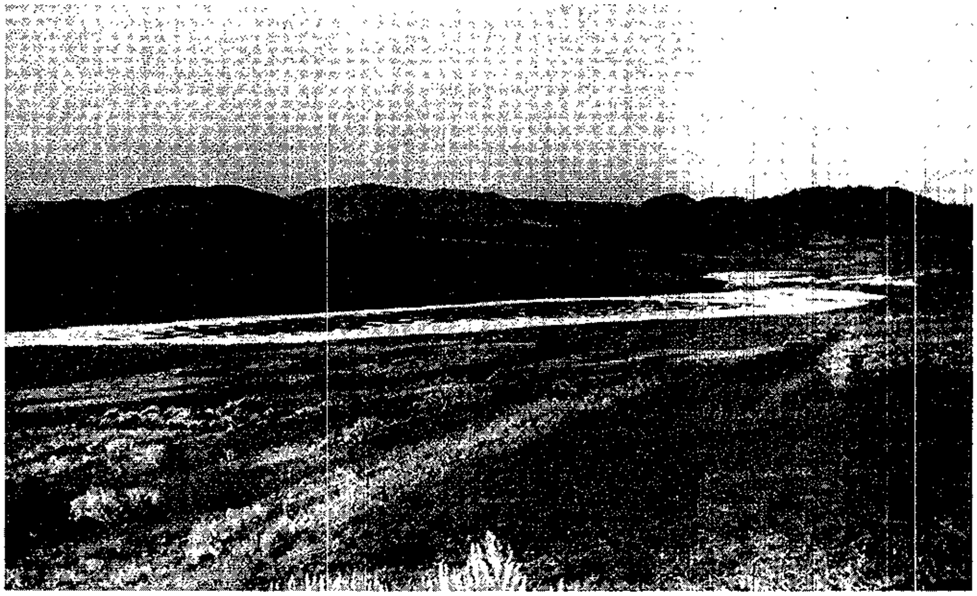
In October 1937, the surface of the lake was heavily encrusted with a white efflorescence of dried salts, but no permanent layer of crystal was observed. Beneath the encrustation was soft black mud containing, in places, sparsely disseminated mirabilite crystals and smelling strongly of hydrogen sulphide. The writer put down a number of 4-foot holes but as the mud surface of the lake was too soft for traffic, these were necessarily restricted to a zone within 40 feet of the shore. A bed of solid crystal was encountered in only three holes near the margin of the tailings dump, beneath 3 to 4 feet of mud. The thickness of the bed was not determined.

The lake was partly drilled several years ago and it is understood that an area of 5 acres was estimated to be underlain by a crystal-bed from 5 to 12 feet thick, containing approximately 50,000 tons. The depth of overlying mud ranged from 3 to 5 feet.

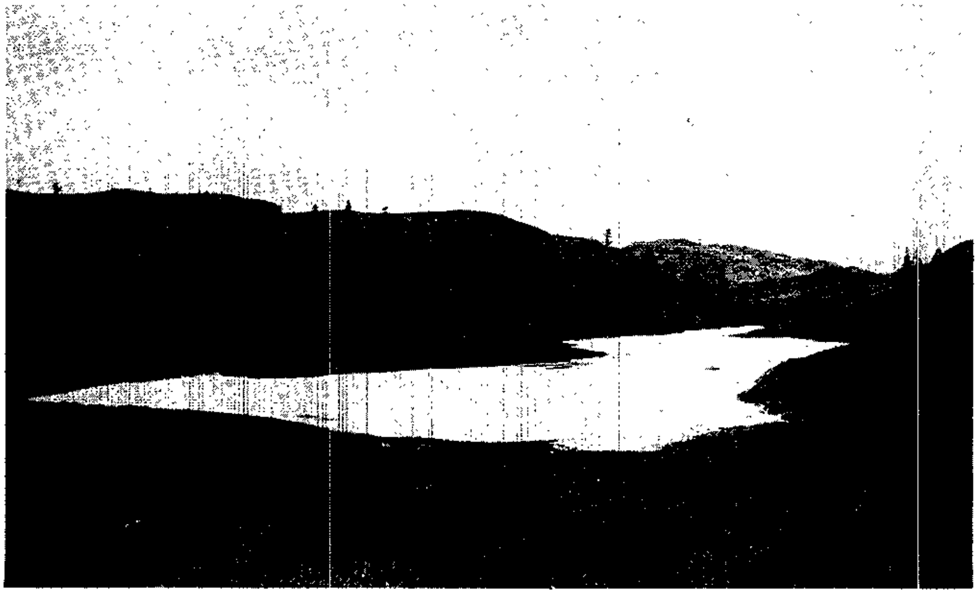
At the time of examination it was impossible to obtain samples of the permanent crystal and no analyses are on record. The following brine sample was taken from an old pit near the west end of the lake: (1)

Brine - Iron Mask Lake

Total Solids - 27.63%
Sp.G. at 16 deg. C. - 1.240



IRON MASK LAKE. (Map 3, No. 5.)
Picture looking north-eastward. Note " crystal bowl " surface of lake.



SODIUM SULPHATE DEPOSIT. (Map 3, No. 2.)
Picture looking northward.

Composition of Solids

Na_2SO_4	35.8%
$MgSO_4$	61.8
Na_2CO_3	2.0
NaCl	.4
$CaSO_4$	tr.

(1) Chief Assayer, Victoria.

Surface crystals formed on the lake later in the season; a sample forwarded to the Department of Mines had the following composition: (1)

Na_2SO_4	94.2%
$MgSO_4$	5.1%
Na_2CO_3	.5%
Insol.	.2%

(1) Chief Assayer, Victoria.

Note: Recalculated to a 100% water free basis. Sample as analyzed contained 5.3% water.

Lake No. 4 (Map 3, No. 4)

NE-74

Lake No. 4, about 4 1/2 acres in area, lies west of Iron Mask Lake in the same general depression, although its surface is 30 to 40 feet lower. The divide between the two is only about 10 feet above the surface of Iron Mask Lake. Diorite outcrops along the south shore.

The lake is roughly circular and the shorelines steep. In October 1937, at least 5 feet of brine was present. The shoreline was encrusted with dried salts but no permanent crystals were noted. A sample of the brine, taken by the writer, had the following composition: (1)

Total solids	11.67%
Sp.G. at 16 deg. C.	1.1075

Composition of Solids

Na_2SO_4	32.8%
$MgSO_4$	62.0%
NaCl	1.6%
Na_2CO_3	1.4%
$CaSO_4$	2.1%

(1) Chief Assayer, Victoria.

The similarity of the brine to that of Iron Mask Lake is notable. For this reason the lake, though containing a preponderance of magnesium sulphate was included with the sodium sulphate lakes.

Crystals - Goudge

	Top crystal - 2"	2"-1'	Stock Pile
Na_2SO_4	91.72%	57.77%	73.52
$MgSO_4$	7.23	14.04	6.98
$NaHCO_3$	0.38	0.97	0.96
NaCl	0.20	0.07	0.06
$CaSO_4$	0.27	5.71	4.86
Insol.	0.20	21.44	13.62

Magnesium Sulphate Lakes

Lakes in which magnesium sulphate is the predominant constituent occur in the Clinton, Ashcroft, Kamloops, and Osoyoos areas. All are small undrained lakes similar to the sodium carbonate and sulphate lakes already discussed. Actually the only distinction which can be drawn between the sodium sulphate and magnesium sulphate lakes is one of convenience insofar as both components are invariably present in each type.

Clinton Area (Map 2)

Clinton Lake (Map 2, No. 18)

Clinton Lake is 1 mile south of Clinton on the east side of the Clinton-Cache Creek Highway. It occupies a shallow depression flanked on the east by a high ridge composed of rocks of the Cache Creek Series. The lake, although of little if any present economic importance is interesting, not only as having been a commercial source of epsomite in the past, but through the series of changes it has undergone.

Brine covered approximately 15 acres to a depth of several feet in October 1937; the area and depth were much the same in October 1924 (Ref. 7, p. 76). No crystal-deposit was present at either time.

The following description of the lake in 1919 is quoted from a report by Reinecke (Ref. 9, p. 53):

> "During the summer the ... lake is generally occupied by only a few inches of water surrounded by a rim of white salt. Beneath the few inches of water are numerous, roughly circular areas 10 to 35 feet across, somewhat crowded together and white or dark according to the light conditions. The upper part of each of these areas or what are known as pools consists of a layer of nearly pure epsomite, and epsomite mixed with dark mud

"occurs between the pools. The quantity of water in the lake seems to vary daily even during continued periods of rainless weather. According to the older inhabitants of Clinton, the site of this lake was at one time an irrigated hay meadow, at another time it was occupied by a lake, and the deposits of epsomite have been in evidence for the last few years only. The writer was informed by the manager of the salt works that an inch or more of epsomite crystallizes in the pools during certain seasons.

"The epsomite lake at Clinton covers an area of about 24 acres, of which it is estimated, less than one-half is floored by the circular epsomite deposits. Since the actual aggregate areal extent of the pools is not known and since only scanty data as to thickness are available, no close estimate of the tonnage can be made."

Goudge (Ref. 7, p. 76) gives the following analysis of a brine sample taken by him in 1924:

Total Solids - 13.97%
Sp.G. at 22 deg. C. - 1.123

Composition of Solids

$MgSO_4$	-	84.05%
$Mg(HCO_3)_2$	-	0.18
Na_2SO_4	-	3.45
NaCl	-	9.50
KCl	-	1.16
Excess HCO_3	-	1.65

The brine in 1924 would have contained some 8000 to 9000 tons of salts representing 6000 to 7000 tons of magnesium sulphate.

From 1918 to 1920 approximately 2000 tons of epsomite was taken from the lake, over 1000 tons of which was sold.

Other Lakes

Reinecke mentions (Ref. 7, p. 53) that in 1919 Three Mile Lake (Map 2, No. 19) contained a strong solution, 10 to 18 degrees Baumé (Sp.G. 1.074 - 1.148) of magnesium sulphate and sodium sulphate in the proportion of 4 to 1. A brine sample taken by the writer in October 1937, from the south end of the lake had a specific gravity of 1.008, one from the north end had a specific gravity of 1.003. The brine contained (1):

Total Solids - .38 to .66%

Composition of Solids

$MgSO_4$	74%
Na_2SO_4	5%
$NaCl$	1.5%
Na_2CO_3	7%
$CaSO_4$	12.5%

(1) Chief Assayer, Victoria.

Ashcroft Area

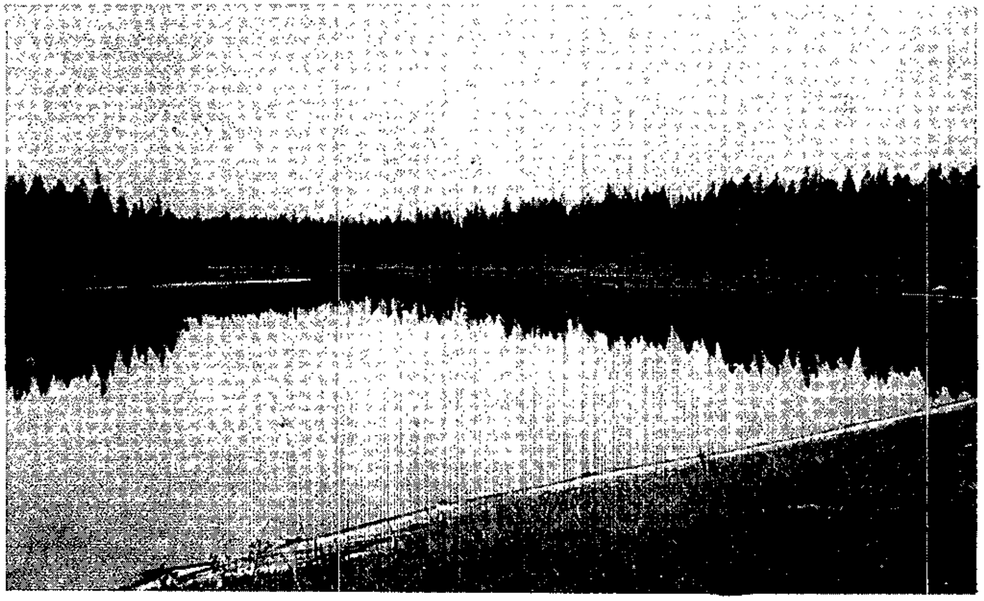
Basque Epsomite Deposits (Map 5)

The Basque epsomite deposits are about 3 miles west of the Canadian National Railway and 3 miles south of Basque. Ashcroft is 12 miles to the northeast.

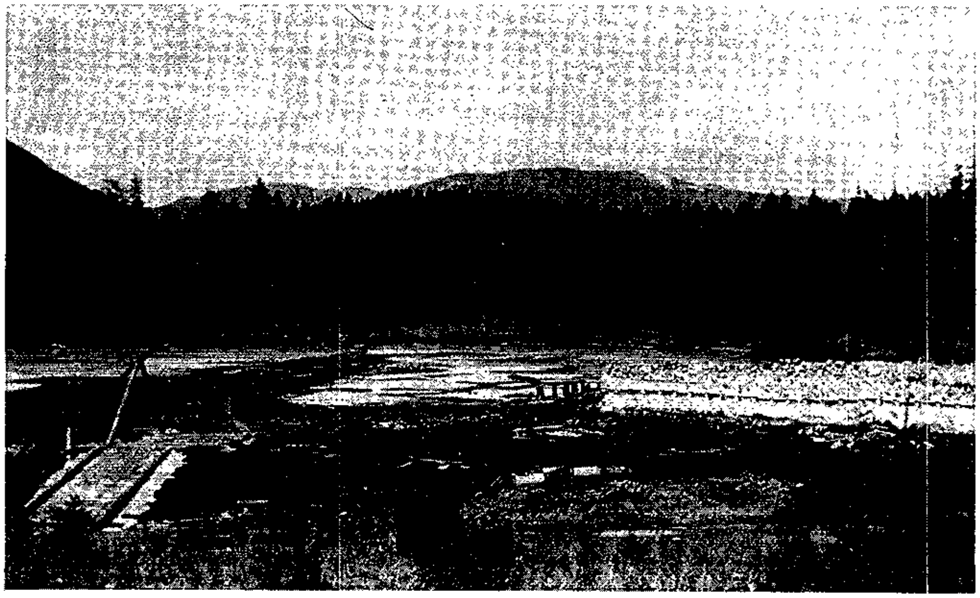
The deposits occur in 4 small ponds in a narrow rocky valley. The surrounding country is mountainous and rugged. Argillite, shale, and argillaceous limestone of the Lower Cache Creek Series are exposed in the vicinity of the deposits.

The writer visited the Basque deposits in October 1937 with the object of obtaining samples and substantiating past reports in respect to present conditions. Neither equipment nor time were available for drilling. The deposits were examined in detail by Goudge during the autumn of 1924, and insofar as there have been no marked changes since that time, the following description is quoted from his report: (Ref. 7, p. 65).

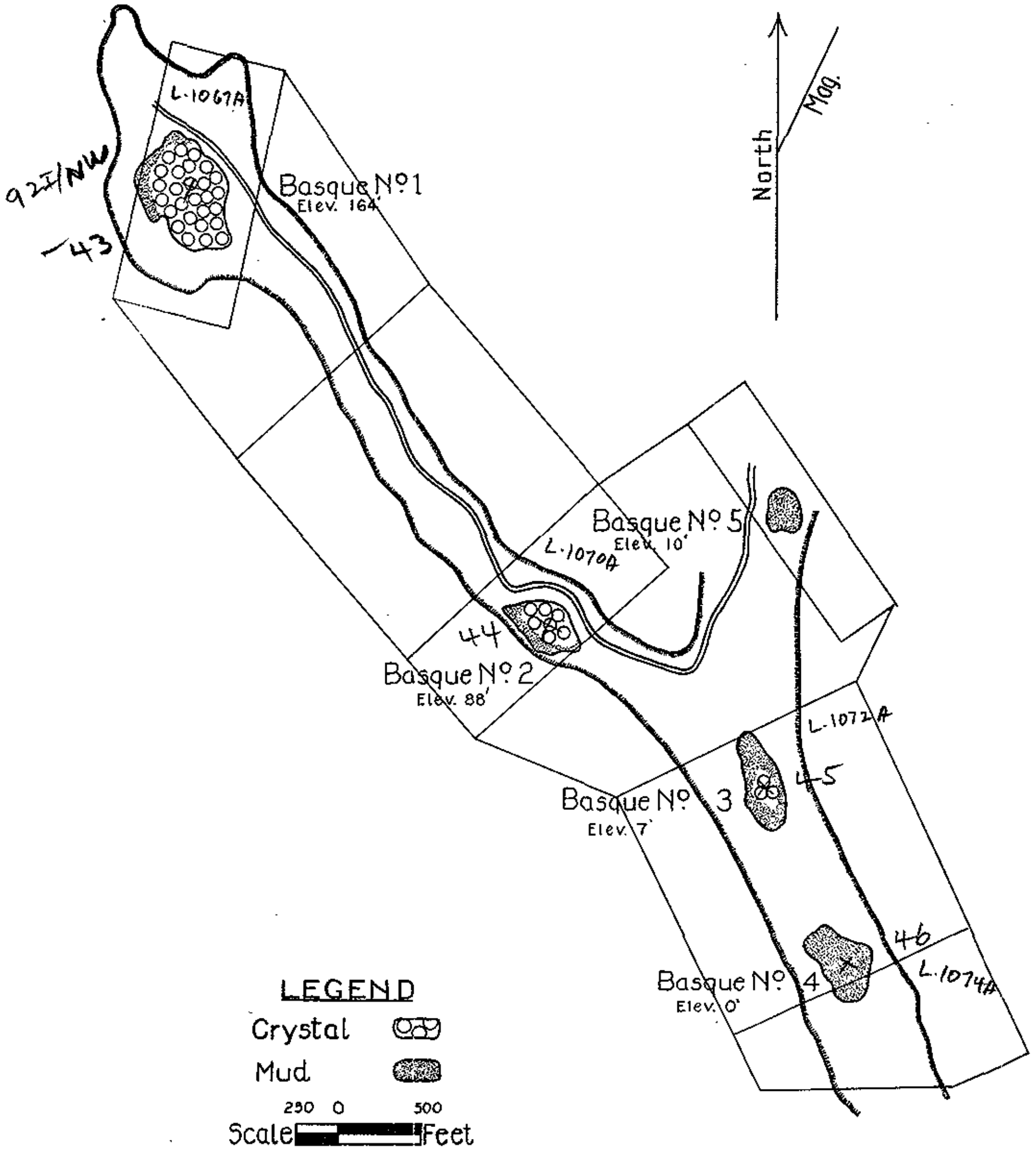
> "The deposits of mixed magnesium and sodium salts occur in four small basins or mud-filled ponds in the sloping floor of the middle valley (Map 5). The distance between the first and fourth basin is about 5000 feet. The basins are formed by transverse dams of boulder clay, which reach entirely across the valley. There is no rock visible in these transverse ridges and presumably they are composed entirely of boulder clay. The ponds vary in length from 450 to 600 feet and in width from 200 to 450 feet. The sodium and magnesium crystal in each of these ponds occurs as bowl-shaped masses of relatively clean crystal separated from each other by mud. This mud is raised up from 2 to 8 inches above the level surface of the crystal and forms a border or ring around the crystal bowl. In wet weather and during the spring and early summer there is brine on top of the



HUTCHISON LAKE. (Map 2, No. 17.)
Looking westward. Black fringe on water-line composed of swarms of soda-flies.



BASQUE EPSOMITE DEPOSIT. (Map 5.)
Basque No. 1, looking northward. Shows typical "crystal bowl" surface in middle distance. Note stock pile of crude salt to right.



MAP 5.
Basque epsomite deposits (after Goudge).

"crystal. At such times when viewed from the shore, the deposit appears as a number of shallow circular pools the bottoms of which are composed of crystal.

"The mud separating the bowls of crystal is a fine silt containing a very few rounded pebbles. It is very compact even at the surface; at depth it is jet black "in color, has a pungent odor in which hydrogen sulphide is recognizable, and contains tiny shining crystals, presumably epsomite. On exposure, this black mud quickly changes to a greyish green colour. Chemical analysis shows this mud to contain from 45 to 60 per cent calcium sulphate and from 2 to 7 per cent organic matter.

"In the official mining records at Ashcroft, B. C., the mineral claims enclosing these ponds are named Basque No. 1, Basque No. 2, etc., but in this report these names will be applied to the ponds to distinguish them from one another."

The following information respecting the individual deposits is based on Goudge's description augmented by comments by the writer. It is presented in semi-tabular form for the sake of brevity.

Basque No. 1

92I/NW -43

Area - The pond covers approximately 234,000 square feet; about 190,000 square feet are covered by crystal-deposits (including mud between).

Form of Crystal-Deposits - Some bowl-like masses are up to 60 feet in diameter and retain their area with only slight diminution to a depth of at least 5 feet. The "bowls" drilled showed very hard crystals at 4 to 6 feet. Only a small one near the shore, was penetrated to the mud beneath at 10 feet. Another near the centre of the pond showed 14 feet of crystal without bottom being reached. Goudge considers the general depth to exceed 10 feet.

Nature of the crystals - Pits could not be dug to a greater depth than 4 1/2 feet owing to an inrush of brine; the deeper ones indicated that the hard layer was composed of bloedite ($Na_2SO_4.MgSO_4.4H_2O$) mixed with epsomite ($MgSO_4.7H_2O$). The clean top crystal-layer is about 2 1/2 inches thick; beneath it, and commonly separated from it by a thin layer of mud, is a layer averaging 3 1/2 feet thick composed of interlocking epsomite crystals with a little admixed mud.

Analyses

Surface Crystal - 3" thick

	Goudge (Ref. 7, p. 68)			Writer (1)
	Top	Middle	Bottom	3" thickness
$MgSO_4$	99.10%	97.10%	92.17%	99.0%
Na_2SO_4	---	1.75	6.56	.5
$NaHCO_3$	0.48	0.49	----	) tr.
Na_2CO_3	---	---	0.45	)
NaCl	0.15	0.15	0.14	tr.
Insol.	0.27	0.51	0.68	.5

(1) Chief Assayer, Victoria.

Note: Recalculated to 100% water free basis. The writer's sample contained 51.3% water of crystallization as analyzed.

Analyses of Crystal Bed - Goudge
(Ref. 7, p. 69)

	0-1'	1'- 3'	3'- 4'	$3\frac{1}{2}$'- 4'	4'- $4\frac{1}{2}$'	1'- 3'	3'- 4'
$MgSO_4$	81.89%	90.85%	90.03%	81.43%	77.72%	91.00%	71.07
Na_2SO_4	0.83	---	---	2.26	10.54	2.42	17.06
$NaHCO_3$	0.47	0.43	0.54	0.40	0.34	0.24	0.91
Na_2CO_3	---	---	---	---	---	---	0.33
NaCl	0.15	0.16	0.17	0.67	0.24	0.05	0.73
$CaSO_4$	9.31	3.23	3.20	9.93	7.43	4.41	3.95
Insol.	7.35	5.33	6.06	5.31	3.73	1.88	5.95

Note: Analyses recalculated to 100% water free basis.

Brine - 2 to 6 inches of brine covered the crystal pools in October 1924. None was present in October 1937, other than in a pit of unknown depth at the south end of the lake.

Analyses of Brine Samples

	Goudge (Ref. 7, p. 75)			Writer
	1	2	3	4
Total Solids	25.8%	31.7%	28.9%	33.3%
Sp.G.	1.283	1.334	1.318	1.29

Composition of Solids

$MgSO_4$	-	80.95%	69.52%	76.56%	75.0%
$Mg(HCO_3)_2$	-	1.41	----	0.29	-----
Na_2SO_4	-	16.30	26.64	21.10	24.5
NaCl	-	0.19	0.12	----	----
K_2SO_4	-	----	----	0.50	----
KCl	-	1.15	3.72	1.55	----
Na_2CO_3	-	----	----	----	----
$CaSO_4$	-	----	----	----	tr.

1. Composite sample from 10 pools on surface of Basque No. 1 - Oct. 1924.
2. Large flow encountered at depth 2 1/2 feet in pit in one of central crystal bowls - Basque No. 1.
3. Large spring encountered at depth of 8 feet in pit in mud near centre of Basque No. 1.
4. Pit at north end of lake. - Analyzed by Chief Assayer.

Tonnage - Assuming the average depth in Basque No. 1 deposit to be 10 feet, Goudge estimates the total quantity of sodium and magnesium salts available to be about 64,800 tons. This may be taken as a minimum figure, insofar as the average depth of crystal probably exceeds 10 feet. The top 3 feet in all the bowls is principally epsomite; on this basis the amount of practically pure epsomite present in 1924 was 20,000 tons.

Basque No. 2

NW-44

Area - The pond covers approximately 90,000 square feet of which 47,000 is underlain by crystal "bowls" with their encircling mud rings.

Form of Crystal-Deposits - The crystal-masses are separated from each other by only a few inches to 1 1/2 feet of mud. Their average depth including mud layers is 5 1/2 feet, the deepest being slightly over 10 feet.

Nature of the Crystals - Pits were dug without trouble from brine inflow. The following is a typical section:

0 - 7" - Clean top crystal.
7" - 1'1" - Dark colored, compact crystal.
1'1" - 1'7" - Clear massive crystal.
1'7" - 2'9" - Mud and loose crystals.
2'9" - 6'6" - Hard dark crystal.
6'6" - 9' plus - Black Mud.

The top layer averages 1 foot thick and covers practically the whole pond; it was deposited from solutions drained from Basque No. 1 to facilitate operations during the period this was worked.

Analyses

Goudge (Ref. 7, p. 70)

	1	2	3	4	5	6	7	8	9	10	11
$MgSO_4$	78.39%	93.90%	69.94%	63.39%	18.89%	65.84%	63.28	54.55%	8.67%	94.79%	66.20%
Na_2SO_4	18.96	4.62	28.03	35.82	8.61	29.10	32.64	40.18	18.53	tr.	19.90
$NaHCO_3$	0.56	0.50	0.60	0.49	0.08	0.83	0.76	0.58	0.92	0.34	0.69
Na_2CO_3	0.63	0.03	----	tr.	----	----	----	----	tr.	----	----
NaCl	1.05	0.27	0.18	0.10	0.54	0.16	0.14	0.17	0.13	0.05	0.48
$CaSO_4$	tr.	0.44	tr.	tr.	13.45	2.20	1.46	2.05	13.31	2.99	5.61
Insol.	0.41	0.24	1.25	0.20	58.43	1.87	1.72	2.47	58.44	1.83	7.12

Note: Recalculated to 100% water free basis.

1. Hole No. 1 - Top crystal 0-3"
2. Hole No. 1 - Crystal 3"-4"
3. Hole No. 1 - Crystal 4"-1'1"
4. Hole No. 1 - Crystal 1'1"-1'7"
5. Hole No. 1 - Mud 1'7"-2'9"
6. Hole No. 1 - Crystal 2'9"-3'9"
7. Hole No. 1 - Crystal 3'9"-4'9"
8. Hole No. 1 - Crystal 4'9"-6'6"
9. Hole No. 1 - Mud 6'6"-7'10"
10. Hole No. 2 - Crystal 3"-1'3"
11. Hole No. 2 - Crystal 1'3"-2'3"

Brine - In October 1924, 2 to 6 inches of brine covered the surface of the pond; about the same quantity was present in October 1937.

Analyses of Brines - Goudge (Ref. 7, p. 73)

	Surface of Basque No. 2	Seepage into pits
Total Solids	28.3%	3.21%
Sp. Gr.	1.304	1.349

Composition of Solids

$MgSO_4$	73.54%	66.07%
Na_2SO_4	20.37	30.07
$Mg(HCO_3)_2$	1.34	----
NaCl	----	----
K_2SO_4	0.27	0.21
KCl	4.45	3.65

Tonnage - Assuming the average depth to be 4 feet, Goudge estimates the amount of combined sodium and magnesium salts in Basque No. 2 deposit to be 8500 tons.

NW-45

Basque No. 3

Area - The pond has an area of 90,000 square feet of which 27,000 are covered with crystal bowls and intervening mud rings.

Forms of Crystal-Deposits - The "bowls" average 30 feet in diameter and have an average depth of 3 feet.

Nature of the Crystal - A pit showed a clean top crystal-layer 3 inches thick, underlain by soft black mud 4 inches to 1 foot thick, followed by hard clean crystals composed principally of bloedite.

Analyses

Basque No. 3 - Goudge (Ref. 7, p. 72)

	1	2	3	4	5	6
$MgSO_4$	98.79%	95.10%	90.90%	53.64%	55.24%	53.41%
Na_2SO_4	tr.	1.31	tr.	44.30	42.87	43.45
$NaHCO_3$	0.79	1.46	0.82	0.49	0.46	0.53
Na_2CO_3	----	0.10	----	----	----	----
NaCl	0.10	0.11	0.12	0.14	0.06	tr.
$CaSO_4$	0.07	1.46	3.46	0.65	0.54	1.01
Insol.	0.25	0.46	4.70	0.78	0.83	1.60

Note: Recalculated to 100% water free basis.

1. Top crystal - 0-3"
2. Crystal - 3"-6"
3. Hole No. 1 - Crystal 6"-1'6"
4. Hole No. 1 - Crystal 1'6"-2'6"
5. Hole No. 1 - Crystal 2'6"-3'6"
6. Hole No. 2 - Crystal 6"-1'6"

Brine

Analysis of surface brine - 1" Goudge
(Ref. 7, p. 73)

Total Solids	26.7%
Sp.G.	1.301

Composition of Solids

$MgSO_4$	80.56%
Na_2SO_4	17.64
$Mg(HCO_3)_2$	0.05
NaCl	----
K_2SO_4	0.39
KCl	1.36

Tonnage - Assuming an average depth of 2 1/2 feet, Goudge estimates the pond to contain about 2000 tons of hydrous salts.

NW-46

Basque No. 4

Area - About 1600 square feet covered by crystal.

Form of crystal-deposits - The crystal-masses, 18 in number, range from 6 to 15 feet in diameter and 2 to 8 feet in depth.

Analyses

Crystal - Goudge (Ref. 7, p. 72)

	Hole No. 1 - 0 to 1 foot	Hole No. 2 - 0 to 1 foot
$MgSO_4$	70.69%	73.60%
Na_2SO_4	9.87	14.98
$NaHCO_3$	1.11	1.19
Na_2CO_3	tr.	----
NaCl	0.14	0.05
$CaSO_4$	3.53	1.14
Insol.	14.66	9.04

Note: Recalculated to 100% water free basis.

Brine

Analysis of Surface Brine

1" depth - Goudge (Ref. 7, p. 73)

Total Solids	-	19.2%
Sp.G.	-	1.193

Composition of Solids

$MgSO_4$	-	65.43%
Na_2SO_4	-	32.71
K_2SO_4	-	0.48
KCl	-	1.38

Tonnage - Goudge estimates about 200 tons of mixed sodium and magnesium salts present in Basque No. 4.

According to Goudge's estimates (Ref. 7, p. 73) the minimum tonnage of crude hydrous salts, chiefly epsomite and bloedite, in the Basque deposits in 1924 was as follows:

Basque No. 1	Epsomite	20,000 tons
	Combined sodium and Magnesium salts	44,800 tons
Basque No. 2	Combined sodium and Magnesium salts	8,500 tons
Basque No. 3	Combined Sodium and Magnesium salts	2,000 tons
Basque No. 4	Combined Sodium and Magnesium salts	200 tons
	Total	75,500 tons

About 2300 tons of surface crystal was shipped to Vancouver during the period from 1919 to 1923. The deposits lay idle from 1924 to 1933. At least 3000 tons more was removed from 1934 to 1937, and approximately 2400 tons of this refined and sold.

Kamloops Area

NE-18

Several small lakes (Map 3, No. 7), on the rolling plateau surface north of Kamloops and west of the North Thompson River, contain concentrated brines in which magnesium sulphate predominates. One of these, about 6 miles from Kamloops, contained brine of the following composition: (1)

Brine Sample	-	(October, 1937)
Total Solids	-	20.8%
Sp.G. at 16 deg. C.	-	1.1895

Composition of Solids

$MgSO_4$	-	84.0%
Na_2SO_4	-	14.7
Na_2CO_3	-	1.0
$NaCl$	-	.2
$CaSO_4$	-	tr.

(1) Chief Assayer, Victoria.

The lake, slightly over 2 acres in area, occupies a sharp basin-like depression. The depth of brine in the centre probably exceeds 5 feet. The quantity of salts in solution is approximately 800 tons per foot depth. The only crystal noted was in the form of thin films of interlocking epsomite crystals occupying depressions along the shore.

Another small lake about 1 1/2 miles to the south was sampled. The brine analysis was as follows: (1)

Total Solids	-	6.0%
Sp.G. at 16 deg. C.	-	1.049

Composition of Solids

$MgSO_4$	-	65.0
Na_2SO_4	-	31.0
Na_2CO_3	-	1.4
$NaCl$	-	tr.
$CaSO_4$	-	2.4

(1) Chief Assayer, Victoria.

The area in which the lakes occur is underlain by argillite, quartzite, and limestone of the lower Cache Creek Series.

Osoyoos Area

Spotted Lake Deposit

The Spotted Lake deposit occurs in a lake covering approximately 20 acres, situated near the summit of Richter's

Pass about 6 miles from Osoyoos. The Osoyoos-Similkameen Road is about a quarter of a mile to the north.

The region traversed by Richter's Pass is rolling to mountainous, the summits of Richter and Kruger Mountains, on the northwest and southeast respectively, being over 4500 feet in elevation. Precipitation is light, averaging only 8 inches a year at Oliver, 10 miles to the north.

On the north and west of the lake occurs (Map 85A with G.S.C. Mem. No. 38) a complex of schists and basic intrusives, on the east metamorphosed sediments intruded by granodiorite, and on the south nepheline syenite.

When examined by the writer in June 1938 the lake was covered with 6 to 8 inches of brine. Insofar as this precluded further investigation, the following description is quoted from a report by Goudge (Ref. 7, p. 78)

> "The crystal in this lake occurs in the same bowl-like formation that characterizes the other magnesium sulphate deposits in British Columbia.
>
> "The crystal-bowls occupy from 50 to 60 per cent of the area of the lake bed. In size they vary from 20 to 80 feet in diameter, and average about 3 1/2 feet in depth.
>
> "The encircling mud rings are raised 4 inches to 1 1/2 feet above the crystal level and the mud which is dark in color, contains numerous crystals of gypsum. The analyses of two samples of this mud show it to contain 70 to 80 per cent calcium sulphate."

When examined by Goudge about 4 inches of brine covered the lake; it was therefore impossible to dig pits for the purpose of obtaining samples. A number of "bowls" were tested for depth. He notes that down to 2 feet the crystal-deposit was hard but from there to the bottom it was comparatively soft. The surface layer, about 2 inches thick, was very clean.

Analyses of the surface crystals follow:

Goudge (Ref. 7, p. 78)

	1	2	3	4	5	6
$MgSO_4$	50.20%	44.67%	47.25%	47.04%	47.21%	69.
Na_2SO_4	48.08	53.80	51.16	51.67	46.62	23
$NaHCO_3$	0.49	0.57	0.56	0.48	0.50	
Na_2CO_3	----	----	----	tr.	----	----
NaCl	0.17	0.22	0.15	0.14	0.22	
$CaSO_4$	0.70	0.28	0.70	0.41	3.11	
Insol.	0.36	0.46	0.18	0.26	2.44	2

The samples 1 to 5 represent surface crystals from "bowls"; No. 6 is from the interior of one of the stock piles on the shore.

The following analysis of surface crystals, as harvested commercially when the deposit was worked, was furnished through the courtesy of Chas. Newall, of Seattle.

$MgSO_4$	-	57.58%
Na_2SO_4	-	42.38%
Alkalinity	-	nil
Cl		tr.

Note: Recalculated to 100% water free basis. Analysis as furnished contained 40.26% water of crystallization.

Goudge estimates the lake to contain approximately 50,000 tons of hydrous salts of magnesium and sodium.

According to records about 1500 tons of crystal were taken from Spotted Lake between 1915 and 1919 and shipped to Oroville, Washington, 12 miles distant, for refining and sale.

Summary

The more important sodium carbonate, sodium sulphate, and magnesium sulphate deposits of British Columbia are listed below with pertinent data.

Sodium Carbonate

Deposit	Ref.	Occurrence	% Solids	Estimated Tonnage	
				Total Salts	Sodium Carbonate
83 Mile L.	Map 2, No. 1	Brine	4.85%	1,100	1,000
Goodenough L.	" No. 4	Muddy, permanent crystals	-----	10,000	3,000
Liberty L.	" No. 7	Brine and Winter-crystal	13.78%	1,800	1,500
Rob and Nan L.	" No. 9	Brine	11.29%	3,000	2,600
Last Chance L.	" No. 10	Permanent crystals	----	70,000	17,500
Margaret L.	" No. 11	Brine and Winter-crystal	13.38%	900	850
Anita L.	" No. 12	Brine and Winter-crystal	12.44%	3,200	3,000
Lela L.	" No. 12	Brine	7.02	600	550
White Elephant L	" No. 14	Brine	8.3%	2,050	2,000
Rose L.	" No. 15	Brine	8.17%	6,500	6,500
Hutchison L.	" No. 17	Brine	7.0%	13,000	12,500
Lake No. 1	Map 3, No. 1	Permanent crystals	----	100,000	20,000
Soap Lake	Map 5,	Brine and Winter-crystal	14.69(1926)	45,000	40,000 (1926)
	Approximate total salts -			257,150	
	" " sodium carbonate -				103,000

Table (continued) Sodium Sulphate

Deposit	Ref.	Occurrence	% Solids	Estimated Tonnage Total Salts	Sodium Carbonate
Lake No. 2	Map 3, No. 2	Permanent crystal	----	150,000 =	60,000
Iron Mask Lake	Map 3, No. 5	Permanent crystal	----	50,000 =	20,000
Lake No. 4	" No. 4	Brine	11.67%	3,000	1,000
	Approximate total salts -			203,000	
	" " sodium sulphate -				81,000
Magnesium Sulphate					Magnesium Sulphate
Basque Deposits	Map 4	Permanent crystal	----	Epsomite 20,000 Mixed 55,500	10,000 25,200
Spotted Lake		Permanent crystal	----	Mixed 50,000	13,000
Clinton Lake	Map 2, No. 18	Brine	13.97 (1924)	8,000	6,000(1924)
Lake No. 7	Map 3, No. 7	Brine	20.8%	- 4,000	3,400
		Approximate total	salts -	137,500	
		" "	magnesium sulphate -		57,600

History and Development

The soda lakes of the Green Timber Plateau were first reported upon in 1897 (Ref. 8, p. 11R). At that time winter-crystal was known to form only in Goodenough and Last Chance Lakes. These were staked in 1897 and natron harvested from the former during the winter of 1897-98. No further interest was taken, however, until war-time prices gave encouragement to the exploitation of local soda deposits. Margaret, Anita, White Elephant, Rose, and Rob and Nan Lakes were staked from 1916 to 1921, and two small plants installed for the purpose of producing soda ash. No commercial production was made, although winter-crystal was shipped. A more ambitious but futile attempt to dehydrate the permanent crystal-deposit of Last Chance Lake was made in 1924. In the same year Lela and Hutchison Lakes were staked. A dehydrating plant was erected at White Elephant Lake in 1926, and a second one in 1928. Altogether only 2 carloads of soda ash were shipped before operations were permanently suspended. In 1929 a plant was built at Last Chance Lake but did not operate commercially.

In 1930 Lake No. 1 (Kamloops) was staked, a boiler and pumping equipment installed, and exploratory work done. From 1931 to 1935 regular shipments of natron were made.

For the last ten years small but regular annual shipments of winter-crystal or natron have been made by operators in the Green Timber Plateau area; no further developments have been attempted.

As far as can be ascertained from old records, a total of 7750 tons of natron, valued at approximately $70,000 has been produced and sold from soda lakes in the Green Timber Plateau and Kamloops areas.

A brief summary of the dehydrating plants erected at the more important lakes is presented.

Last Chance Lake (Map 2, No. 10)

1923 - Owners - Lillooet Soda Company
Other Deposits held - Goodenough and Rob and Nan Lakes.

Description of Plant
Quoted from report by Goudge (Ref. 6, p. 96)

"During that summer (1923) the Lillooet Soda Company erected several substantial log buildings at this "lake and the first unit of a small plant designed to produce soda ash was built. The unit consisted of a horizontal fire-tube boiler with a portion of the outer shell removed on one side, and a steel box or sump rivetted to the side where the shell was cut away. The proposed method of operating the plant was to fill the boiler and sump with brine (obtained either direct from the lake or by dissolving the muddy crystal, letting it settle, and siphoning off the clear brine), and then to concentrate the brine by evaporation until the monohydrate dropped out. Rakes fastened to an endless chain were constantly in motion in the sump and were supposed to set up currents in the brine that would sweep the monohydrate crystals into the sump as they were formed, from where they could be discharged by the rakes. It did not work satisfactorily."

1929 - Owners - B. C. Chemical Co.
Other deposits held - Rob and Nan Lake.
Description of Plant - Quoted from Report of the Minister of Mines for British Columbia, 1929 (Ref. 3, p. 230)

"A plant capable of handling an estimated output of 1.5 tons an hour has been erected, the scheme of treatment being briefly as follows: The salt which at the present time is being dug by hand from the encrusted surface of the dried-up lake, is delivered by an incline conveyor to a dissolving and cleaning tank. This tank is a steel punt-shaped receptable 30 feet long and 5 feet 6 inches in diameter, in which a travelling link-belt is fitted. Heat is applied to the bottom of this receptacle by steam-coils by means of which the crystal is liquefied, and the suspended mud is withdrawn on the slowly-travelling belt, being elevated above the surface of the liquid. The clarified solution is pumped to three storage tanks, in which the temperature requisite for maintaining solution is maintained by exhaust steam, and is withdrawn by a high-pressure pump and delivered in an atomized condition through sprays into a cyclone-type evaporator. This evaporator is in the form of an asbestos-covered steel inverted cone having a maximum diameter of 30 feet and 28 feet in height.

"Furnace gases from an oil-feed furnace adapted with Ray steam turbine oil-feed are introduced through an annular passage at the top of the evaporator; a thor-

"ough admixture of the whole content, together with a swirling motion, is provided by a central exhaust through a pipe submerged to a depth of several feet in the apparatus.

"The exhaust is maintained by a fan by which the gases and vapours are delivered to a second smaller evaporator which is introduced for the purpose of catching a proportion of the pulverized soda-ash which is carried off in the first operation.

"The soda-ash which is dessicated and pulverized in the evaporator at a temperature of approximately 600 degrees F. accumulates in the bottom of the cone and is withdrawn by a blower, and together with that recovered from the second evaporator is delivered to a storage silo in marketable form."

The results obtained from the plant described above were not satisfactory.

White Elephant Lake (Map 2, No. 14)

1926 - Owners - J. A. Coulson and Sons
Other Deposits - Rose Lake
Description of Plant

No details of the plant erected in 1926 are available other than that it had a daily capacity of 20 tons.

1928 - Owners - Dominion Soda Producers, Ltd.
Other Deposits - Rose, Anita, and other lakes.
Description of Plant

Details of the process employed are not on record. It was proposed to dehydrate natron, a sufficient quantity being harvested in the form of winter-crystal during the winter months to supply the plant for the year at the rate of 45 tons per day. Most of the equipment had been removed at the time of the writer's visit in 1937 except for 40 by 6 foot rotary drier. This, it is understood, was used for the actual dehydration of the natron. To what extent the plant was a success is not known; only a small amount of soda-ash was actually prepared, however, before the operation was permanently discontinued.

Anita Lake (Map 2, No. 12)

1918 - Owners - Pacific Coast Contractors, Ltd.
Other Deposits - no data.
Description of Plant

Quoted from Report by Goudge (Ref. 6, p. 96)

> "The plant of the Pacific Coast Contractors consisted of a large sheet-iron, evaporating pan 43 by 14 feet in plan, and 3 feet deep, with sloping sides. The lake brine was pumped into the pan and there concentrated by boiling. The heat was supplied by wood fuel. The hot concentrated brine was piped to crystallizing tanks, where, on cooling, crystal was deposited. The intention was to produce sodium carbonate crystal and then to calcine this to soda-ash but the ash furnace was never erected. Difficulties in evaporation and crystallization were the cause for the plant shutting down late in 1918 and operations were never resumed by this company."

Goodenough Lake (Map 2, No. 4)

1922-23 - Owners - Lillooet Soda Co., Ltd.
Other Deposits - Last Chance and Rob and Nan Lakes.
Description of Plant.

A small evaporating and crystallizing plant, similar in principle to that built at Anita Lake, was tried but was not successful.

Lake No. 1 (Map 3, No. 1)

1929 - Owners - C. W. Austin and A. C. Knowles
Other Deposits - Lake No. 2 (Map 3)
Description of plant

Boiler and pumping equipment was installed and a steam drill used to explore the crystal-deposit.

In 1930 the recovery process consisted of dissolving the permanent crystals by steam, pumping the solution to a settling tank to remove muddy impurities, and recrystallizing the sodium carbonate in the form of natron.

Sodium Sulphate

No sodium sulphate is known to have been produced commercially from natural deposits in British Columbia. Lake No. 2 (Map 3) was staked prior to 1923 but very little exploratory work was done until 1929. In that year pits were dug and the deposit drilled. There have been no further developments.

Iron Mask Lake was staked prior to 1932 and a little drilling and exploratory work carried out in the winter of 1932-33. Lake No. 3 was staked in 1932.

Magnesium Sulphate

Epsomite was first produced commercially in British Columbia during the early war years. Since then production has been intermittent. To date over 7000 tons of crude epsomite has been refined and sold, approximately 2800 tons of which was shipped between 1915 and 1920.

Spotted Lake was first worked in 1915 and shipments of crude salts were made annually until 1919. In 1918 both Clinton Lake and the Basque deposits were developed and epsomite produced until 1920 from the former and 1922 from the latter. Production from the Basque deposits was renewed in 1934 and has continued until the present.

A brief summary of the recovery methods used at the three deposits follows.

Spotted Lake

1915-1920 - Owners - Stewart-Calvert Co., Oroville, Wash.

Description of Methods and Plant

Crystal-slabs were dug from the lake by pick and shovel, taken ashore in wheelbarrows over plank runways and shipped to the Company's refinery at Oroville by truck.

The following description of the refining process is quoted from the Annual Report of the Minister of Mines for British Columbia, 1918 (Ref. 1, p. 213).

> "The process for treating the salts is as follows: First the raw product, a crystalline salts dug from the lake, is dissolved in tanks by means of steam; from thence the liquid salts pass through launders into the evaporating-tanks, where it is brought to a certain density; then run into other tanks lined with cement (magnesite), where it is cooled and recrystallized; the li-

"quid remaining being drawn off and pumped back into the boiling tank for further treatment. The crystals are then put through a Watson Laidlaw dryer with a 2-inch basket having a capacity of 15 tons every ten hours. After this preliminary drying the crystals pass through a chute into a rotary circular dryer, 25 feet long by 4 feet in width, which revolves from eight to ten times a minute. The screens at the discharge end have meshes varying from 1/2 × 1/16 to 3/32 × 1/2 inch. Directly outside the discharge end of the screen are a set of steam-coils so placed that the fan draws the hot air over the revolving salts. The temperature is kept below 80 degrees, so that the salts will not melt.

"Two grades of these salts are shipped, the finer crystals being used for medicinal purposes, whilst the coarser ones are used for tanning leather."

Crude epsomite from Spotted Lake, Clinton Lake and Epsom Lake, a small lake on Kruger Mountain, 2 1/2 miles north of Oroville, were treated in this plant. It is understood that the use of Spotted Lake material was largely restricted to the tanning industry owing to its relatively high content of sodium sulphate.

Clinton Lake (Map 2, No. 18)

1918-1920 - Owners - Stewart-Calvert Co.,
Oroville, Wash.

Description of Methods and Plant

Crystal-slabs were dug by pick and shovel from beneath the few inches of covering brine, transported to the shore by wheelbarrow over plank runways, sun-dried, broken by wooden mallet and screened through 1/4 inch mesh and shipped to Oroville where the less pure material was refined.

The plant at Oroville has been described in the previous section.

Basque Deposits (Map 5)

1917-18 - The deposits were staked and small shipments made.

1919-22 - Owners - Basque Chemical Co.

Description of Methods and Plant

Quoted from report by Goudge (Ref. 7, p. 75)

> "Crude surface crystal from Basque No. 1 was shipped to Vancouver and there prepared for market. The company erected at the deposits 15 or 20 wooden buildings including a number of comfortable dwelling houses for their workmen. A large building intended as a mill was also erected but very little machinery was installed. Operations ceased in 1923, after 2,300 tons of crystal had been removed from the surface of Basque No. 1....
>
> "The top crystal on Basque No. 1 was very pure when operations were first begun, but has since been contaminated. It was dug out of the various bowls by means of picks, crowbars, and shovels and taken ashore in carts. As the market warranted, shipments of the crude crystal were made to the company's refining plant in Vancouver where it was prepared for the market, the major part of the material, however, was stored in two sheds and in a large storage pile on the shore of the deposit....
>
> "The epsomite shipped to Vancouver only needed to be freed from the small amount of mud that was mixed with it, to provide, according to the company's statement, Epsom salt over 98 per cent pure."

In the refinery at Vancouver the crude went to a dissolving tank thence to settling and crystallizing tanks, the mother liquor being kept in circulation. The epsomite was dried and screened to three grades.

1934-1938 - Owners - Epsom Refineries Ltd.
Description of Methods and Plant

Crude crystal was taken from Basque No. 1 to the company's refinery at Ashcroft by trucks. Here it was dissolved and recrystallized to remove muddy impurities, dried and screened. Three grades were marketed and the plant had a capacity of 10 tons per day. The material was mined during the summer, a sufficient supply being accumulated for refining during the fall and winter.

1938-39 - Operations ceased in the spring of 1938 but refining was recommenced by a new company, Ashcroft Epsom Salts Co., Winnipeg, in the autumn of 1938 and was carried on during the winter of 1938-39.

Transportation

Data respecting transportation are listed in the following table.

Deposit	Ref.	Shipping Point & Railway	Approx. Distance to Shipping Point
83 Mile L.	Map 2, No. 1	70 Mile Stn., P.G.E.	13 miles by the Cariboo Highway.
Goodenough and Safety L.	" No. 4	Chasm, P.G.E.	22 miles by fair road.
Liberty L.	" No. 7	5 miles poor road 9 miles good road	Chasm, P.G.E.
Snow White L.	" No. 8	Chasm, P.G.E.	1 mile poor road. 13 miles fair road.
Rob and Nan and Last Chance L.	" Nos. 9 & 10	Chasm, P.G.E.	12 miles fair road.
Margaret L.	" No. 11	70 Mile Stn.,P.G.E.	4 miles poor road.
Anita and Lela L.	" No. 12	70 Mile Stn.,P.G.E.	4 miles poor road.
White Elephant L.	" No. 14	Coulson, P.G.E.	1/4 mile poor road.
Rose L.	" No. 15	Coulson, P.G.E.	none
Hutchison L.	" No. 17	70 Mile Stn., P.G.E.	6 miles by abandoned road.
Soap L.	Map 5	Spences Bridge, C.P.R.	7 miles pack trail.

Deposit	Ref.	Shipping Point & Railway	Approx. Distance to Shipping Point
Lake No. 1	Map 3, No. 1	Kamloops, C.P.R. or C.N.R.	12 miles good road could be handled by aerial tram to C.P.R. 1/2 to 3/4 mi. distance.
Barnes L.	Map 3	Kamloops, C.P.R. or C.N.R.	17 miles good road--3 miles to Vernon Branch C.N.R.
Lake No. 2	Map 3, No. 2	Kamloops, C.P.R. or C.N.R. - aerial tram could be used as mentioned for Lake No. 1	13 miles good road.
Iron Mask L.	Map 3, No. 5	Kamloop, C.P.R. or C.N.R.	6 miles good road.
Spotted L.		Oliver, C.N.R.	12 miles fair road.
Clinton Lake	Map 2, No. 18	Clinton, P.G.E.	1 mile good road.
Basque Dep.	Map 4	Basque, C.N.R.	3 miles fair road--12 miles to plant at Ashcroft.

Origin of Deposits

It is beyond the scope of the present report to deal with the many theoretical factors relating to the origin of the saline lakes of British Columbia. The origin of similar deposits elsewhere has been discussed (see General Bibliography) by Cole, Chatard, Wells, Clarke, Bayley, and others. In general the salts are considered to have been derived originally from the leaching of rocks or soil, to have been carried into undrained basins by surface or sub-surface drainage, and there concentrated through evaporation.

The following generalizations are included for the sake of interest:

Sodium Carbonate Deposits

1. All the known soda lakes of British Columbia in which sodium carbonate is the only important constituent, occur in relatively arid regions underlain by Tertiary basaltic lava flows.

2. The lakes occupy small shallow depressions in glacial drift.

3. Springs occur on the shorelines of four of the soda lakes. The water in each is a dilute solution of sodium carbonate and other salts although three are potable. The orifice of one is in a low mound of calcareous tufa.

4. In general all lakes in the areas under discussion show evidence of having stood at a considerably higher level within fairly recent time.

5. Only two of the purer soda lakes are known to contain deposits of permanent crystal. The remainder, although having diminished in volume in every case since 1919 and 1924, contain brines little or no more concentrated today than at those times. In brief there has been a definite decrease in the total quantity of salts in solution in the soda lakes of British Columbia without corresponding deposits of permanent crystal having formed.

6. Winter-crystal formed in only two lakes in 1898, in at least seven in 1924, and in only 3 in 1937.

Sodium and Magnesium Sulphates

1. Lakes in which magnesium sulphate predominates are

confined to areas underlain by rocks of the lower Cache Creek series (argillite, quartzite, and limestone). Deposits in which sodium sulphate is the major constituent occur in areas in which greenstone and diorite predominate.

References

Ref. 1 - Report of Minister of Mines for British Columbia, 1918.

Ref. 2 - Report of Minister of Mines for British Columbia, 1922.

Ref. 3 - Report of Minister of Mines for British Columbia, 1929.

Ref. 4 - Report of Minister of Mines for British Columbia, 1930.

Ref. 5 - L.H. Cole - Sodium Carbonate at Soap Lake, B. C. Investigations of Mineral Resources and the Mining Industry, 1926, Mines Branch No. 687, Dept. of Mines, Ottawa.

Ref. 6 - M.F. Goudge - Sodium Carbonate in British Columbia. Investigations of Mineral Resources and the Mining Industry, 1924, Mines Branch No. 642, Dept. of Mines, Ottawa.

Ref. 7 - M.F. Goudge - Magnesium Sulphate in British Columbia. Investigations of Mineral Resources and the Mining Industry, 1924, Mines Branch No. 642, Dept. of Mines, Ottawa.

Ref. 8 - Hoffmann - Geological Survey of Canada, Annual Report, vol. XI, 1898. Pt. R.

Ref. 9 - L. Reinecke - Mineral Deposits between Lillooet and Prince George, British Columbia.
Mem. 118, Geological Survey of Canada, 1920.

CHAPTER 2

Technology and Uses of Sodium and Magnesium Salts

Mineralogy and Origin

Sodium Carbonate

The compound sodium carbonate does not occur in nature but is obtained by the dehydration of one of its hydrates of which at least three are known. Pure sodium carbonate contains 58.49 per cent Na_2O and 41.51% CO_2.

Sodium Monohydrate - $Na_2CO_3.H_2O$ - Mineral name Thermonatrite

Na_2O	-	50.0%
CO_2	-	35.4%
H_2O	-	14.6%

Sp.G. - 1.5 to 1.6 ; Hardness - 1 to 1.5

Occurrence - efflorescence on soil and around lakes in Egypt, Hungary, California, etc. Encrustation on lava from Vesuvius.

Properties - the monohydrate is the stable solid phase in aqueous solution above 32.5 deg. C. It is less soluble at higher temperatures than around 33 deg. so that on heating a saturated solution, crystals of the monohydrate are precipitated and redissolve on cooling. It does not melt when heated, but loses its combined water between 87 and 100 deg. C., forming a pulverulent mass. On exposure it absorbs moisture from the atmosphere, and also carbon dioxide to form the sesqui-carbonate.

Sodium Decahydrate - $Na_2CO_3.10H_2O$ - Mineral name Natron

Na_2O	-	21.69%
CO_2	-	15.37%
H_2O	-	62.94%

Sp.G. - 1.42 to 1.47 - Hardness - 1 to 1.5

Occurrence - in many soda lakes.

Properties - the decahydrate is the stable solid phase in aqueous solution below 32.5 deg. C. It fuses at approximately 34 deg., yielding a solution from which the monohydrate is precipitated.

Sodium heptahydrate is not known to occur naturally. It has been prepared by cooling the liquid obtained by heating the decahydrate to its melting point, or by cooling a hot saturated solution at a temperature lower than that at which crystals of the monohydrated carbonate are formed and higher than that at which the decahydrated carbonate is formed.

Trona - $Na_2CO_3 . NaHCO_3 . 2H_2O$ - Sodium sesquicarbonate

Occurrence - Searles and Owens Lakes, etc.

Properties - Trona has been obtained synthetically by removing carbon dioxide from sodium bicarbonate in solution through the addition of sodium hydroxide or sodium carbonate, and crystallizing at about 35 deg.; by the spontaneous evaporation of a solution of sodium carbonate which had been exposed to the air for some time and thereby absorbed carbon dioxide. It has also been obtained from the ammonia-soda process, and by the evaporation of certain lake brines. In general temperatures below 35 degrees are not favourable to the formation of trona; the crystals develop better in a sodium chloride solution; and excess of the normal carbonate favours its development.

Na_2O - 41.2%
CO_2 - 38.9%
H_2O - 19.9%

Sodium Bicarbonate - $NaHCO_3$

Na_2O - 36.94%
CO_2 - 52.36%
H_2O - 10.70%

Sp.Gr. - 2.163 to 2.22

Occurrence - Direct product of the Solvay Process; in alkaline spring waters; in association with normal carbonate as trona; but not alone as sodium bicarbonate.

Properties - All solutions of sodium carbonate in contact with carbon dioxide contain a proportion of the bicarbonate. The salt, sodium bicarbonate loses carbon dioxide rapidly to the air if exposed in a moist condition. Solutions of the bicarbonate are stable only in an atmosphere containing an excess of carbon dioxide.

Solubility - per cent in water

	0 deg. C.	5	10	20	25
$NaHCO_3$	6.90%	7.45%	8.15%	9.60%	10.35%

	30	40	50	60
$NaHCO_3$	11.10%	12.7%	14.45%	16.4%

Sodium carbonate also forms a number of double and triple salts, some of which occur naturally. Most important are Pirssonite ($CaCO_3.Na_2CO_3. 2H_2O$), Gay-Lussite ($CaCO_3. Na_2CO_3. 5H_2O$), Tychite ($2MGCO_3. 2Na_2CO_3. Na_2SO_4$), Northupite ($MgCO_3. Na_2CO_3. NaCl$), Burkeite ($Na_2SO_4. Na_2CO_3$), etc.

Natron occurs as winter-crystal, and in deposits of permanent crystal, in the soda lakes of British Columbia. Whether other sodium compounds described are present is unknown. Accurate moisture determinations on the samples were impossible in view of the considerable elapsed time between their taking and analysis, with consequent natural dehydration.

Sodium Sulphate

Unlike sodium carbonate, sodium sulphate occurs naturally in the anhydrous form (thenardite, Na_2SO_4). The decahydrate mirabilite ($Na_2SO_4. 10H_2O$), however, is more common.

Sodium sulphate - Na_2SO_4 - Mineral name Thenardite

Na_2O - 43.68%
SO_3 - 56.32%

Sp.G. - 2.68 Hardness - 2.5

Occurrence - In some crystal deposits in the Western United States and elsewhere; also as surface layer on mirabilite due to dehydration.

Properties - Deposited from saturated solutions above a temperature of 33 deg. C. Hydrates on exposure to air. Very soluble in water.

Decahydrate or Glauber's salt - $Na_2SO_4. 10H_2O$
Mineral name Mirabilite

Na_2O - 19.3%
SO_3 - 24.8%
H_2O - 55.9%

Sp.G. - 1.48 Hardness - 1.5 to 2

Occurrence - Common form in which sodium sulphate occurs in Canada and the northern United States.

Properties - Deposited from saturated solutions below a temperature of 33 dec. C. Dehydrates on exposure to air. Dissolves in its own water of crystallization above 33 deg.C. Very soluble, and solubility increases with temperature to a maximum of 33 deg. C.

The heptahydrate is not known to occur in nature although it has been prepared artificially. Other combined or mixed salts in which sodium sulphate is an important constituent are listed below.

Bloedite - $Na_2SO_4 . MgSO_4 . 4H_2O$

Na_2SO_4 - 42.5%
$MgSO_4$ - 36.0
H_2O - 21.5

Glauberite - $Na_2SO_4 . CaSO_4$

Na_2SO_4 - 51.7%
$CaSO_4$ - 48.9%

Aphthitalite - $(Na,K)_2SO_4$

usually Na_2SO_4 - 21 to 38%
K_2SO_4 - 62 to 78%

Hanksite - $9Na_2SO_4 . 2Na_2CO_3 . KCl$

Na_2SO_4 - 81.7%
Na_2CO_3 - 13.5
KCl - 4.8%

Loeweite - $2Na_2SO_4 . 2MgSO_4 . 5H_2O$

Na_2SO_4 - 46.3%
$MgSO_4$ - 39.1
H_2O - 14.7

Other combinations with iron, aluminium, etc., are known.

Magnesium Sulphate

Two hydrates of magnesium sulphate occur naturally, i.e., epsomite ($MgSO_4 . 7H_2O$) and kieserite ($MgSO_4 . H_2O$). The first is the common form, the latter being relatively rare apart from certain specific deposits, notably those of Stassfurt, Germany.

Epsomite ($MgSO_4 . 7H_2O$)

MgO	-	16.3%
SO_3	-	32.5%
H_2O	-	51.2%

Kieserite - $MgSO_4 . H_2O$ - Relatively insoluble salt. Epsomite is very soluble and is the salt normally deposited from magnesium sulphate solutions. Epsomite is more soluble than mirabilite.

Commercial Possibilities

The economic value of the sodium carbonate, sodium sulphate, and magnesium sulphate deposits of British Columbia depends upon their amenability to cheap production of the various sodium and magnesium products for which there is a local demand.

Only a very small proportion of the sodium carbonate and sodium sulphate consumed in the world is derived from natural deposits, the rest being manufactured from other materials or recovered as by-products from various industrial processes. A fairly large part of the world's epsomite consumption is derived from natural deposits of magnesium sulphate; the remainder, however, is made or recovered from other sources.

Insofar as production is world wide, Provincial deposits can only be expected to supply relatively local markets, and these only if production costs are sufficiently low to allow competition with imported products.

Sources and Uses

Sodium Carbonate

The most important sodium carbonate products for commercial use are soda ash, sal soda, and sodium bicarbonate. Soda ash or calcined sodium carbonate, is widely used industrially, its more important applications being in the manufacture of glass, various chemicals, soaps and cleansing compounds, pulp and paper, water softening compounds, etc.

It is also employed by metallurgical, tanning, textile, dyeing, and paint industries. Sal soda, washing soda, or sodium decahydrate ($Na_2CO_3 . 10H_2O$) is more soluble than soda ash, as well as being purer in general than commercial soda ash. Its main use is in the preparation of washing compounds, but it may also replace soda ash for certain purposes. Sodium bicarbonate ($NaHCO_3$) is used principally in baking powder and medicines. Its industrial applications are few.

Natural

Lake deposits of sodium carbonate, either dry or containing concentrated brines, are found in many parts of the arid regions of the Western United States. Natural soda has been produced commercially from lakes in California, Wyoming, Nevada, and Washington; present production is restricted to Searles and Owens Lakes in California. Similar deposits, for the most part unexploited, are found in East Africa, South Africa, Egypt, Venezuela, Chile, Peru, Armenia, Hungary, Russia, Spain, Germany, India, etc.

Production of sodium carbonate in British Columbia is confined to recovery of natron or winter-crystal, which in its natural form is sufficiently pure to meet commercial standards for sal soda. The winter-crystal forms with the coming of cold weather in the autumn. During the winter it is broken into rectangular slabs with bars, mud or ice are scraped off, and the slabs piled along the shore. In the summer it is shipped to Vancouver for use by soap companies. No soda ash or sodium bicarbonate is made in the Province.

The only production of natural sodium carbonate in the United States is from Searles and Owens Lakes in California. These are large lakes containing concentrated solutions of sodium chloride, sodium carbonate, sodium sulphate, borax, and other salts. Four companies, two on each lake, recover a variety of products including soda ash, sodium bicarbonate, and trona, as well as salt cake, borax, and potash salts. The following processes are, or have been used.

Owens Lake

Quoting Ladoo (Ref. 14, p. 568)

> "Manufacture of Trona. Owens Lake brine is evaporated in shallow solar ponds to the saturation point of trona in the brine, at which point the brine is drawn into smaller ponds in which further solar evaporation will crystallize trona ($Na_2CO_3 . NaHCO_3 . 2H_2O$). The end point is reached with the saturation in common salt, after which the brine is drawn off and replaced with fresh solar-evaporated brine. The trona forms a hard, solid

"crust on the bottom of the ponds and is taken up by hand at the end of the evaporating season. Calcining of trona will yield soda ash containing about 95 per cent sodium carbonate. Trona is one of the cheapest alkaline materials known, and as such has a number of industrial uses.

"Manufacture of Soda ash. The process used by the California Alkali Company is similar in many respects to the ammonia-soda process, the main difference being that no ammonia is used. Owens Lake brine is subjected to solar evaporation until the saturation of trona in the brine is reached. Further solar evaporation would result in the precipitation of trona, which is not desirable in this instance. The brine at this point is pumped to the plant and after careful filtration treated with carbonic acid gas, the latter being generated by burning lime stone with coke. The sodium carbonate of the brine is converted by the action of the carbonic acid gas into bicarbonate, which, as soon as its saturation in the brine is reached, will be precipitated as a white powder and is separated by filtration. A small quantity of this bicarbonate is dried at low temperatures and marketed as crude bicarbonate of soda. This material is used for fire extinguishers as well as in certain cleansers and for sap stain.

"The bulk of the bicarbonate, however, is converted to soda ash by calcining in a rotary furnace, in which process water and carbonic acid gas are driven off, the latter to be used over again in the carbonating process. It will be understood that the reaction which is taking place is exactly the reverse of the previous reaction.

"The product of this calcining process is light soda ash. Certain industries like glass making, prefer a heavier ash, which is manufactured by subjecting light ash to a second calcining process. The product of this operation is so-called dense ash."

Although the plant to which the above description refers has discontinued operations, the general process is similar to those used today.

Searles Lake

The following process, used at Searles Lake is described by Wells (Ref. 16, p. 745):

> "In outline it (the process) consists in evaporating the brine in multiple-effect evaporators in which the salts NaCl, Na_2SO_4, and Na_2CO_3 separate, the last two as the double salt burkeite, $Na_2CO_3 . Na_2SO_4$. The resulting solution is allowed to settle, then cooled quickly to deposit potassium chloride, and the remaining solution is agitated with air and slightly acidified to deposit borax $Na_2B_4O_7 . 10H_2O$.
>
> "Further recrystallization of the first three salts yields the separate products Na_2CO_3 and Na_2SO_4."

A comprehensive description of the recovery of borax and soda ash from Searles Lake by another method is given by Hellmers (Ref. 12, p. 4). The following abstract is quoted:

> "The brine as pumped from the lake is treated with carbon dioxide gas, whereby the normal carbonate of soda is converted to the bicarbonate, which is quite insoluble in the brine and consequently precipitates out-- Na_2CO_3 plus CO_2 plus $H_2O = 2NaHCO_3$.
>
> "During carbonation the borates contained in the brine as sodium metaborate and sodium tetraborate, are converted to the more acid higher borate of sodium by the reaction with CO_2, eliminating part of the Na_2O by forming $NaHCO_3$.
>
> "$2Na_2B_2O_7$ plus $2CO_2$ plus $H_2O = Na_2B_4O_7$ plus $2NaHCO_3$.
>
> "After separation of the sodium bicarbonate from the carbonated brine, the latter is mixed with additional untreated brine from the lake in such proportions that practically all the borates in the mixture are in the form of sodium tetraborates. This results in a state of supersaturation with respect to sodium tetraborate, which is crystallized from the mixture by the simple process of cooling and agitating. After settling the waste brine is returned to the lake and the settled borax recovered and refined. The bicarbonate recovered in the first step of the process is filtered, washes free of impurities, and converted to the various grades of soda ash."

The brine of Searles Lake fills the interstices of a crystalline bed; it contains approximately one third solids, the more important constituents, expressed as percentages in the brine, being NaCl-16.5%, Na_2SO_4-6.85%, KCl-4.82%,

Na_2CO_3-4.85% and $Na_2B_2O_7$-1.6%.

Manufactured Sodium Carbonate

A large part of the sodium carbonate consumed in the world is manufactured from common salt. Two main processes are used; the ammonia-soda or Solvay process, and the electrolytic process. The former is the important one from the viewpoint of production. The Leblanc process, little used at present for this purpose utilizes common salt, sulphuric acid, limestone and coal.

Solvay Process

The following description is quoted from Cole (Ref. 10, p. 95):

> "The reaction upon which his (Solvay) process is based may be stated in the following equation:
>
> "$NaCl$ plus NH_4HCO_3 = $NaHCO_3$ plus NH_4Cl
>
> "The raw materials required for this process are: lime-stone, sodium chloride (either as brine as it comes from the wells or rock salt dissolved) ammonia (either in the form of ammonium hydrate solution or ammonium sulphate), and fuel.
>
> "In brief, the essential operations in this process are: to manufacture carbon dioxide from limestone; to pass this gas into the ammoniacal brine which has previously been prepared by saturating the brine with ammonia gas; the separation of sodium bicarbonate which forms as a precipitate from the solution; and the calcining of this precipitate to form sodium carbonate, or soda ash. The carbon dioxide formed from the calcining of the carbonate is employed again as is also the ammonia, which is recovered from the solution--where it is in the form of ammonium chloride."

Electrolytic Process

Quoting Cole (Ref. 10, p. 96)

> "This process known as the 'Hargreaves and Bird' process consists of a diaphragm cell in which the walls of the cell are the diaphragm and the cathode. The diaphragm is impervious to the salt solution, but permits the sodium ions to pass. As the sodium ions are set

free, they are converted into soda crystals by the blowing in of steam and carbon dioxide."

Le Blanc Process

The first step in the Le Blanc process, i.e., the reaction of sulphuric acid with common salt to yield sodium sulphate is widely used in the manufacture of salt cake. Soda ash is made from the sodium sulphate by melting it with proper proportions of coal or coke and limestone in a reverberatory furnace.

The fused mass, called "black ash" and consisting of sodium carbonate and calcium sulphide, is cooled and the sodium carbonate leached by water. The solution is then evaporated and the resultant crystals calcined to produce soda ash.

Sal Soda

Sal soda is obtained either from natural deposits or produced by recrystallization from a solution of soda ash in water. The resulting crystals are dried until efflorescence begins, then stored. One to 3 per cent sodium sulphate is said to be desirable in the crystals to render them hard and less friable.

Sodium Bicarbonate

Sodium bicarbonate is made by the Solvay process, by carbonating a concentrated solution of sodium carbonate, or by treating soda with carbon dioxide.

Sodium Sulphate

Sodium sulphate is marketed in two main forms; as salt cake or anhydrous sodium sulphate, and as Glauber's salt or $Na_2SO_4 . 10H_2O$. A by-product material, nitre cake, largely composed of sodium bisulphate is also widely used.

The main uses of salt cake are in the pulp and paper, glass, dye, textile, tanning, and nickel industries, although nitre cake replaces it in some, notably the last. Glauber's salt is of more restricted application being employed chiefly in dyeing and for medicinal preparations.

Natural

Sodium sulphate occurs naturally both as mirabilite or Glauber's salt ($Na_2SO_4 . 10H_2O$) and thenardite (Na_2SO_4) as well as in association with other salts in such compounds as glauberite ($Na_2SO_4 . CaSO_4$) and bloedite ($Na_2SO_4 . MgSO_4 . 4H_2O$). It is the major constituent in the brines and crystalline deposits of many saline lakes in the Prairie Provinces of Canada and the western United States, as well as in other parts of the world.

Canadian Deposits

The sodium sulphate lakes of Manitoba, Saskatchewan, and Alberta occupy undrained, or partly drained depressions in surface drift. Some contain only dilute brines, other extensive deposits of permanent crystal. In recent years production of sodium sulphate from certain deposits has attained interesting proportions. For further information the reader is referred to "Sodium Sulphate in Western Canada" by L. H. Cole, (Ref. 11). The following review of recovery methods used or suggested in connection with these deposits is abstracted from Cole's report.

Quoting Cole (Ref. 11, p. 47)

> "The sodium sulphate may be recovered either as 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 crystal 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 cases completely disappearing, so that crystal can be gathered........"

Recovery as a Brine

> ".....In using ..... 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."

Recovery as Crude Glauber's Salt

"The more feasible method to recover the sodium sulphate seems to be in the crystal form as crude Glauber's salt....The crystals known as the intermittent or harvest crystals are generally very pure when first deposited, and can be readily gathered when all 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 protects it from contamination. At one deposit--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. These 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 plows, 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 drag-line 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 a few months each year, 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.

"...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 and easily gathered material of a considerably higher degree of purity than could be excavated from the permanent bed."

Refining Crude Material

"The salts as excavated from the deposits contain approximately 56 per cent water of crystallization. They may also contain 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 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 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 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 only 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 be quickly driven off by artificial heat."

This method has been employed at one deposit in Saskatchewan. A shed was erected 100 feet long by 10 feet high, by 12 feet wide, with walls removable in sections to allow free circulation of air. The hydrous salts were exposed in trays with cotton bottoms, arranged in rows, one above another and about 2 inches apart. About two weeks exposure lowered the moisture content from 56 per cent to 15 per cent. The material was then removed to another building and placed on shallow tin trays above a small stove; here the last water was removed in about 2 days. About 5 tons of dried material was obtained in 2 weeks. The cost of building and maintaining sufficient drying space for even 5 tons per day or less would be considerable.

Evaporation with Artificial Heat

Quoting Cole further (Ref. 11, p. 50)

> "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 deg. 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 deg. 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 deg. is reached. Above this temperature the salt thenardite starts separating out and this fact has led many to attempt to recover the salt in this way.

> "..Experiments have shown that when the crystals are heated in this way (open pans) 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...has not been demonstrated.
>
> "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 deg. C. and to collect the per centage of sodium sulphate which is precipitated in the anhydrous form and dry it by some suitable means. Experiments made in the Mines Branch laboratories showed that percentages of sodium sulphate varying from about 33 per cent at 60 deg. C. to nearly 44 per cent at 100 deg. C. could be recovered in this manner. The material thus obtained was in a finely crystalline form rather than a powdered form."

Since the time of Cole's report there have been several commercial applications of methods outlined above.

One plant operated in 1932 as follows: Crystal was harvested by means of an electric shovel after blasting with 40% dynamite or black powder, and loaded to dump cars hauled by an electric locomotive. From bins the crystal went to rotary drum dissolvers fired by coal.

From these, brine was pumped to tanks and thence splashed on the outside of drums heated internally by steam. The dried material with a moisture content of 20-25 per cent was scraped off and fed to direct-fired rotary driers and thence to shipping bins.

In another plant crystal from a stock pile was fed to an oil-fired rotary kiln in which it was completely dehydrated. The salt cake was then screened and where necessary, further refined.

Several Canadian patents have been taken out in respect to processes involving the removal of thenardite by settling from mirabilite dissolved through heat. At least one plant in Saskatchewan has employed a modification of this method.

Evaporation in Space

Quoting Cole (Ref. 11, 53)

> "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 in a small disc into a large chamber in close proximity to a current of 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.
>
> "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."

Other processes such as vacuum pan evaporation and chemical precipitation have been suggested and some applied commercially.

In 1937 there were four principal producers of natural sodium sulphate in Canada, all in Saskatchewan. At least three of these used direct-fired rotary driers for dehydration of crystal.

United States Deposits

Sodium sulphate deposits occur in many parts of the Western United States, notably in North Dakota, Arizona, Nevada, New Mexico, Texas, Utah, Wyoming, and Washington. It has been produced commercially from Arizona, California, Nevada, New

Mexico, Texas, Utah and Wyoming. Most deposits are in the form of permanent crystal-beds of mirabilite, but some contain thenardite and glauberite, while others occur as brines.

Production in 1937 was made from Searles Lake, California, as well as from three plants in Texas. Deposits were developed in Utah and Washington. Hydrated sodium sulphate or Glauber's salt was recovered from two deposits in Wyoming.

The following description of methods is quoted from a report by Wells (Ref. 16, p. 745)

> "Sodium sulphate is mined in many placed by blasting out the crude solid salt and in other places by leaching out a warm saturated solution from the crude salt, which is then cooled to precipitate Glauber's salt or evaporated to yield the anhydrous salt. At Casper, Wyoming, two ponds are used and the brine is pumped from one pond to the other in order to get at each new crop of Glauber's salt. Sodium sulphate has been purified at the Great Salt Lake by dissolving crude Glauber's salt, found undersand along the shore in places and also deposited in winter, and evaporating the solution to deposit anhydrous sodium sulphate. At Wabuska, Nev., the temperature is high enough in the dry season to yield thenardite on solar evaporation."

In general, the process (Ref. 17, p. 55) used in recovering salt cake from impure Glauber's salt at Great Salt Lake is as follows: In 5 tons of 'ore' there are 1 ton of sodium sulphate, 1 ton of water, and 3 tons of sand. The salt is scooped out by dragline and hauled in cars to the plant, where it is put through roll crushers, delivered by conveyor to a melter tank, and mixed by propeller agitators with water heated to 150 deg. F. From the melter tank the brine passes to a Dorr Classifier where the sand is removed. The classifier overflow passes to settling tanks where it remains 24 hours. It is then pumped through a heater and raised to 150 deg. F., and then passed through vertical evaporators heated by exhaust steam. A Dorr Classifier is used to remove sodium sulphate crystals from the brine; these go to a centrifugal for further brine removal. The brine is returned to the evaporators and the salt cake passes to a horizontal kiln-dryer. After screening to 30 mesh the product is ready for shipment.

For a general discussion of the technology of sodium sulphate production from natural sources the reader is referred to Tyler (Ref. 15) Kobe and Hauge (Ref. 13), and Wells (Ref. 16), as well as to the aforementioned report of Cole (Ref. 11).

Manufactured Sodium Sulphate

A large part of the salt cake used in commerce is produced artificially as a by-product from the manufacture of hydrochloric acid from common salt. Other processes are also employed.

Salt Cake Process

The following description is quoted from Cole (Ref. 11, p. 58).

> "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) $NaCl$ plus H_2SO_4 = $NaHSO_4$ plus HCl
> (2) $NaCl$ plus $NaHSO_4$ = Na_2SO_4 plus HCl
>
> "The first of these reactions begins at ordinary temperatures whereas the second is only completed at 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 deg. C. which is the melting point of ordinary salt cake.
>
> "The raw materials required in this process are sodium chloride (common salt) and sulphuric acid.
>
> "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 in water.
>
> "The hot mass is then raked into a muffle or reverberatory furnace and the reaction is complete at a high-

"er temperature. The hydrochloric acid evolved in the muffle furnace is collected separately. When no more vapors are seen rising in the muffle furnace the batch is drawn out and usually left to cool in a closed box.

"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."

In discussing this process Tyler says (Ref. 15, p. 11)

"In the United States the Mannheim mechanical salt cake furnace has entirely superseded the older pot-and-muffle method (described above), and in other countries mechanical furnaces have likewise displaced the older, laborious, and generally discontinuous operations."

Until recently the output, and hence the price, of by-product salt cake followed the production of hydrochloric acid closely. However, an increasing proportion of hydrochloric acid is being manufactured synthetically by direct combination of hydrogen and chlorine, and some is recovered as a by-product from the chlorination of coal tar derivatives.

Another process discussed by Cole (Ref. 11, p. 59) but largely discontinued today is the Hargreaves process which depended upon the reaction of pure sulphur dioxide gas upon common salt in the presence of air and steam.

Nitre Cake Process

Quoted from Cole (Ref. 11, p. 60)

"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 45 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 Le Blanc soda plants, large quantities 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 salt 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. The process depends on the following equation:
>
> "$NaHSO_4$ plus NaCl - Na_2SO_4 plus HCl"

Today comparatively little nitric acid is manufactured from sodium nitrate, however, with the result that the production of by-product nitre cake has dropped enormously.

Salt cake is also recovered as a by-product from other processes including the manufacture of sodium dichromate. In Germany waste magnesium sulphate from potash works is converted into salt cake by the following reaction:

$MgSO_4$ plus 2NaCl - Na_2SO_4 plus $MgCl_2$

Common salt is added at a suitable temperature and the temperature conditions of the solutions controlled.

Epsom Salts ($MgSO_4 . 7H_2O$)

Epsomite is a constituent of ocean, and certain salt lake and spring waters. It occurs associated with sodium sulphate in lake deposits in British Columbia and the Prairie Provinces of Canada as well as in the Western United States and other countries. It is found in quantity in the Stassfurt deposits of Germany and is also recovered from extensive kieserite ($MgSO_4 . H_2O$) beds in these deposits. Epsomite is likewise deposited from spring waters at Epsom, England, and is associated with gypsum in an occurrence near Paris, France.

Epsomite represents the only form in which magnesium sulphate is used to any extent commercially. Its chief use is in the tanning of leather, although it is also used in the dyeing textile and other industries, and for medicinal purposes.

Natural

Several of the methods used in recovering epsomite from natural deposits in British Columbia have been reviewed in a former section. In general these are similar to those employed elsewhere.

Manufactured

Ladoo (Ref. 14, p. 209) lists the following methods by which epsomite is produced.

1. Technical and U.S.P. grades made as a by-product in the evaporation of common salt.

2. Recrystallization from kieserite (Germany).

3. Action of sulphuric acid on magnesia, magnesium hydroxide, magnesite, or dolomite.

4. Crystallization from mineral waters.

5. Separation and crystallization from alkaline waters containing mixtures of salts.

In respect to the last the most common associate of magnesium sulphate is sodium sulphate. Separation of the two is effected through crystallization from solution, magnesium sulphate being more soluble than sodium sulphate.

Prices

Trade names, composition, theoretical formulae, and recent price quotations are listed below.

Trade Name	Composition	Formula	Price	
			New York	Toronto
Soda Ash	98-100% Na_2CO_3	Na_2CO_3	58% light - $1.05/100#	$2/100#
Sodium Bicarbonate	99.5-99.7% $NaHCO_3$	$NaHCO_3$	$1.85/100#	$2.75/100#
Caustic Soda	75-99% NaOH	NaOH	Solid 76% - $2.30/100#	- $3.70 - $3.95 /100#
Salt Cake	95-100% Na_2SO_4	Na_2SO_4	$15/ton	f.o.b. Sask. - $8.50/ton
Glauber's Salt	44% Na_2SO_4	$Na_2SO_4 . 10H_2O$	95¢/100#	$16/ton
Nitre Cake	61-86% $NaHSO_4$	$NaHSO_4$	$16/ton	--------------
Epsom Salt Tech.		$MgSO_4 . 7H_2O$	$1.80/100#	$35-40/ton
Epsom Salt B.P.		"	-----	.02 1/2-.03¢/#

Canadian and American Tariffs

Material	Canadian Tariff		U. S. Tariff
	Pref.	Gen.	
Soda Ash	1/5¢/#	3/10¢/#	1/4¢/#
Sal Soda	1/5¢/#	3/10¢/#	------
Salt Cake	1/5¢/#	3/5¢/#	free
Sodium Bicarbonate	----	----	free
Glauber's salt	----	----	$1/ton
Nitre Cake	free	20%	----
Epsom Salts		25%	

Production and Consumption

Sodium Carbonate

British Columbia and Alberta

An average of 150 to 250 tons of sal soda is produced annually in British Columbia, and sold largely to soap companies in Vancouver. In the past, shipments have been made to soap companies in Calgary but none has been recorded in recent years.

No soda ash, sodium bicarbonate, or caustic soda are produced in British Columbia. Although figures are incomplete the estimated annual consumption of soda ash in the province is between 750 and 1000 tons, of which at least 75 per cent is brought in from Ontario, the remainder being imported from the United States and United Kingdom. Delivered prices for 58 per cent soda ash range from $35 to $75 per ton, depending on quantity and situation. The average delivered price is approximately $40 per ton.

The quantity of sodium bicarbonate used annually is only a few tons. The requirements for caustic soda are variable, 224 tons being imported in 1936 (Ref. 18), none in 1937, and 125 tons in the first three months of 1939. Delivered prices of flake caustic soda in small lots range from $70 to $80 per ton.

Approximately 5000 tons of salt cake are used annually in the province, largely in the pulp and paper industry. Somewhat less than half is of local by-product origin, the rest being brought in from Saskatchewan. Delivered prices range from $18 to $19 per ton.

Little or no nitre cake is used in British Columbia, and the quantity of Glauber's salts imported annually is only a few tons.

Epsom salt is produced in British Columbia. In addition 59 tons were imported in 1936 and 54 tons in 1937 (Ref. 18).

Insufficient data are available to allow an estimate of the total amounts of sodium carbonate, sodium sulphate, and epsomite used annually in Alberta. At least 2500 tons of soda ash, and 250 tons of caustic soda, however, are known to be utilized. Practically all the soda ash is brought in from Ontario and the delivered cost is about $40 per ton.

Canada

Soda ash is manufactured by one plant, salt cake, nitre cake, and Glauber's salt in two plants, and caustic soda in two plants, all in Ontario. In addition salt cake and Glauber's salt are produced from natural sources in Saskatchewan. The only producer of Epsom salt is in British Columbia.

In the following table approximate imports and exports are listed. (Ref. 21)

for 1937	Imports	Exports
Soda Ash	5000 tons $113,000)	Soda & sodium compounds - 46,000 tons - $4,674,000
Bicarbonate of Soda	6000 tons $199,000)	
Caustic Soda	6000 tons $296,000)	
Salt Cake	-------)	
Glauber's Salt	1700 tons $ 24,348)	
Nitre Cake	1100 tons $ 18,618)	
Epsom Salts	1700 tons $ 33,100	----------

No data are available on the consumption or production of these materials in Canada. The following remarks are quoted (Ref. 19) in respect to the production of natural sodium sulphate in Canada.

> "At the present time the operating plants are capable of producing over 600 tons of dried salts per day. The development of these sodium sulphate deposits has been one of the major factors that has made possible the erection of the plant for separating nickel from copper, at Copper Cliff, Ontario, by the Orford process.

> "The production of natural sodium sulphate in 1937 amounted to 79,884 tons valued at $618,028, as against 75,598 tons valued at $552,681 in 1936.
>
> "Although there were small shipments from the deposits in Western Canada to the United States the figures are not shown in the customs reports....
>
> "The production of natural sodium sulphate from the deposits of Western Canada again increased sharply during the past year, and a new all-time high for this industry was established...."

Distribution by uses and other features discussed under the following heading apply in general to Canada as well as to the United States.

United States

The following table (Ref. 20, p. 1430) gives the percentage distribution of sales of soda ash and sodium sulphates in 1936, as estimated by Chemical and Metallurgical Engineering.

Industry	Soda Ash %	Sodium Sulphates %
Heavy Chemicals	27.4	2.5
Dyes and Organic Chemicals	10.9	2.5
Glass and Ceramics	38.3	10.2
Explosives	.2	---
Leather, glue and gelatin	.1	.2
Pulp and Paper	4.4	56.0
Petroleum Refining	.4	---
Rayon and Cellulose film	.1	1.2
Soap and Glycerine	9.3	.5
Textile Processing	2.7	19.9
Other Process Industries	.6	---
All other industries	5.6	7.0

Import figures are listed below. (Ref. 20, p. 1431). Figures for sodium carbonate are not given as they were relatively insignificant in comparison with domestic sales and consisted wholly of manufactured salts.

Imports for 1935-36 by Countries

Country	Salt Cake		Glauber's Salt		Anhydrous	
1935	Tons		Tons		Tons	
Germany	83,016	$739,314	551	$4,479	5,760	$113,108
Belgium	23,433	$181,820	------	------	------	------
Chile	1,353	$ 9,912	------	------	------	------
Netherlands	1,122	$ 10,190	------	------	28	$ 599
Canada	906	$ 8,305	------	------	------	------
USSR	504	$ 9,900	------	------	------	------
Totals	110,379	$959,411	551	$4,479	5,788	$113,771
1936	Tons		Tons		Tons	
Germany	119,766	$1,094,461	574	$4,595	11,700	$222,263
Belgium	21,078	$ 163,789	------	------	22	$ 344
Canada	6,589	$ 46,072	------	------	------	------
Netherlands	3,301	$ 24,591	------	------	132	$ 2,951
Chile	686	$ 4,912	------	------	------	------
Totals	151,420	$1,333,825	575	$4,620	11,854	$225,613

In the following table the imports of salt cake for 1935 and 1936 are listed by Customs Districts.

Customs District	1936	1935
Pacific Ports and Canadian Border		
Washington	3,433 tons	4,592 tons
Oregon	1,528 "	2,601 "
San Francisco	55 "	-----
Duluth and Superior	1,615 "	-----
Dakota	4,974 "	906 "
Gulf Ports		
Florida	28,506 "	18,773 "
Mobile	81,237 "	47,952 "
New Orleans	14,579 "	22,803 "
Sabine	5,020 "	6,583 "
Atlantic Ports		
Georgia	6,015 "	-----
Maine and New Hampshire	645 "	-----
Maryland	3,192 "	4,872 "
New York	731 "	1,297 "

Approximately 2,100 tons of epsom salts were imported in 1936. A major part of requirements, however, are supplied by by commercial producers.

In 1937 natural sodium carbonate was produced by 4 operators in California; sodium sulphate was produced by one operator in California, one in Texas, and two in Wyoming. Other deposits are being developed. One operator near Oroville, Washington, reported sales of natural epsom salts.

Domestic Production of Natural Sodium Carbonates and Sulphates

	Carbonates		Sulphates	
1937	104,711 tons	$1,191,485	80,053	$599,266
1936	102,866 "	$1,106,364	51,608	$336,559
1935	93,230 "	$1,173,003	38,706	$275,943

The only United States markets which might possibly be reached economically by British Columbia producers of sodium carbonate and sodium sulphate are those of Washington and Oregon. Consumption figures are not available for these States but pulp and paper producers use from 10,000 to 15,000 tons of salt cake and 1,000 to 2,000 tons of soda ash annually.

Exploitation of British Columbia Deposits

1. Sales of sodium products from local deposits would be restricted to a relatively small area comprising, at best, Alberta, British Columbia, Washington, and possibly part of Oregon. The nearest producers of sodium carbonates are in Ontario and California; of sodium sulphates in Saskatchewan and California.

2. Estimated minimum annual consumption of soda ash and salt cake in British Columbia, Alberta, Washington and Oregon are listed below.

	Soda Ash	Salt Cake
British Columbia	800 - 1000 tons	4000 - 5000 tons
Alberta	2000 - 3000 "	small ? "
Washington and Oregon (Pulp and Paper only)	1000 - 2000 "	10,000 - 13,000 "
Totals	3800 - 6000 "	14,000 - 18,000 "

Present delivered prices of soda ash in British Columbia and Alberta range from $35 to $45 per ton; of salt cake in British Columbia and Washington from $16 to $19 per ton. The United States tariff of 1/4¢ per pound or $5 per ton on soda ash would effectively preclude competition with California producers unless local processing could be done at a sufficiently low cost. This is improbable in view of the magnitude and variety of products recovered from California deposits. There is no United States tariff on salt cake at present, and it is probable that local material could reach the Washington market if it could be sold for about the same price as that from Saskatchewan deposits, i.e., $8.50 per ton. On the other hand, large deposits of sodium sulphate occur in Central Washington, and should these be developed in future, would afford serious competition to local producers.

3. No epsomite is produced in Canada other than in British Columbia. The products from the operation at Ashcroft are shipped to all parts of Canada. Chief competition is furnished by cheap foreign imports.

4. Estimated quantities of the compounds under discussion are listed below.

a. Sodium Carbonate

	Crude	Equiv. Soda Ash
Comparatively free of other salts		
Permanent Crystal (more or less mixed with mud)	80,000 tons	20,000 tons
Brine (Sp.G. greater than 1.040) - salts -	75,000 "	70,000 "
Mixed with sodium sulphate		
Permanent Crystal (more or less mixed with mud)	100,000 "	20,000 "
Totals	255,000 "	110,000 "

b. Sodium Sulphate

	Crude	Equiv. Salt Cake
Comparatively free of other salts		
Permanent Crystal (more or less mixed with mud)	200,000 tons	80,000 tons
Mixed with sodium carbonate		
Permanent Crystal (more or less mixed with mud)	100,000 "	13,000 "
Mixed with magnesium sulphate		
Permanent Crystal (more or less mixed with mud)	105,000 "	20,000 "
Totals	405,000 "	113,000 "

c. Epsom Salts

	Crude	Equiv. Epsomite
Comparatively free of other salts		
Permanent Crystal (more or less mixed with mud)	20,000 tons	20,000 tons
Mixed with sodium sulphate		
Permanent Crystal (more or less mixed with mud)	105,000 "	75,000 "
Totals	125,000 "	95,000 "

5. Both sodium carbonate and sulphate, occurring naturally as natron and mirabilite, must be dehydrated before a market of any size can be reached. Small tonnages of sal soda and Glauber's salt could probably be sold as well, however.

6. Recovery and dehydration of natron and Glauber's salt should present no more difficult a problem in British Columbia than elsewhere. The matter merits careful investigation, however, from both the technological and economical standpoint insofar as volume of sales will be particularly dependent upon relative cheapness of manufacture. The maximum market is not large and a compromise between size of plant and manufacturing cost must be made.

Although the deposits as a whole are easily accessible they are, for the most part too small to justify expensive development. Several, however, in which deposits of permanent crystal occur, and one or two containing brine, are sufficiently large to merit a small plant capable of supplying the available market. In general the most satisfactory method of developing the saline deposits of British Columbia appears to be control of the important deposits under one management with manufacture and sale of a variety of products. This is especially applicable to those lakes, including the epsomite deposits, in which mixed salts occur.

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CHAPTER 3

Occurrences of Hydromagnesite in British Columbia

Hydromagnesite

Deposits of hydrated magnesium carbonate occur in the Cariboo, Atlin, and Kamloops districts of British Columbia. These have been referred to in the literature as hydromagnesite, and although they rarely correspond in composition to the mineral, will be discussed under this head in the present report.

The hydromagnesite occurs typically as horizontal deposits in valley-bottoms or on flats near the base of adjacent slopes. The surface of the purer deposits is hummocky and cracked, resembling that of a cauliflower, and is commonly raised slightly above the surrounding ground level. In general a layer of white, massive, hydromagnesite, overlies loose, rather granular, creamy material, which in turn grades into soil below. The calcium content is higher in the creamy layer than in the white, and increases progressively towards the base.

Cariboo and Kamloops Districts

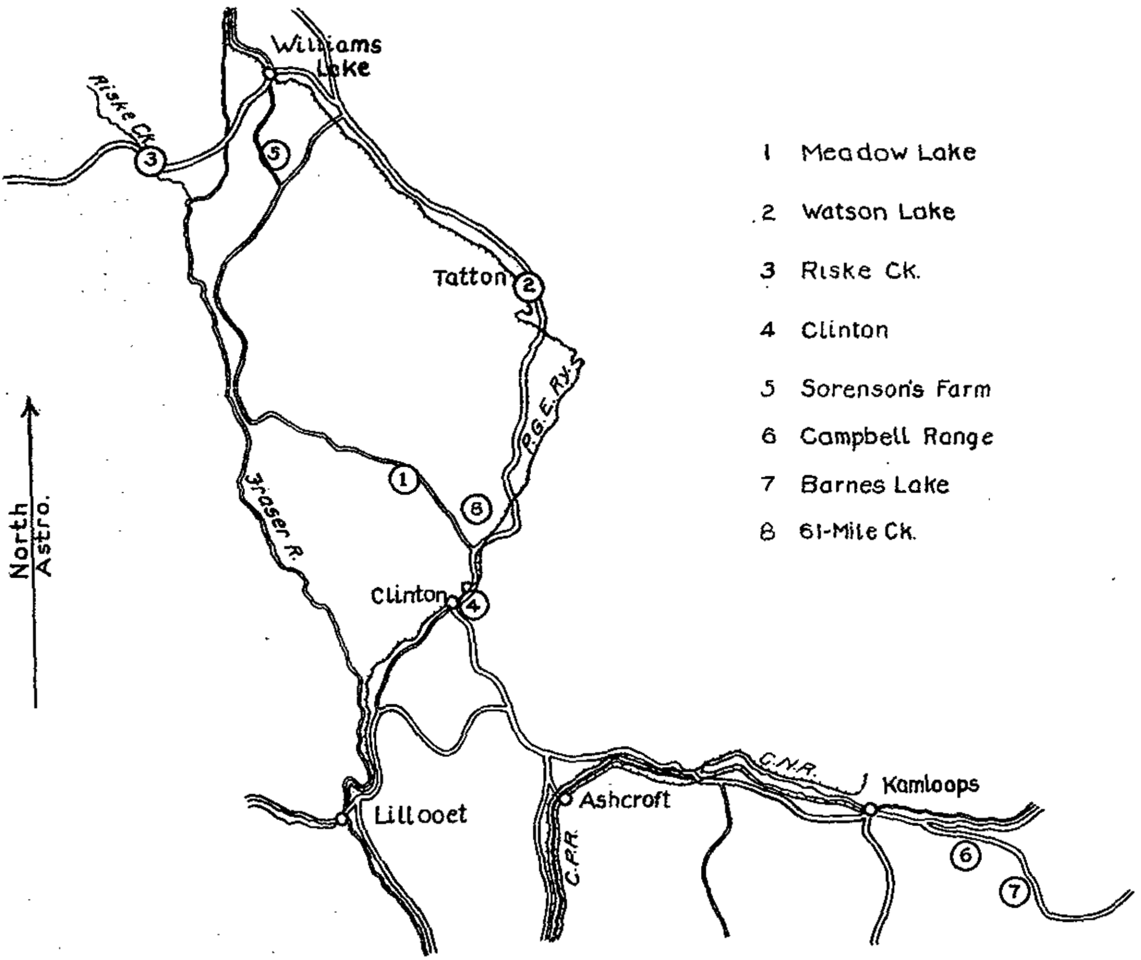
The location of known hydromagnesite deposits in the Cariboo and Kamloops Districts is shown in the accompanying Key Map. The present report is based on field examination by the writer during the summer of 1937. A complete and detailed report on the Meadow Lake, Watson Lake, Riske Creek, and Clinton occurrences will be found in Memoir 118, Geological Survey of Canada (Ref. 2); other references are listed at the end of this section.

The most important deposits are those at Meadow Lake, Watson Lake, and Riske Creek; the others are either small, impure, or of unknown extent.

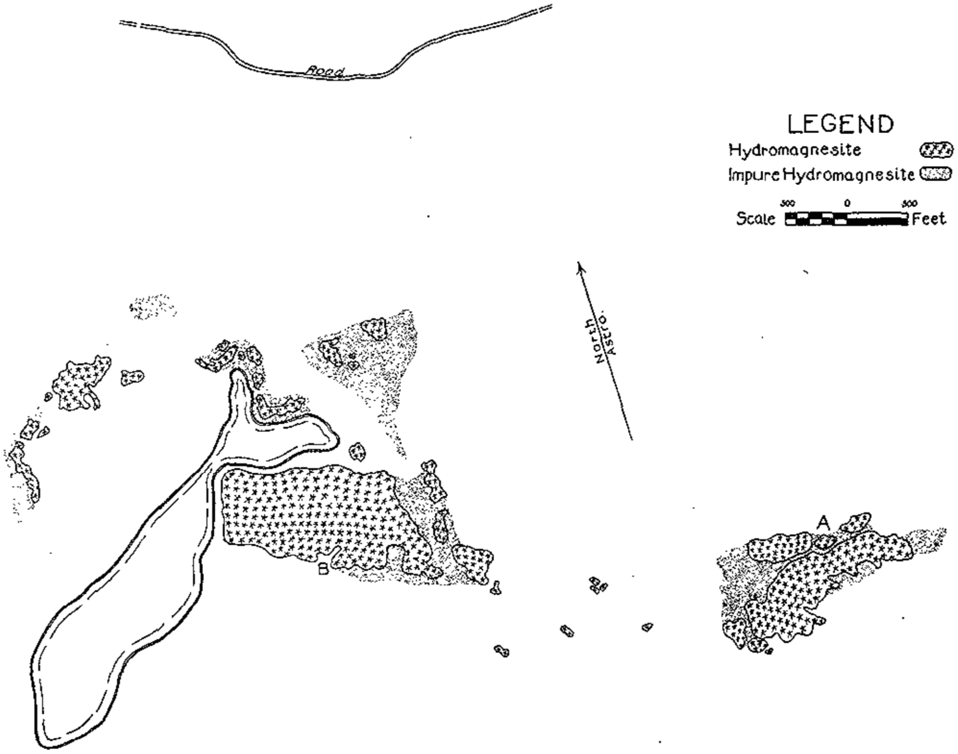
Meadow Lake Deposit (Key Map 6, No. 1)

Meadow Lake is on the south side of the Clinton-Dog Creek road about 15 miles from its junction with the Cariboo highway, and 16 miles from Chasm on the Pacific Great Eastern Railway. The lake, about 2 1/2 miles long by 1/2 mile wide, is one of a number along a shallow depression some 15 miles in length. All are approximately at the same elevation, and without apparent outlet.

The main hydromagnesite occurrences lie in the abovementioned depression from 1/2 to 2 miles east of Meadow Lake. Relatively large areas of impure hydromagnesite also occur at each end of the lake.



Map 6. (Key-map.)
Showing location of known hydromagnesite deposits in Central British Columbia.



MAP 7.
Meadow Lake hydromagnesite deposits.

The distribution and extent of purer deposits is shown on Map 7. The larger of these are sheet-like in form; the smaller are irregular, commonly circular, or formed of several circular areas, either in contact or separated in groups. All have the typical "cauliflower-like" surface, and are raised a few inches to two feet above the surrounding swampy ground. The impure hydromagnesite deposits noted on the map have a flat, cracked surface, and are composed of dense greyish material.

Estimates of area underlain by relatively pure hydromagnesite follow:

	Writer	Reinecke (Ref. 2, p. 44-46)
Area A	70,000 sq. yds.	56,000 sq. yds.
Area B	142,000 "	154,000 "
Others	32,000 "	24,700 "
Totals	244,000 "	234,700 "

The deposits comprise two more or less distinct layers; the upper white, massive, and relatively free of calcium, the lower creamy, loosely granular, and containing an increasing proportion of calcium towards the base. In view of this the amount of material actually available for commercial purposes depends, within limits, upon the use to which it is to be applied, in other words upon the minimum calcium content allowed for the purpose in question.

As disclosed in drill holes the depth of white material in Area A varies from 12 to 24 inches, in Area B from 8 to 32 inches, and in the smaller areas from 5 to 20 inches. Average figures are 16 inches for Area A, 18 inches for Area B, and 12 inches for the others. Taking the weight of a cubic yard of the hydromagnesite as 2050 pounds (Ref. 2, p. 43), tonnages would be as follows:

Estimate of tonnage of white hydromagnesite at Meadow Lake

	Writer	Reinecke
Area A	31,200	25,920
Area B	72,000	78,900
Others	11,000	9,140
Totals	114,200	112,960

The following analyses are typical of this material:

	Writer (3)	Reinecke A (4)	Reinecke B (5)
MgO	38.8%	41.38%	40.56%
CaO	0.8	1.32	1.26
CO_2	38.7	37.67	35.96
H_2O	11.5	12.12	18.00
FeO		0.23	0.63
Fe_2O_3)	2.5	0.14	0.18
Al_2O_3)		1.36	0.67
Insoluble	7.4	SiO_2 4.00	1.22

(3) Composite sample of white material taken by writer from 7 drill holes in Areas A and B. Analyzed by Chief Assayer, Victoria.

(4) Reinecke, Mem. 118, p. 31 - white earth, 0-15" from surface. (Ref. 2)

(5) Reinecke, Mem. 118, p. 31 - average of 5 analyses from deposits at Meadow Lake. (Ref. 2)

Underlying the surface layer of Areas A and B is 3 to 4 feet of cream-colored granular earth overlying impure cemented material.

Typical analyses of this granular material follow:

	Writer (6)	Reinecke C (7)	Reinecke D (8)	Reinecke E (9)
MgO	39.5%	36.63%	24.32%	35.68%
CaO	2.8%	2.86%	20.12%	6.38%
CO_2)		35.64	38.64	36.63
H_2O)	45.7	7.00	2.93	4.15
FeO)		0.17	----	0.20
Fe_2O_3)	1.0	0.11	0.49	0.24
Al_2O_3)		1.34	1.35	2.88
Insoluble	10.1	SiO_2 13.10	10.32	11.33

(6) Composite sample of creamy material below white layer to depth of 36 inches. Analyzed by Chief Assayer, Victoria.

(7) Reinecke, Mem. 118, p. 31-0-39" includes white and part of creamy layer. (Ref. 2)

(8) Reinecke, Mem. 118, p. 31 - below (7) - 39"-60" in creamy layer. (Ref. 2)

(9) Reinecke, Mem. 118, p. 31 - 15-51" below surface, cream colored material. (Ref. 2)

The above analyses indicate a fairly low calcium content to a depth of at least 3 feet; below this the proportion of calcium increases rapidly. Areas A and B therefore may be estimated to contain the following additional tonnages carrying less than 5 per cent lime.

	Tonnages (estimated)
Area A	35,000
Area B	71,000
	106,000

In summation the Meadow Lake Deposits are estimated to contain approximately 114,000 tons of material containing less than 1 1/2 per cent lime, and an additional 106,000 tons containing less than 5 per cent lime, or a total of 220,000 tons with a lime content not exceeding 3 per cent. The question of lime and other impurities in the hydromagnesite is discussed in greater detail under Commercial Possibilities.

The greyish impure hydromagnesite occurring at each end of Meadow Lake varies widely in composition but in general contains a high proportion of both lime and siliceous material. The following analysis is characteristic:

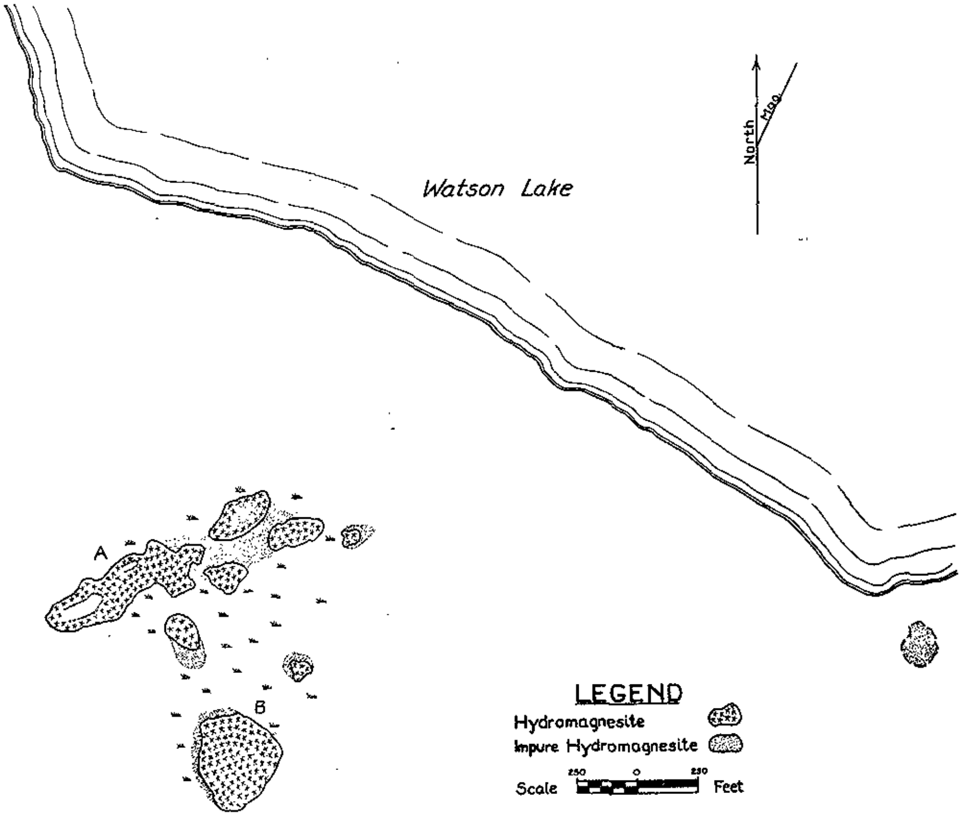
	Reinecke (10)
MgO	20.14
CaO	9.20
CO_2	20.24
H_2O	6.80
FeO	0.59
Fe_2O_3	0.84
Al_2O_3	1.54
SiO_2	36.78

(10) Reinecke, Mem. 118, p. 31 - grey earth northeast end Meadow Lake, 0-24 inches. (Ref. 2)

Watson Lake Deposits (Key Map 6, No. 2)

Watson Lake, a small body of water about 1 1/2 miles long by 1/3 miles wide, lies about 1 mile west of 105 Mile House on the Cariboo Highway, and 1 mile east of Tatton Station on the Pacific Great Eastern Railway.

The hydromagnesite is situated about 1/4 mile south of, and 5 feet above Watson Lake, on a swampy flat near the base of low hills rising gently to the southeast.



MAP 8.
Watson Lake hydromagnesite deposits.

The deposits, shown on Map 8, are similar to those at Meadow Lake. When examined the surrounding ground was swampy, the surface of the deposits being raised 1 to 3 feet above the water level.

The areas estimated to be underlain by purer hydromagnesite are:

	Writer	Reinecke (Ref. 2, p. 46)
Area A	11,000 sq. yds.	7300 sq. yds.
Area B	10,000 sq. yds.	8950 sq. yds.
Others	5,000 sq. yds.	4800 sq. yds.

Drilling by the writer indicated the white layer to be from 1 1/2 to 3 feet deep in Area A, at least 3 feet in Area B, and from 1 to 2 feet in the others. Reinecke (Ref. 2, p. 46) found Area B to contain fairly pure material to depths of 37 to 60 inches. Average figures are 2 feet for Area A, 4 feet for Area B, and 1 1/2 feet for other areas.

The following estimates represent the probable tonnage of white hydromagnesite available from the Watson Lake Deposits.

(Weight of 1 cu. yd. taken as before as 2050 pounds.)

	Writer	Reinecke (Ref. 2, pp. 46-48)
Area A	7,500 tons	4,570 tons
Area B	13,000 tons	13,232 tons
Others	3,000 tons	4,935 tons
	23,500 tons	22,737 tons

The analyses below are typical of the white material from these deposits.

	Writer (14)	Reinecke (15)	Reinecke (16)
MgO	39.4%	43.17%	41.06%
CaO	2.1	1.14	1.62
CO_2)		43.64	38.04
H_2O)	50.5	5.26	11.25
FeO			
Fe_2O_3)	1.3	0.16	0.12
Al_2O_3)		0.16	0.20
Insoluble	5.7 SiO_2	4.62	6.36

(14) Composite sample from 7 drill holes, representing white material from all deposits. Analyzed by Chief Assayer, Victoria.

(15) Mem. 118, p. 31 - Area B - 0-36 inches. (Ref. 2)

(16) Mem. 118, p. 31 - Area A - includes 26 inches of white earth and part of layer of cream earth, base at 85 inches. (Ref. 2)

Insufficient data are available to allow an intelligent estimate of the amount of creamy earth containing less than the arbitrary 5 per cent of lime. It is improbable, however, that the quantity exceeds 5000 tons.

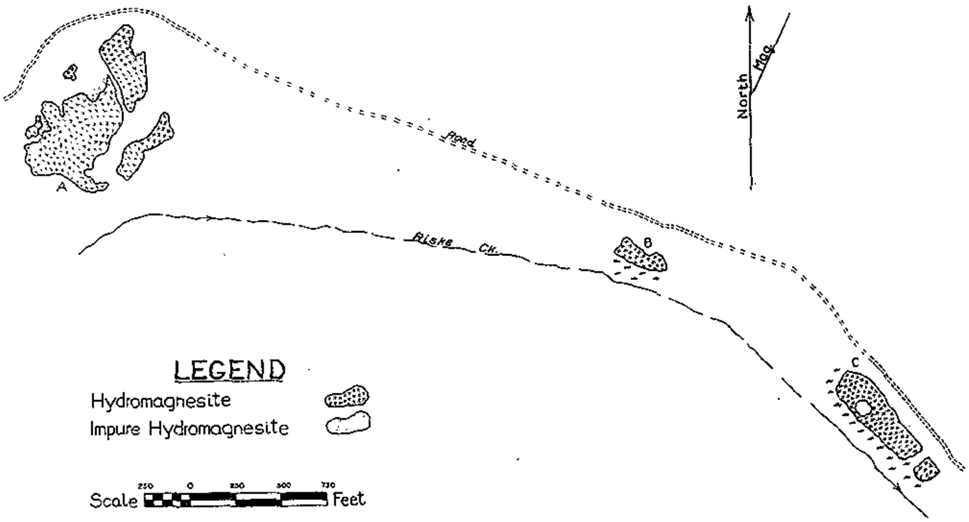
In summation, the Watson Lake Deposits are estimated to contain about 23,000 tons of white hydromagnesite, containing less than 2 per cent of lime.

A small deposit containing only a few hundred tons of white hydromagnesite occurs about 1 mile north-west of the main occurrences at Watson Lake. Reinecke (Ref. 2) gives the following typical analysis:

MgO - 36.70%
CaO - 1.54
CO_2 - 31.08
H_2O - 14.86
Fe_2O_3 - 0.57
Al_2O_3 - 0.33
SiO_2 - 8.62

<u>Riske Creek Deposits</u> (Key Map 6, No. 3)

The deposits lie in the valley bottom of Riske Creek (see Map 9) on the south side of the Chilcotin Road about 35 miles west of Williams Lake on the Pacific Great Eastern Railway.



MAP 9.
Riske Creek hydromagnesite deposits.

Estimates of the areas underlain by purer hydromagnesite are compared in the following table:

	Writer	Reinecke (Ref. 2, p. 48)
Area A	19,000 sq. yds.)	7,775 (26,000 sq. yds. of
Area B	2,500 sq. yds.)	less pure)
Area C	10,000 sq. yds.	10,000 sq. yds.

The above estimate of 19,000 sq. yds. for Area A includes surface material which is not only typically white but also creamy in color. Normally the latter is high in calcium elsewhere, and hence was not included in Reinecke's figure above.

A composite sample, taken by the writer, from 5 drill holes 2 to 3 feet deep in various parts of Area A, had the following analysis. (1)

MgO	-	42.3
CaO	-	0.7
CO_2	-	41.9
H_2O	-	9.2
Fe and Al	-	1.0
Insol.	-	4.4

(1) Chief Assayer, Victoria.

Although some of Area A may contain material high in lime, most of it is fairly pure hydromagnesite to an average depth of 2 1/2 feet. A drill hole in Area B indicated a depth of 1 1/2 feet and one in Area C showed 2 feet of white hydromagnesite. Reinecke (Ref. 2, p. 29) gives the following thicknesses and analyses for Areas A and B:

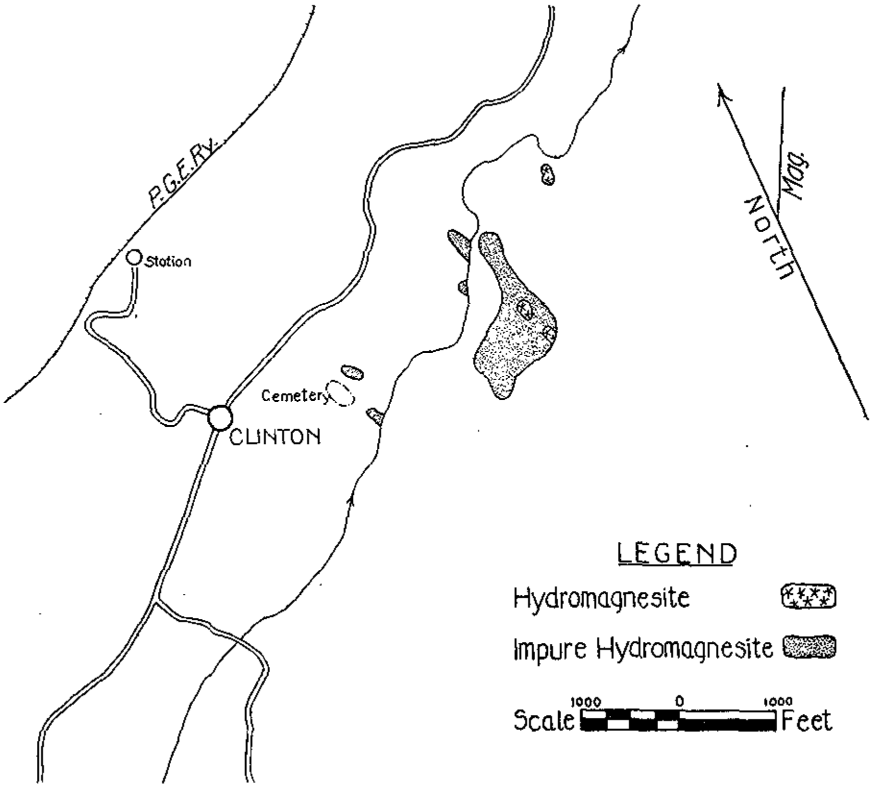
	Area A 2 holes - 2 and 3 feet 0-26"	Area B 1 hole - 2 feet 0-24"
MgO	41.14%	41.74%
CaO	0.10	0.17
CO_2	37.70	40.85
H_2O	17.78	12.98
FeO	0.09	0.16
Fe_2O_3	0.25	0.20
Al_2O_3	0.48	0.48
SiO_2	1.22	1.85

Assuming average depths of 2 1/2 feet for Area A, 1 1/2 feet for Area B, and 2 feet for Area C, the following figures represent estimates of tonnage of purer hydromagnesite in the Riske Creek deposits.

	Writer	Reinecke (Ref. 2)
Area A	15,000 tons	6,600 tons
Area B	1,200 tons	
Area C	6,700 tons	6,900 tons
Totals	22,900 tons	13,500 tons

<u>Clinton Deposits</u> (Key Map 6, No. 4)

These occurrences lie in the valley of Clinton Creek, about half a mile west of the village of Clinton. The tonnage of pure hydromagnesite is small and the deposits were only given a cursory examination by the writer.



MAP 10.
Clinton hydromagnesite deposits (after Reinecke).

The following description is from Reinecke's report (Ref. 2, p. 44):

> "...three areas have been mapped as commercial hydromagnesite, these are localities 1, 2, and 3 (see Map 10). Area No. 1 covers 260 square yards, the upper 3 1/2 feet to 4 1/2 feet of which is clean hydromagnesite...The calculated amount of hydromagnesite present is 355 tons. Area No. 2 covers 1,200 square yards with two feet of fairly pure material on top; the estimated content is 820 tons. Area No. 3 covers 1,850 square yards. Three holes showed pure material down to 2, 3, and 2 feet respectively, with a little siliceous impurity in two cases. The estimated amount of pure material is 1,474 tons. The total amount of commercially valuable material at Clinton in round numbers, thus is 2,650 tons, but of this amount 965 tons is of doubtful purity."

9.6

Sixty-One Mile Creek Deposits (Key Map No. 6)

1.6 3.2

An occurrence of hydromagnesite lies about 2 miles east of Goose Lake, 1 mile north-west of the head of 61 Mile Creek, and about 6 miles from Chasm Station by road. As far as the writer is aware the deposit has not been reported upon previously.

The deposits adjoin a small swampy lake occupying a depression between low hills. Purer hydromagnesite, with a typical cauliflower-like surface, underlies at least 13,000 square yards.

No drilling equipment was available at the time of the writer's visit, so the determination of thickness was consequently impossible. White material, however, was found in the bottom of pits to a depth of 1 foot, and by comparison with other deposits, probably averages at least two feet in depth. Based on these figures at least 4,500 tons, probably 9,000 to 10,000 tons of white hydromagnesite are available.

Typical analyses of surface material are given below:(1)

MgO	38.0	34.4%	32.75%
CaO	1.6	1.76	3.32
CO_2	32.9)	48.16	47.74
H_2O	16.0)		
Fe and Al	1.7	0.69	0.67
Insoluble	9.80	11.60	12.40

(1) Chief Assayer, Victoria.

Several small areas of hydromagnesite occur in the marshy valley of 61 Mile Creek near its head. Those seen were too impure to be of commercial interest.

West Cariboo Block

The occurrence of small hydromagnesite deposits in various parts of the West Cariboo Block is mentioned in the Survey of Resources Report, Pacific Great Eastern Railway Lands. These have not been examined by the writer but are included to indicate their widespread distribution and the possibility that larger undiscovered deposits may be found.

The more important deposits discussed (Logie - Vol. 11, Pt. 2, 1929. Unpublished Manuscript) and their estimated tonnages are tabulated below:

Location	Tonnage
Lot 2833, 2 mi. E. of Alexis Lake	2,000 tons
Lot 561, 8 mi. N. of Alexis Ck.	1,000 "
Big Creek	500 "
Fletcher Lake	350 "
Gay Lake	100 "
Taseko River	60 "

The following analyses are given as typical:

Lot 2833		Lot 561	Big Creek	
$Mg(HCO_3)_2$	80.0%	84.0%	$MgCO_3$	64.2%
CaO	nil	nil	$CaCO_3$	5.7
Al_2O_3	1.0)	0.2	Al_2O_3	0.6
Fe_2O_3	0.2)		Fe_2O_3	1.0
Mn	tr.		H_2O	11.0
Insol.	9.2	13.0	Insol.	16.0
			Na_2CO_3	1.1
			SO_3	0.4

Springhouse Area (Key Map 6, No. 5)

Several settlers in the vicinity of Springhouse have reported the presence of white clay-like material underlying soil in parts of their fields. A typical occurrence on the Williams Lake-Springhouse Road, near Boitano Lake, was examined by the writer and a sample had the following composition: (1)

MgO	-	33.1%
CaO	-	4.9
CO_2) H_2O)	-	42.0
Fe and Al	-	4.3
Insol.	-	14.8

(1) Chief Assayer, Victoria.

From the analysis the materisl is obviously hydromagnesite but too impure for commercial interest. The fact, however, that it is overlain by 6 inches to 1 foot of soil, suggests the possibility of larger and purer deposits occurring similarly in the district.

Other Deposits

Other small deposits occur in the vicinity of Kamloops and Ashcroft. The most important of these (Map 6, No. 6) lies in the Campbell Range about 10 miles south-east of Kamloops. It is estimated to contain about 600 tons of white hydromagnesite. The following is a typical analysis: (1)

NE-50

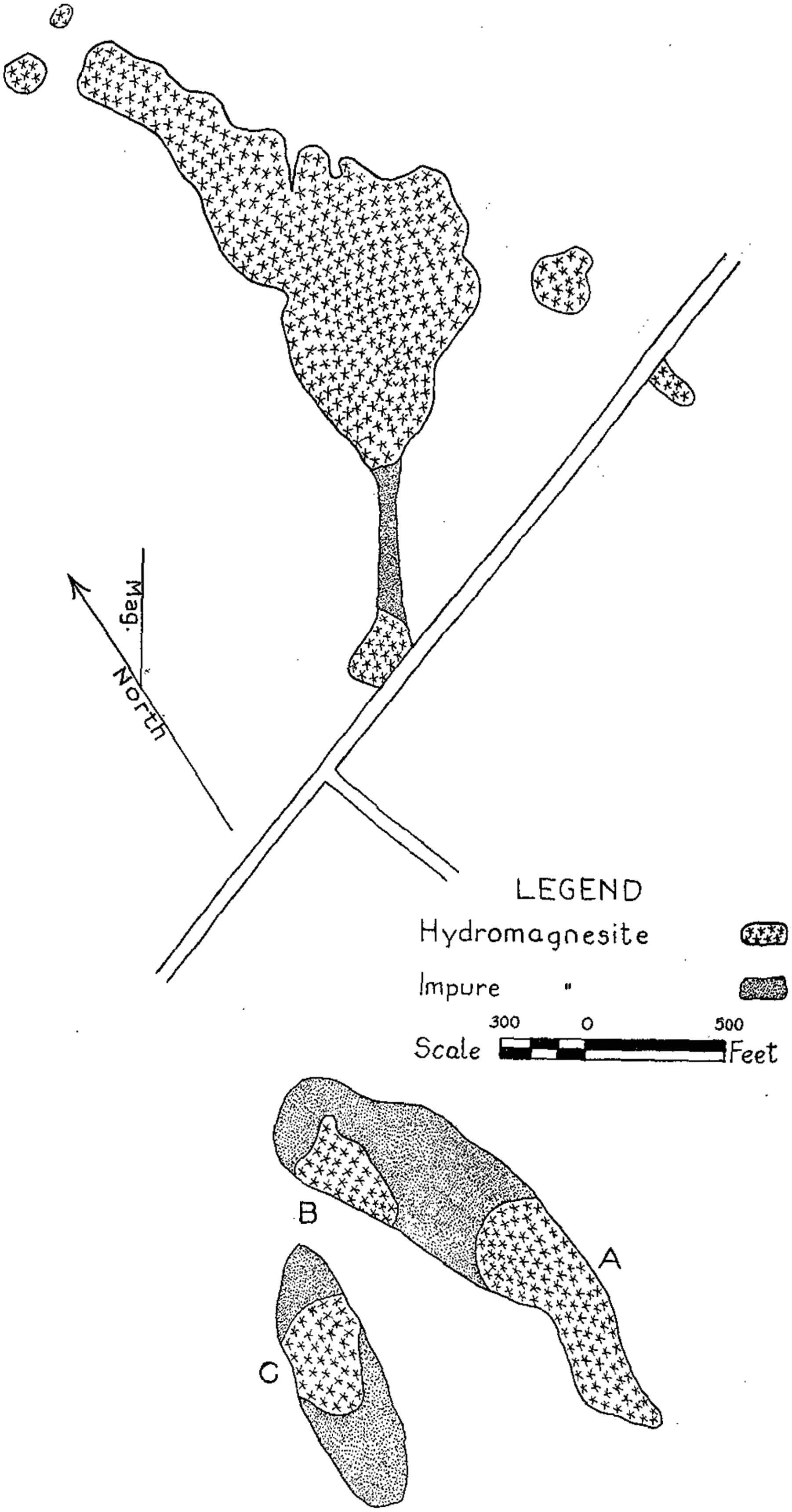
MgO	-	41.0%
CaO	-	nil
Al_2O_3	-	1.15
Fe_2O_3	-	0.25
Ig. Loss	-	54.2
Insol.	-	2.4

(1) Chief Assayer, Victoria.

Impure greyish hydromagnesite in a layer up to 2 feet thick, and covered with soil to a depth of 1 foot, underlies several acres near the north end of Barnes Lake, about 27 miles from Kamloops near the Kamloops-Vernon Road (Map 6, No. 7). Another small area of white hydromagnesite occurs close to the Basque epsomite deposits, 12 miles from Ashcroft.

Atlin Deposits

Relatively large deposits of hydromagnesite occur in the vicinity of Atlin. Insofar as these were not examined by the writer, the following description is abstracted from the detailed account (Ref. 3) by G. A. Young in Summary Report, 1915, of the Geological Survey of Canada.



MAP 11.
Atlin hydromagnesite deposits (after Young).

The hydromagnesite deposits (see Map 11) are situated close to Atlin; one group of deposits lying on the southeast border of the townsite, the other occurring on the highway leading to Discovery about one-half mile from Atlin wharf. Besides the two main groups, small isolated patches occur for two miles along a general course running northwestard from the lakeshore at Atlin. These, however, are in general too small or impure to be of commercial value.

The deposits situated about one-half mile from Atlin wharf lie in a rather faintly marked depression opening to the northwest into a swampy area. No solid rocks outcrop nearby, the country being floored by thick deposits of unconsolidated material. The group comprises one large and four small areas or beds. The surface of the deposits is from description similar to those previously described, in other words is slightly raised, somewhat hummocky, and traversed by cracks. The hydromagnesite is white, plastic when wet, but fine grained and powdery when dry. Young, on the basis of numerous drill holes, mentions that there is no distinctly apparent variation with depth as far as the base of the deposits, but gives an analysis of creamy granular material encountered in one hole 16 inches above the base. Insofar as this contains a relatively high lime content, it is probable that at least part of the white hydromagnesite is underlain by the typical creamy layer encountered in most of the deposits elsewhere.

From the various determinations of the depth of the main body Young concludes that the average thickness is 2'8", and that the volume is 80,000 cu. yds. Using the assumed figure of 115 lbs. per cu. ft. he estimates the quantity available in the main body as about 125,000 tons. In this connection the writer feels that the figure of 2,050 lbs. per cu. yd., as determined by Reinecke on samples from Cariboo deposits, is more nearly correct, and that the 80,000 cu. yds. mentioned above would probably contain little more than 81,000 tons. Young estimates the nearby small areas to contain about 9,000 tons. This, recalculated, would represent about 6,000 tons.

Two sets of samples were taken from the main body; the results of the analyses are tabulated below:

	Depth of hole 2'2"			Depth of hole 3'6"		
	depth 3"	depth 1'1"	depth 1'11"	depth 4"	depth 16 $\frac{1}{2}$"	depth 2'4"
MgO	41.13%	42.35%	42.19%	40.56%	41.93%	35.23%
CaO	2.04	0.82	0.68	1.26	1.50	6.44
CO_2	35.98	36.10	36.17	35.96	36.04	37.70
H_2O	18.02	18.95	19.05	19.04	17.66	8.20
FeO	0.60	0.45	0.64	0.63	0.65	0.78
Fe_2O_3	0.15	0.09	0.11	0.18	0.45	0.73
Al_2O_3	0.67	0.10	0.17	0.67	0.14	0.94
SiO_2	1.86	0.90	0.54	1.22	1.96	9.22

The second group of deposits just east of Atlin lies in marked depressions formed in unconsolidated materials. The group consists of three large bodies of hydromagnesite, (A, B, and C on Map 11) varying in thickness from 1 to 7 feet, in different parts, but estimated to have average thicknesses of 3 feet, 5 feet, and 2 feet respectively.

Area A, with an average thickness of 3 feet, covers about 4 1/2 acres and has a volume of 21,400 cubic yards. Assuming 2,050 lbs. per cu. yd. for the material in place this would represent about 22,000 tons.

Area B, underlying three quarters of an acre to an average depth of 5 feet, would have a volume of 5,500 cu. yds. and contain about 5,600 tons.

Area C covers about 1 acre to an average depth of 2 feet, representing 2,900 cu. yds. of material weighing about 3,000 tons.

Typical analyses of these deposits are given below:

	Deposit A		Deposit B		Deposit C
Depth	1'9"	1'4"	1'6"	Surface	20" (4" above base)
MgO	42.85	38.94	43.04	43.45	42.12
CaO	0.32	0.42	0.16	0.26	0.48
CO_2	36.35	34.31	36.21	36.23	35.89
H_2O	19.10	18.10	19.26	18.95	19.42
FeO	0.66	0.81	0.53	0.36	0.71
Fe_2O_3	0.15	0.56	0.12	0.09	0.10
Al_2O_3	0.35	2.85	0.23	0.41	0.33
SiO_2	0.74	3.48	0.96	0.62	1.18

In summation about 118,000 tons of white hydromagnesite is probably available from the Atlin deposits. The reason for the discrepancy between this and Young's figure of 180,000 tons has been explained. Young considers that about 150,000 of the 180,000 tons would represent material carrying between 41 and 42 per cent of MgO with about 3 per cent of CaO, Al_2O_3, Fe_2O_3, and SiO_2. Of the estimated 118,000 tons therefore, roughly 100,000 tons may be considered to fall within the above compositional limits.

Mining and Transportation

Hydromagnesite could be easily and cheaply won from the deposits described. The material in place is usually moist, hence tough and somewhat plastic; the surface, however, is commonly dry and hard.

The upper layer of white hydromagnesite would be somewhat tough for hand digging, but could be handled with ease by power shovel or power scraper.

Climatic conditions would restrict mining to 5 or 6 months of the year. Again the deposits are relatively small and of isolated occurrence. Mechanical methods of exploitation must therefore be confined to either inexpensive or portable equipment.

Excavation and loading trucks at the deposits by power shovel or power scraper should cost (25) from 10 to 40 cents per ton depending on type of equipment, capacity, and location. Cost of trucking to the nearest railroad loading point will naturally vary for each deposit.

Mining should be preceded and controlled by systematic drilling and analyses, in view of the wide variation in the amount of impurities both laterally and vertically.

In the following table the more important deposits are listed with data in respect to transportation.

---

(25) Based on costs of various clay winning operations elsewhere under comparable conditions - see Ref. 1.

Deposit	Distance by road to nearest railroad loading point	Type of Road	Present freight rate from loading point to Vancouver (crude material)
Meadow Lake	to Chasm - 16 mi.	Good in dry weather--no bad grades.	P.G.E. - $2.50 per ton, min. 40 tons. (x)
Watson Lake	to Tatton - 1 mi.	Old road abandoned--easily repaired. Slight uphill grade.	P.G.E. - $3.00 per ton, min. 40 tons (x)
Riske Creek	to Williams Lake --about 35 Mi.	Surface good in dry weather. A number of steep grades and road crooked.	P.G.E. - not quoted probably about $3.50 per ton, min. 40 tons. (x)
Clinton	to Clinton Station 1 1/2 miles	Surface good. Steep up-hill grade.	P.G.E. - $2.50 per ton, min. 40 tons. (x)
61 Mile Creek	to Chasm - 6 mi.	4 miles fair. Last 2 easily improved--all level ground.	P.G.E. - $2.50 per ton, min. 40 tons. (x)
Deposits near Alexis Lake	to Williams Lake--about 85 mi.	Roads fair when dry.	P.G.E. - not quoted probably about $3.50 per ton. (x)

Table (Continued)

Deposit	Distance by road to nearest railroad loading point	Type of Road	Present freight rate from loading point to Vancouver (crude material)
Campbell Range	to Kamloops--about 12 mi.	6 miles of main road --remainder narrow and hilly.	C.P.R.--not quoted.
Atlin	to Carcross (boat transportation)--about 70 mi.	Boat across Atlin Lake, 4 mile tramway, boat on Taghish Lake to Carcross.	--------

(x) - plus 25¢ per ton switching and harbor dues at Vancouver.

Summary

In the accompanying table the more important deposits are listed with pertinent data.

Deposit	Est. Tonnage	MgO Content	Impurities	CO_2 + H_2O	Est. Cost Transportation to Ry. (per ton)	Freight to Vancouver (per ton)	Total cost Transportation (per ton)
Meadow Lake	114,000 tons 106,000 "	39-41% 35-39%	4-11% 14-17%	50-54% 40-45%	$1-$4	$2.75	$4-$7
Watson Lake	23,500 "	39-43%	4-9%	49-50%	$.25-$.50	$3.00	$3.00
Riske Creek	23,000 "	40-42%	3-5%	50-55%	$4-$9	$4.00	$8-$13
Clinton	2,650 "	42%	4%	53%	$.25-$.50	$2.75	$3.50
61 Mile Creek	4,500-10,000 "	33-38%	12-15%	47-49%	$0.75-$1.50	$2.75	$4.00
L. 2833 Alexis Lake L. 561 Alexis Creek	2,000 " 1,000 "	----	10-13%	-----	$10-$20	$4.00	$14-$24
Big Creek, etc.	950 "	----	20%	-----	$8-$15	$2.75	$11-$19
Campbell Range	600 "	41%	5%	54%	$2-$3	Est. at $3	$5-$6
Atlin	100,000 " 20,000 "	41-42% 35-40%	3% 5-10%	54-55% 45-50%	----	----	----
Totals	403,700 "	35-43%	3-17%	45-54%			

In summation roughly 136,000 tons of hydromagnesite representing some 54,000 tons of MgO could be obtained from the Meadow Lake, Watson Lake, and Clinton deposits and shipped to Vancouver for an overall estimated cost of $3.00 to $7.00 per ton. An additional 120,000 tons of less pure material, containing about 40,000 tons of MgO, is probably available from these and the 61 Mile Creek deposits, and could be handled at approximately the same cost.

At least 100,000 tons of hydromagnesite, containing 40,000 tons of MgO are present in the Atlin deposits.

Cost of mining and shipping from Riske Creek deposits would probably be $8.00 to $11.00 per ton; costs from the Alexis Creek and Big Creek deposits would be considerably higher.

Mineralogy

Given analyses not only vary from deposit to deposit, but from place to place in the same deposit; apart from the content of extraneous material (Insoluble, SiO_2, Al_2O_3, FeO, Fe_2O_3) the chief variation is in the relative amount of combined water. Several samples from Atlin and two from the Cariboo show sufficient water with magnesia and carbon dioxide to approximate the composition of the mineral hydromagnesite ($3MgCO_3 . Mg(OH)_2 . 3H_2O$). Most of them, however, contain far too little water to correspond to hydromagnesite, much less nesquehonite ($MgCO_3 . 3H_2O$) or other hydrous magnesium carbonates. Lateral changes in composition are erratic; vertical represent a definite increase in lime and decrease in combined water content from the surface downward.

Microscopic Examination

The following minerals occur in all the samples examined:

(1) Magnesite - as minute (1 to 10 microns in size) colorless, stubby, prisms rounded to hexagonal in end section.

Uniaxial, negative

N_o - 1.510 ± .003
N_e - 1.700 ± .003
N_o-N_e - 0.190 ±

(2) Hydromagnesite (?) - as rounded to irregular plates

and platy to fibrous aggregates. Very fine-grained (largely less than 50 microns) so that optical properties not definitely determinable. Birefringence on plates very low, somewhat higher on edges and fibres.

N_m on plates - 1.525 ± .005
N fibres - 1.540 ± .005 (elongation)
1.520 ± .005 (across fibres)
Extinction variable.

(3) Extraneous minerals - quartz, feldspar, hornblende, muscovite, biotite, apatite, augite, sphene, etc. As angular to semi-angular grains ranging in size from .05 mm. to 1 mm.

In addition to the above amorphous and indeterminate material is present. The proportions of the constituents are variable, although magnesite and hydromagnesite (?) form the bulk of all purer samples.

No high calcium samples were available for microscopic examination. Of those studied, however, none yielded any clue to the manner in which calcium occurs in the material.

Chemical Examination

Under the microscope "hydromagnesite" seems to be composed essentially of the two minerals magnesite and hydromagnesite. On this assumption the mineral content corresponding to available analyses was calculated in each case. SiO_2, Al_2O_3, FeO, Fe_2O_3, and insoluble were grouped as impurities; sufficient CO_2 attributed to CaO to form calcite; and remaining CO_2, MgO, and combined H_2O distributed between magnesite and hydromagnesite. It is interesting and probably significant that this last distribution was in every case possible without leaving an appreciable excess of any of the three components.

Meadow Lake Analyses

	(3)	(4)	(5)
Hydromagnesite $3MgCO_3 . Mg(OH)_2 . 3H_2O$	60.%	62%	95%
Magnesite $MgCO_3$	29%	30%	---
Calcite $CaCO_3$	1%	3%	3%
Impurities	10%	5%	3%

Meadow Lake Analyses - lower layers

	(6)	(7)	(8)	(9)
Hydromagnesite	40.0%	37%	15%	21%
Magnesite	45.0%	40%	34%	55%
Calcite	5.0%	6%	36%	11%
Impurities	10.0%	17%	15%	13%

Watson Lake Analyses - typical

	(14)	(15)	(16)
Hydromagnesite	55%	27%	56%
Magnesite	34%	63%	32%
Calcite	4%	2%	3%
Impurities	7%	7%	7%

Riske Creek - typical

	Writer	(20) Area A	(20) Area B
Hydromagnesite	47%	92%	67%
Magnesite	47%	3%	28%
Calcite	1%	---	---
Impurities	5%	5%	5%

61 Mile Creek Analyses

	Writer
Hydromagnesite	82%
Magnesite	4%
Calcite	3%
Impurities	11%

Atlin Analyses - main body

	3"	1'1"	1'11"	4"	$16\frac{1}{2}$"	2'4"
Hydromagnesite	91%	95%	96%	94%	89%	41%
Magnesite	2%	1%	---	---	5%	35%
Calcite	4%	2%	1%	2%	3%	11%
Impurities	3%	2%	2%	3%	3%	12%

Atlin Analyses - Deposits A, B, and C

	1'9"	1'4"	1'6"	Surface	20"
Hydromagnesite	96%	91%	98%	96%	97%
Magnesite	2%	---	---	2%	---
Calcite	---	---	---	---	---
Impurities	2%	8%	2%	2%	3%

All samples effervesced violently with cold hydrochloric acid leaving a residue composed of magnesite crystals, sand grains, and amorphous material. Further treatment with hot acid dissolved the magnesite.

In general "hydromagnesite" from all deposits described is essentially alike, differing only in the proportion of magnesite to hydromagnesite and in the amount of contained lime and extraneous mineral grains.

Origin of Deposits

The following remarks are necessarily restricted to the hydromagnesite deposits of Central British Columbia, which the writer has visited. Written description suggests, however, that the Atlin and Chilcotin deposits are of similar origin.

All major deposits have the following features in common:

(1) Occurrence in depressions or on flats near ground-water level.

(2) Sheet-like form with relatively shallow depth.

(3) Cauliflower-like surface raised above the surrounding ground.

(4) Presence of clay or soil underlying the deposits.

(5) Progressive increase in lime and decrease in combined water with depth.

(6) Definite overlap of the raised surface over the soil at the edges of deposits.

In addition the Meadow Lake deposits contain, in places, pits up to 5 feet in depth and 10 feet diameter filled, or partly filled, with angular boulders.

Two possible modes of origin suggest themselves: deposition from solution in lakes and deposition from underground waters or springs. Both offer plausible explanations of certain features; only the latter, however, satisfactorily accounts for the raised and overlapping surface, "rock-pits," and the irregular distribution of deposits within a group.

The general impression formed by examination of the deposits is that they have been fed by underground water either through capillarity or springs, and have grown upward and outward. In so doing rocks and soil have been displaced, accounting for the relative absence of admixed soil, the over-lapping edges and the rock piles and pits. The higher calcium content with depth probably follows from the fact that calcium carbonate is less soluble than magnesium carbonate, and is consequently precipitated earlier from a rising solution containing both. No explanation is immediately apparent for the decrease in combined water, or increase in the proportion of magnesite versus hydromagnesite, towards the base of deposits.

Beneficiation

Microscopic study of various samples of hydromagnesite revealed in general a marked size difference between magnesitic constituents and sand grains. In view of this it was felt that the purity of material might be substantially increased through some method of sizing and elimination of larger grains.

Preliminary testing, to check the feasibility of this suggestion, was carried out by the writer on several samples of typical material. The work was not carried to its logical conclusion but does indicate a field for further investigation should the need arise.

The following procedure was followed in testing samples: A half pound sample was thoroughly dried, pulverized, and passed through a small air separator set to yield two products--one plus 325 mesh (43 microns), the other minus 325 mesh. The head sample and undersize product were analyzed by the Chief Assayer, Victoria, in each case. Analyses of samples tested follow:

Meadow Lake	Heads	Undersize
MgO	38.8%	41.5%
CaO	0.8%	1.3%
CO_2	38.7%	40.3%
H_2O	11.5%	8.3%
Fe & Al	2.5%	0.9%
Insol.	7.4%	6.7%
Watson Lake		
MgO	39.4%	41.0%
CaO	2.1%	1.7%
CO_2)	50.5%	40.2%
H_2O)		11.2%
Fe and Al	1.3%	0.8%
Insol.	5.7%	4.3%
Riske Creek		
MgO	42.3	42.3
CaO	0.7	0.6
CO_2	41.9	42.8
H_2O	9.2	8.6
Fe and Al	1.0	1.7
Insol.	4.4	3.4
Sixty-One Mile Creek		
MgO	38.0	41.0
CaO	1.6	1.5
CO_2	32.9	43.3
H_2O	16.0	8.4
Fe and Al	1.7	1.0
Insol.	9.0	4.1

The above analyses are of interest in indicating a possible line of research. It is obvious that the minus 325 mesh product in all cases is freer of undesirable impurities than the coarser, or untreated material. Recoveries of the former in the tests averaged only 50 per cent. Microscopic examination, however, showed the coarser fraction to contain a large proportion of magnesite and hydromagnesite which had not been completely pulverized. It is probable, therefore, that with careful control of drying and pulverizing a recovery of a minus 325 mesh product, constituting at least 75 per cent of the total, could be made without difficulty. Again the purity of this could probably be increased considerably over that of the products in the above tests through care in preventing the comminution of sand particles in processing.

References

Deposits

Ref. 1 - McMahon - A Study of Clay Mining and Its Costs in the Provinces of Ontario and Quebec. Mines Branch No. 754, Dept. of Mines, Ottawa.

Ref. 2 - L. Reinecke - Mineral Deposits between Lillooet and Prince George, British Columbia. Mem. 118, Geological Survey, Canada, 1920.

Ref. 3 - G. A. Young - Hydromagnesite Deposits of Atlin. Geological Survey of Canada, Summary Report 1915.

CHAPTER 4

Technology and Uses of Magnesite, Hydromagnesite, and Other Magnesium Compounds

Commercial Possibilities

The hydromagnesite deposits of British Columbia have been known for many years but remain unexploited. Earliest reference to the Atlin deposits was recorded in 1897, and to the Cariboo in 1898. An experimental shipment of 200 tons was made from Atlin to San Francisco in 1904; during 1915 and 1916 several hundred tons more was sent to Vancouver. In 1921 two or three carloads were shipped from Watson Lake to Vancouver. No further activity has been recorded.

Commercial exploitation of these deposits depends upon local or foreign demand for hydromagnesite, either to replace material at present used or to form the basis of new manufactures. In the former case hydromagnesite must have superior properties to the material used or be deliverable at a lower cost; in the latter a sufficient market for the product or products to be made must be assured in competition with imported goods. The total quantity of available hydromagnesite is relatively small and this too must have an important bearing on its utilization.

Possible uses for hydromagnesite are listed below:

1. Refractories.
2. Cements and Insulation.
3. Metallic Magnesium.
4. Chemical and other uses.

Refractories

Magnesitic refractories are resistent to the action of basic slags at high temperatures, hence are widely used in many branches of industry. The bulk of consumption is for the construction and repair of basic open-hearth steel furnaces, the remainder being used in copper refining and reverberatory furnaces, copper converters, electric steel-melting furnaces, lead smelting and refining furnaces, rotary kilns burning cement, dolomite and lime, and various chemical furnaces such as those melting and treating sodium carbonate or sodium sulphate.

Most magnesitic refractories are prepared from magnesite calcined at temperatures above 2,700 deg. F. to yield a dense, hard clinker. The clinker, known as "dead burned" magnesite is marketed either in a granular form (grain magnesite) or is fabricated, alone or with chromite and other materials, into brick. Grain magnesite is used almost exclusively for making open-hearth steel furnace bottoms; bricks serve a wider field.

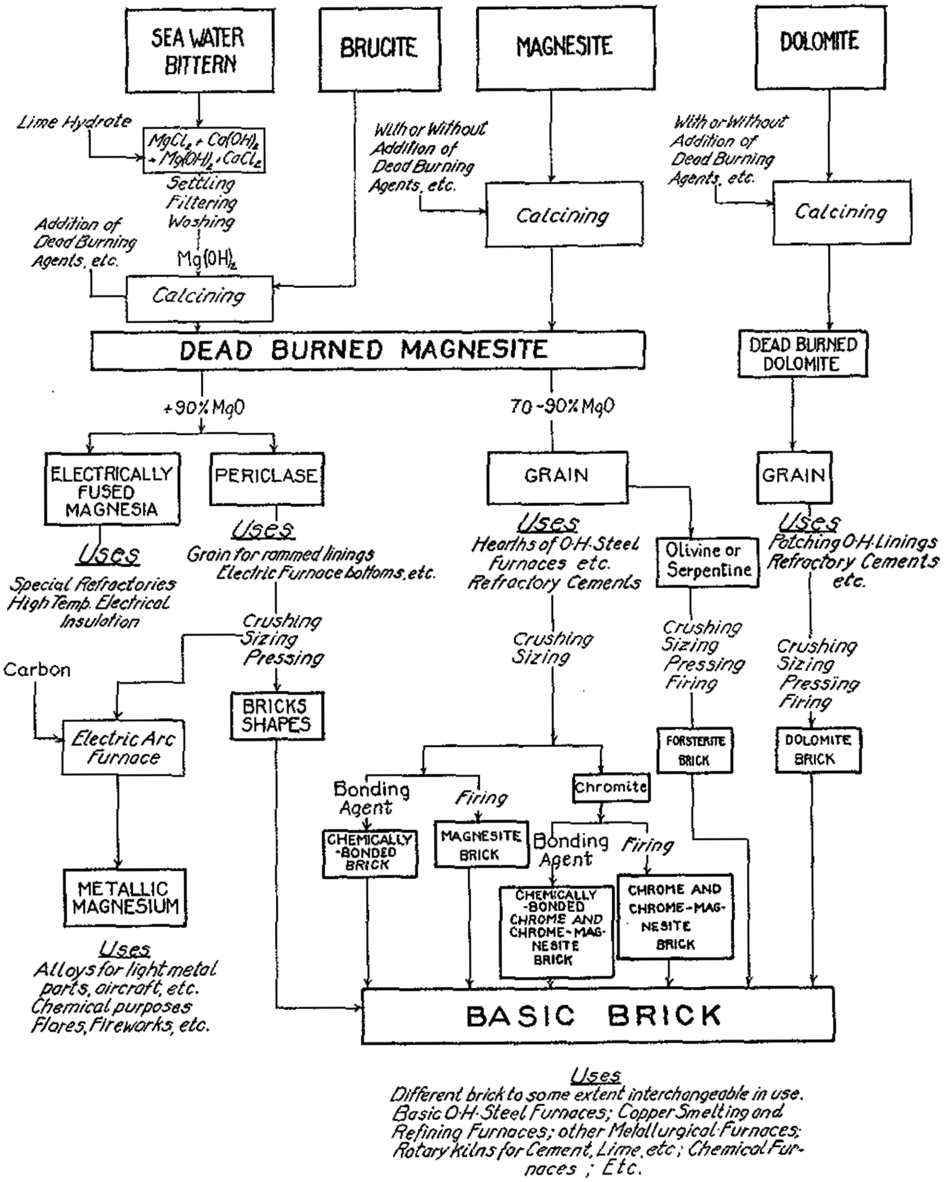


FIG. 1.
Sources and uses of magnesitic refractories.

Typical analyses of commercial dead burned magnesites follow:

	Austrian (Ref. 7, p. 335)	Manchurian (Ref. 10, p. 1128)	Washington, U.S.A. (Ref. 7, p. 335)
MgO	85	91	83
CaO	3	2	3
Fe_2O_3) Al_2O_3)	8	3(a)	7(b)
SiO_2	3	4	7

(a) Too low iron for grain magnesite for bottom making.
(b) Iron added to crude magnesite before calcining.

Prior to 1914 magnesite was the only satisfactory material for the manufacture of basic refractories. Improvements in chrome brick, however, coupled with lower prices, resulted in an increasing displacement of magnesite brick from markets which it had formerly monopolized. By 1927 the two were being produced in nearly equal quantities and were the only types on the market, each with certain inherent disadvantages. Several factors, however, have served to check the decline in the use of magnesite for brick-making. One has been the discovery that superior characteristics were imparted to brick by the use of chromite and magnesite in combination; another has been the introduction of cheaper, but in some respects superior, chemically-bonded magnesite brick.

Research has been directed successfully in recent years to dolomite and high-calcium magnesite for refractories; magnesite containing 12 per cent or more of lime is now being used, and it is announced (Ref. 11) that

> "development has now been carried to the point where, with the presence of certain stabilizing agents, it is possible to make highly effective refractories from dolomite and silica, or even from calcium limestone and silica. These new products, on account of the low cost of raw materials, can be made much more cheaply than can the corresponding magnesitic products and their development bids fair to have a major effect on the production of refractories made from magnesite and magnesitic dolomite."

Another interesting development is the use of dunite, or olivine-rich rock, blended with magnesite for the manufacture of shaped refractories. In Europe mixtures of serpentine and magnesite have been similarly employed. Although magnesite remains the most important source of refractory material for the steel industry, it does not occupy its former unique position among basic refractories. Other sources of magnesia are being developed, including dolomite, brucite, and sea water. In the last case it is interesting to note that extraction of magnesia from sea water is being carried on commercially in both California and England and part of the material obtained is converted into refractory products.

For some purposes the presence of impurities is objectionable and magnesite refractories are made containing up to 92 per cent magnesia.

In certain cases even greater resistance to temperature is required and 95 to 99 per cent magnesia may be used. These special products are usually calcined electrically at temperatures ranging from 2,900 to 4,500 degrees F. A related "super-refractory," synthetic spinel is made electrically from a mixture of magnesia and alumina. In general the market for these special refractories is very small owing to the high cost of manufacturing them.

Production and Markets

No magnesite is produced commercially in British Columbia, nor are any basic refractories made. Large deposits of rock magnesite occur in East Kootenay (Ref. 1), the most accessible being controlled by the Consolidated Mining and Smelting Company of Canada. Other occurrences have been reported from the following areas: Atlin (Ref. 4), Germansen Creek (Ref. 5), Bridge River (Ref. 3), Williams Lake (Ref. 2), and Clinton (Ref. 6). These are, as far as is known, either too remote, too impure, or too small to be of immediate interest.

The present demand for basic refractories in British Columbia is very small. Neither iron and steel nor copper are smelted in the province and electric steel melting is confined largely to furnaces with siliceous lining. The chemical industry is meagrely represented, and lime is manufactured in vertical kilns. Small quantities of magnesite and chrome brick are used in the lead smelting industry and for sundry purposes, but although exact figures are not available, it is improbable that average consumption exceeds a few thousand bricks a year.

Canada

The only known deposits of magnesitic dolomite, or magnesite of commercial grade in eastern North America are found in Argenteuil County, Quebec. These are mined and calcined at Kilmar and Harrington East, the products marketed comprising dead-burned grain material, bricks and shapes (burned and unburned), and refractory cements. Chromite is used in conjunction with magnesite in the preparation of several products. The value of magnesitic dolomite products marketed in 1937 was $677,207, while exports are recorded as 2,028 tons valued at $49,401. Within the last year experimental work has been done in respect to the utilization of extensive deposits of brucite-bearing limestone discovered in Ontario.

Canadian imports of magnesite brick, caustic and dead-burned magnesite and crude and ground magnesite were valued at $626,351 in 1937. Of this figure the largest part is attributable to material for refractory purposes. In addition chrome firebricks were imported to the value of $103,287. Imports of both originated largely in the United States.

Average annual consumption of basic and neutral refractories with a value in excess of one million dollars is accounted for almost entirely by the industries of Eastern Canada.

United States

Commercial production of magnesite in the United States is confined to Washington and California. The output from Washington is largely sold in the dead-burned form, whereas California produces a preponderance of caustic-calcined material for other than refractory purposes. Virtually all dead-burned magnesite from both sources is used for furnace bottoms.

Sales for refractory purposes represented about 85% of domestic production in 1937 amounting to 83,204 tons of dead-burned magnesite valued at $1,598,336 or about $19.00 per ton.

By the close of 1937 all important magnesite mines in California had closed, and production was confined to the extraction of magnesia from sea water. Satisfactory refractory material has been made and, insofar as the process has proved satisfactory and present capacity is in excess of 20,000 tons a year, the mines may remain closed indefinitely. Attention has been directed to extensive deposits of brucite in Nevada, and in 1937 a moderate tonnage was distributed to the Eastern States for testing in refractory manufacture.

Domestic production normally accounts for 60 to 75 per cent of the dead-burned magnesite used in the United States. Imports in 1937 amounted to 56,021 tons valued at $795,047, of which about 43 per cent was from Austria, 37 per cent from Manchuria, and 16 per cent from Czechoslovakia. Manchurian magnesite entered the field for the first time in 1936, and since has captured a considerable part of the market formerly dominated by the Austrian product. A large proportion of imports is utilized by the three American manufacturers of basic refractories, who, situated on the Atlantic seaboard, depend entirely upon foreign supplies.

The following are average recent prices for various basic refractories.

Dead Burned Magnesite

Domestic	f.o.b. Washington	$25.00 per ton.
	f.o.b. California	$22.00 per ton.
Austrian	f.o.b. Austria	$14.47 per ton.
Manchurian	f.o.b. Kwantung	$12.19 per ton.

Note: Delivered price in Pittsburgh for all is about $35.00 per ton. Tariff rates on imported crude and dead-burned magnesite are $9.375 and $11.50 per ton respectively.

California - 92% dead-burned magnesite f.o.b. Cal. - $35.00 per ton.
94% or high grade periclase f.o.b. Cal. - $65.00 per ton.

Chromite

Chrome ore - 48-50% c.i.f. Atlantic ports - $22.00 to $23.00 per long ton.

Brick

All prices f.o.b. Philadelphia.

Magnesite brick	$67.00 per ton.
Chemically-bonded magnesite brick	$57.00 per ton.
Chrome brick	$47.00 per ton.
Chemically-bonded chrome brick	$47.00 per ton.
Fused magnesia brick	$1.00 per brick.

Note: Standard magnesite bricks weigh 10 lbs. each and standard chrome brick 11 lbs.

World Production and Markets

World production of crude magnesite in 1936 was roughly 1,800,000 long tons of which the largest part, at least two-thirds, was used for refractory purposes. Chief producing countries are listed below:

Country	Production (1936) (long tons)	Exports (long tons)	Remarks
U.S.S.R.	No data--probably between 800,000 and and 900,000 long tons annually.	No data--large quantities to Eng., France, Germany and others.	Large reserves of high grade magnesite containing over 95% $MgCO_3$.
Austria	Crude - 391,494 long tons; dead-burned - 97,025 long tons; bricks - 42,015; caustic-calcined - 57,621.	Crude - 9,058 dead-burned - - 62,934. Bricks - 38,643 caustic-calcined - 43,274.	Large reserves. Imports negligible. United States leading buyer, followed by U.K., France, etc. Germany chief market for caustic.
Manchoukuo	Crude - 203,000	Crude and ground 108,535.	Large reserves. Imports negligible. Large part of exports as dead-burned, to Japan, United States, etc.
Greece	Crude - 118,000 not over one-third dead-burnt, bulk is caustic-calcined.	Crude - 44,841 caustic-calcined - 23,340 dead-burned - 11,796.	Fairly large reserves. Material most suitable for caustic. Germany and Netherlands main buyers.

Country	Production (1936) (long tons)	Exports (long tons)	Remarks
Czecho-slovakia	No data - see exports.	Crude - 8,545 calcined - 34,957.	Large reserves - Hungary, Germany, and United States chief buyers.
Australia	Crude - 17,615	Neg.-used in Australia.	Fairly large reserves.
India	Crude - 15,468	4,768 - largely caustic-calcined. Exports to Europe and U.S.A.	Fairly large reserves.
Germany (Prussia)	Crude - 14,789	calcined - 1,789	No data on reserves.

In the following table chief importing countries are listed with pertinent data:

Country	Approx. Consumption (calcined) (long tons)	Imports (long tons)	Sources of Imports (in order of importance)
U.S.A.	132,400	Crude-neg. dead-burnt - 38,043 caustic - 1,960.	Austria, Manchoukuo, Czechoslovakia--minor amts. from India, Canada, Greece, USSR, etc.
Germany	123,100	Crude - 55,074 caustic - 62,757 dead-burnt - 30,606.	Greece, Austria, Czechoslovakia--minor amts. from Yugoslavia, USSR, etc.
United Kingdom	38,000	Crude and calcined - 38,534	Austria, Greece, British India, USSR, Netherlands, Canada.
France	14,000	Crude - 4,100 calcined - 12,223	No data.
Netherlands	11,000	Crude - 1,155 Oxide - 10,411	No data.
Italy	5,600	Caustic - 4,176	No data.

The remaining countries are either essentially producers, or consume only small quantities of magnesite; in several cases, e.g., Japan information is lacking.

World production of magnesite for refractory purposes has increased considerably in the last two years. The above figures (1936 are most recent available) however, are at least indicative of major consumers and sources of supply.

Refractory Possibilities of Hydromagnesite

At present the local market for basic refractories is too small to justify their manufacture in the province. Eastern Canada has developed sources of supply, and competition with producers in Washington and California for United States markets would be virtually impossible because of tariffs and transportation costs. European markets are dominated by Central European producers, and the development of Manchoukuon deposits effectively closes the Oriental market to outside supply. There seems, therefore, little if any commercial possibility of utilizing British Columbia hydromagnesite for refractory purposes under present conditions.

World reserves of magnesite are large and present resources will not be exhausted for many years; again the recent satisfactory extraction of magnesia from sea water makes the supply literally inexhaustible. However, changes in political control of deposits or of foreign policy in respect to them might be such as to allow the economic exportation of hydromagnesite or derived products. It seems more likely, however, that possible development of the deposits as a source of refractory material is contingent upon development of local demand through increased industrial activity in the province.

In this connection quantity, quality, and location of deposits are of paramount importance. An estimated 136,000 tons of hydromagnesite is available from Meadow Lake, Watson Lake, and Clinton, with a further 120,000 tons of less pure material present in these and nearby deposits. Recalculated to the basis of equivalent magnesia, the first grade would represent 54,000 tons of pure magnesia, or 65,000 tons of calcined material containing 2 to 3 per cent lime and from 8 to 20 per cent total impurities (lime, silica, iron oxide, alumina); the second grade would represent 40,000 tons of pure magnesia, or 54,000 tons of calcined magnesite with 4 to 10 per cent lime and 20 to 30 per cent total impurities. Mining and transportation of crude material to Vancouver would cost roughly $5.00 to $7.00 per ton, or $10.00 to $14.00 per ton of dead-burned magnesite if calcining was done in

Vancouver.

The Atlin deposits are estimated to contain approximately 100,000 tons of hydromagnesite carrying less than 3 per cent impurities, the equivalent of 41,000 tons of pure magnesia, or 45,000 tons of dead-burned magnesite with not over 1 per cent lime and 6 per cent total impurities. It is probable that on a quantity basis the cost of mining and transportation to Vancouver would not exceed \$8.00 to \$10.00 per ton of crude, or \$16.00 to \$20.00 per ton of calcined material.

In the table below typical analyses, calculated to their dead-burned equivalents, of hydromagnesite from the deposits under discussion are compared with analyses of various commercial dead-burned magnesites.

	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2
Meadow Lake--centre of main deposit - 0-15"-(4)	84.9	2.7	0.8	2.8	8.2
Meadow Lake--average of 5 samples - 0-2" - (5)	90.1	2.8	2.0	1.5	2.8
Watson Lake--east end of east deposit - 0-36"- (15)	87.0	2.5	.4	.4	9.2
Watson Lake--west deposit 0-26", part creamy - (16)	82.9	3.2	.3	.4	12.8
Atlin--average of 8 analyses	91.2	2.0	1.6	1.4	3.1
Austrian dead-burned magnesite--(Ref. 9, p. 617)	87.38	2.64	3.77	1.61	4.50
Austrian dead-burned magnesite--(Ref. 7, p. 325) Average	85.57 -90.0	0.96 -3.52	7.43 -9.96	---- -2.22	0.26 -1.34
Manchoukuo dead-burned magnesite--(Ref. 10, p. 1128)	90.9	1.78	1.36	1.77	4.19

	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2
Washington dead-burned magnesite - (Ref. 9, p. 617)	81.38	5.28	4.40	2.01	6.90
Washington dead-burned magnesite--(Ref. 7, p. 325)	83.04	3.11	7.02	7.02	6.78
California dead-burned magnesite--(Ref. 9, p. 617)	93.15	2.05	0.49	0.28	3.96
California dead-burned from sea-water--(Ref. 10, p. 1128)	80.9	4.0	7.0	2.0	6.0
California periclase from sea water--(Ref. 10, p. 1128)	92.3	2.0	.2	.4	5.0
Greece dead-burned magnesite--(Ref. 7, p. 325)	90.62	4.10	1.57	1.57	3.00

Wide variations in analyses of commercial dead-burned magnesites are apparent in the above table. Disregarding periclase grades, MgO ranges from 80.9 to 90.9 per cent, CaO from 0.96 to 5.28 per cent, Fe_2O_3 from 1.57 to 9.96 per cent, Al_2O_3 from 0 to 7.02 per cent, and SiO_2 from 0.26 to 6.90 per cent.

MgO, CaO, and Al_2O_3 in material represented by the above Meadow Lake and Watson Lake analyses lie within commercial limits. Iron oxide, however, although likewise between these limits, is too low for satisfactory grain magnesite; on the other hand silica is rather high for all purposes. Atlin hydromagnesite, as represented by the above analysis, is almost pure enough to furnish calcined material of periclase grade; actually much of the hydromagnesite from Atlin deposits is even purer. Recent technologic advances in the manufacture of basic refractories coupled with the probability that a large part of the impurities in hydromagnesite can be economically eliminated (see discussion under Beneficiation) suggest that a variety of refractory materials can be made with hydromagnesite as a base.

The establishment of a steel industry in the province would provide a major market for dead-burned magnesite in both basic open-hearth and electric furnaces. The quantity thus consumed cannot be estimated without knowing the size of operation or the processes employed.

A hypothetical production of 500 tons per day, however, might call for 1,500 to 4,500 tons of dead-burned magnesite and products a year. On this basis the Cariboo deposits would have a maximum life of 10 to 40 years, depending on consumption and usable quality. Additional markets for magnesitic refractories would be afforded by copper smelting, the manufacture of ferro-alloys, certain chemical industries, and by expansion of the present cement and lime industries. Chrome and forsterite replace magnesitic refractories for many purposes, and for others are preferable. Both, however, require magnesite for their manufacture.

Forsterite refractories, first developed in Norway about 1925, are of recent introduction to America. Although rather poorly resistant to basic slags (other than those high in iron), they show promise in many fields, being suitable for high temperature ceramic kilns, rotary kilns, electric furnace bottoms, forging and reheating furnaces in steel works, roofs of copper furnaces, and bulkheads of open-hearth steel furnaces. They are normally made from dunite in which the olivine (forsterite rich variety) content is roughly 90 per cent. Magnesite is added to convert easily fusible impurities to forsterite and magnesioferrite.

Typical analyses of dunites used commercially follow:

	North Carolina	Norway
SiO_2	31.7	41.81
MgO	57.2	50.31
FeO	6.4	5.83
Fe_2O_3	---	0.25
Al_2O_3	1.1	----
Cr_2O_3	0.1	0.37
K_2O plus Na_2O	---	0.01

Crude dunite is quoted at $6.00 per ton f.o.b. North Carolina.

It is notable that forsterite refractories have been made satisfactorily in Germany from mixtures of serpentine and magnesite although at a somewhat higher cost than from olivine rock. In this connection it seems probable that they could be likewise made in British Columbia should a demand for them arise. Dunite deposits are of restricted occurrence and it is questionable if any in the province would approach the desired forsterite content; serpentine on the other hand is widely distributed and easily accessible from a number of deposits for admixture with hydromagnesite.

Results obtained in the removal of impurities from hydromagnesite (see Beneficiation) suggests the possibility of producing material of periclase (93%) or high grade periclase (94%) grade by a relatively cheap treatment. With sufficiently cheap power fused magnesia products may possibly be produced from processed hydromagnesite in future.

Cements and Insulating Materials

Lightly calcined magnesite, or caustic magnesite, mixed with a solution of magnesium chloride sets rapidly to a dense, hard, and strong body. Oxychloride, Sorel, or magnesite cement, made in this way is employed extensively for flooring, as well as for stucco, plaster, insulating board, artificial tile, etc.

Caustic Magnesite

Until recently most of the caustic-magnesite produced was used in oxychloride cement, but today the chief use is in the rubber industry. The subject is most conveniently discussed here, however, in view of its common association.

Caustic magnesite refers to magnesite which has been calcined at a relatively low temperature (800 to 1000 deg. C.) and in which a small per centage of carbon dioxide remains. The carbon dioxide in itself serves no useful purpose, but calcination at temperatures sufficient to remove it entirely results in overburning the product.

Two allotropic forms of magnesia are known: alpha-magnesia and beta-magnesia or periclase. The former first results from the dissociation of $MgCO_3$, but changes readily to the latter with sufficiently high temperature. The transformation temperature is somewhat variable but in general lies above 1100 deg. C. Impurities, chiefly iron oxide, hasten the transformation, and an iron oxide content of more than two per cent usually requires calcining at a considerably lowered temperature.

Alpha-magnesia is chemically reactive whereas periclase is relatively inert; the latter, present in overburned caus-

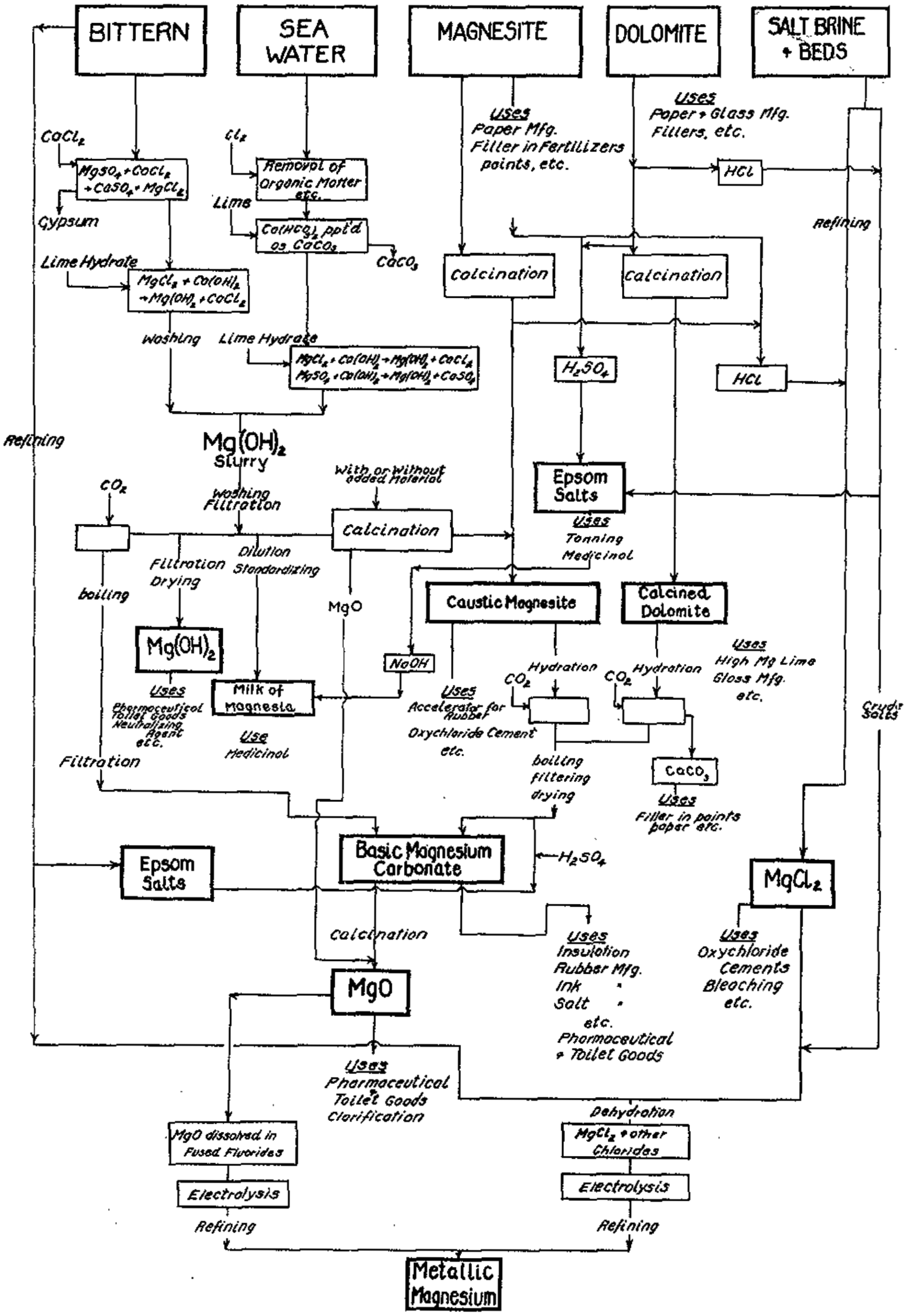


FIG. 2.
Sources and uses of various magnesium products.

tic magnesite, though desirable for refractory use, is valueless in oxychloride cement or for chemical purposes. Actually a balance must be struck and the result is that magnesium carbonate, alpha-magnesia, and periclase may be all present in caustic-magnesite, the desideratum being a minimum content of the first and last.

Calcination of caustic-magnesite for certain purposes is simple; for oxychloride cement, however, the temperature and rate of burning, as well as the grade and fineness of raw magnesite, affect the properties of the final cement and must be carefully controlled. Not all caustic magnesite is suitable for oxychloride cement; that which is suitable, known as plastic magnesia, may show considerable variation in chemical composition and physical properties. Caustic magnesite is burned in either vertical or rotary kilns and marketed in either lump or pulverized form, the former being desirable to minimize hydration and carbonation where prolonged exposure to the air is unavoidable.

Production and Markets

A general resume of the production and marketing of magnesite was given under the head of Refractories. No figures are available relating to the proportional amounts of caustic-magnesite employed by various industries. In the United States, however, the quantity used as a chemical accelerator in the rubber industry is several times that used in oxychloride cement. Minor uses include the manufacture of certain salts, heat insulation, and in Europe of metallic magnesium.

American production in 1937 (Ref. 10, p. 1127) of caustic-magnesite, originating in California and Washington, was 10,000 tons valued at $311,326. An additional 2,798 tons was imported, largely from India, with lesser amounts from Greece and the Netherlands. Prices vary somewhat with purity but in general range from $35.00 to $40.00 per ton f.o.b. mines. Statistics in respect to Canadian production and imports are not available; a relatively small quantity is produced from magnesitic-dolomite at Kilmar-Harrington East.

Oxychloride cement

Oxychloride cement sets quickly to a hard, dense, tough, elastic product, which can be drilled, cut, or planed like wood. It is fire resistant, adheres tenaciously to wood, is reasonably waterproof, and expands slightly while setting.

The main use of oxychloride cement at present is for the preparation of flooring for public buildings, railroad cars, boats, bathrooms, etc. These floors are resistant to wear yet resilient, pleasing in appearance, are water and fire resistant, and warm to the touch. In their preparation fillers such as sawdust, talc, china clay, pulverized silica, and asbestos are added and the mixtures colored with suitable pigments. The flooring may be laid over any surface, old or new, without previous dressing or other preparation.

Oxychloride cement makes a smooth, tough plaster superior in strength to both gypsum and lime, and which may be applied to almost any surface including old plaster or concrete. Free lime must be absent, however, insofar as the presence of appreciable amounts brings about the decomposition of both the oxychloride plaster or flooring and the underlying material. In general the use of oxychloride plaster is restricted in competition with other types by its higher cost. However, very satisfactory drainboard slabs, artificial tile, and other specialities are made.

Some 15 years ago, at least three-quarters of the plastic magnesia produced went into the making of stucco. Magnesia stucco has many recommendable features, among which are its strength (about three times that of cement stucco), quick-setting ability, ease of application, and its firm bond to both lath and rock-dash. On the other hand it is less weatherproof than cement stucco and greater care is required in mixing it. For these reasons it fell into disrepute, probably in large measure due to lack of knowledge as to its correct use and variability in grade of the plastic magnesia obtainable at that time. Since 1929 very little has been used for this purpose. Within the last 10 years, however, research has been directed to the standardization of data respecting oxychloride cements and to the improvement of its deficiencies. Much progress has been made and its use will probably increase in the future.

Oxychloride cement is employed to some extent in the manufacture of artificial lumber, wallboard, and insulating material (Thermax). In addition it is used as dentist's plaster, for small moulded articles such as pipe bowls and a ash trays, as a dilute spray or paint for fireproofing curtains, timber, etc. Insofar as oxychloride cement expands rather than contracts during setting, it is ideal for all types of moulded articles.

The chemical composition of plastic magnesia may vary between relatively wide limits yet yield cements of good quality; satisfactory testing is restricted to the determination of physical properties of typical mortars during and after setting. In general, however, good quality magnesia contains 80 to 90 per cent MgO, 2 to 5 per cent CO_2, and not more than 4 to 5 per cent CaO, the remainder being original impurities such as SiO_2, Al_2O_3, and Fe_2O_3. The last three have little bearing on the quality of the cement, acting merely as inert diluents which must be compensated for in the mortar by lesser additions of other fillers. Free lime, water, and carbon dioxide are important, however, in influencing the physical properties of the final product.

The permissible upper limit of free lime has not been determined but amounts in excess of 3 to 4 per cent are likely to yield cement of poor quality and short life. Undissociated calcium carbonate, on the other hand is no more deleterious than silica or other inert fillers.

The water content is an index of the storage conditions, a relatively high per centage indicating prolonged exposure. The carbon dioxide content depends upon the previous heat treatment of the magnesia; if too little is present the magnesia has probably been overburned. If too much is present, on the other hand, either the magnesia has been underburned or has been stored for an excessive period. In general 2 to 5 per cent of CO_2 is found in good grade material. In passing it is interesting to note that the exposure of plastic magnesia with consequent hydration and recarbonation may produce a stronger cement with reduction in expansion; setting time may be unduly prolonged however. Fresh mortar, properly prepared, acquires an initial set in about one hour and a final set in eight to ten hours.

Plastic magnesia must be finely sized, at least 95 per cent through 100 mesh and 70 per cent through 200 mesh being commonly required. In general the more finely divided the magnesia the greater the set strength and the more rapid the setting.

The standardization of data and specifications respecting oxychloride cement should result in an increased future use for many purposes. In particular it has been found (Ref. 8) that the addition of fine copper powder to oxychloride cement gives a product in which resistance to weathering is greatly increased, and strength expansion characteristics, abrasion resistance, and other properties are markedly improved.

Possibilities for the Manufacture of Plastic Magnesia from Hydromagnesite

Many points in the former discussion of the use of hydromagnesite for refractory purposes are applicable here. Local and Canadian consumption is small; American and other foreign markets are either already adequately supplied domestically or effectively closed by tariffs. Oxychloride cement, however, is used by the construction industry whereas magnesitic refractories are used only in certain specialized industries. In addition oxychloride cement may be made economically on a small scale with a minimum initial investment; refractories, on the other hand, must be made on a much larger scale and entail considerable plant expenditure. As a result it is possible that a small local enterprise might enjoy or create a sufficiently large market for a diversified line of oxychloride cement products, sold at a sufficiently low price to encourage their use, to justify exploitation of the deposits.

In many respects hydromagnesite appears eminently suited to the manufacture of plastic magnesia. It is extremely fine-grained, precluding the necessity of fine-grinding, and is low in lime and iron. Silica is high but its occurrence as relatively large sand grains would minimize the formation of silicates during burning, leaving it as an inert and harmless filler. The total volatile content, including combined water and carbon dioxide, is roughly 50 per cent in average hydromagnesite which compares favourably with 48 to 51 per cent for various commercial magnesites.

Further, the temperature at which the 10 to 15 per cent of combined water is eliminated, is below 575 deg. C., the dissociation temperature of magnesium carbonate. It is probable, therefore, that the actual amount of heat required for the caustic calcination of hydromagnesite would be less than for magnesite.

Some of the less pure hydromagnesites might yield plastic magnesia suitable for certain purposes. Although complete calcination of these would result in an excessive amount of free lime, it is possible to reduce this through carefully controlled calcination or to practically eliminate it through recarbonation. By maintaining calcination temperatures at 750 to 850 deg. C. the dissociation of magnesite can be effected without dissociating calcite appreciably. Again it has been found (Ref. 12) that if calcined magnesia is brought into contact with carbon dioxide gas at temperatures slightly above the dissociation point of $MgCO_3$ but below that of $CaCO_3$

all of the free lime is rapidly converted to $CaCO_3$ with rather large evolution of heat while MgO remains unaffected.

The lowest part of the creamy layer in the Meadow Lake deposit might be of interest as a source of low grade cement. Some 75,000 to 100,000 tons of impure hydromagnesite is probably available of which the following analyses is fairly typical.

Creamy Layer - 39-60"

MgO	-	24.32%
CaO	-	20.12
CO_2	-	38.64
H_2O	-	2.93
Fe_2O_3	-	0.49
Al_2O_3	-	1.35
SiO_2	-	10.32

Assuming that material of the above composition be calcined or recarbonated so that $CaCO_3$ retains its full complement of CO_2 but $MgCO_3$ is completely dissociated, the resulting product would have the following approximate composition

MgO	-	31%
$CaCO_3$	-	53%
Fe_2O_3, Al_2O_3, and SiO_2	-	16%

Since $CaCO_3$ has the properties of an inert filler the material would contain 31 per cent MgO and 69 per cent filler. Although this would represent material too impure for most flooring or plaster mortars, it could possibly be used for stucco and related purposes.

Basic Magnesium Carbonate

The principal use of basic magnesium carbonate is for the preparation of "85 per cent magnesia" insulation. Other uses, dependent on its low apparent density (from 5 to 10 lbs. per cu. ft. for the light grade), absorptive and adhering properties, and mild neutralizing action, are in the salt, rubber, ink, and pharmaceutical industries. The "85 per cent magnesia" insulation is composed of 85 per cent basic magnesium carbonate, and 15 per cent of asbestos fibre. It is employed chiefly as a covering for steam pipes and boilers, and is also prepared in blocks and shapes, and as cement for other purposes.

Basic magnesium carbonate, magnesia alba, or block magnesia, ($4MgCO_3 . Mg(OH)_2 . 5H_2O$) is commonly made from dolomite although magnesite may be used. In recent years considerable quantities have been derived from sea water. In its production, dolomite is calcined and the burnt rock slaked with excess water. Carbon dioxide from the calcination is passed through the slurry and calcium carbonate precipitated and removed by filtration. The clear solution is then boiled causing the precipitation of basic magnesium carbonate which is likewise removed by filtration and dried, or mixed with asbestos fibre and moulded. The basic magnesium carbonate may be further calcined to yield pure magnesia; in addition the by-product calcium carbonate enjoys a considerable demand as a substitute for whiting for many purposes.

The current New York quotation for basic magnesium carbonate, bagged and in carload lots, is 6 1/4 cents a pound or $125.00 per ton. Prices for magnesium oxide and precipitated calcium carbonate are 23 cents per pound ($460.00 per ton) and 2 3/4 cents per pound ($55.00 per ton) respectively. Whiting substitute ranges from $10.00 to $15.00 per ton for the better grades. Production statistics are not available for either Canada or the United States; imports for the latter, however, in 1937 amounted to about 500 tons of basic magnesium carbonate and 100 tons of pure magnesia.

The same factors apply to the manufacture of basic magnesium carbonate from hydromagnesite as already discussed in connection with refractories and caustic-magnesite; the most important consideration being the lack of apparent markets. Small quantities of magnesia insulation are used in Western Canada but certainly insufficient to merit its local manufacture unless foreign markets could be reached or additional markets created.

Hydromagnesite is probably suitable for the manufacture of basic magnesium carbonate by the process outlined although research is necessary to work out operating details. It should be possible not only to utilize impure hydromagnesite in this way but to select material in which the calcium carbonate content is commensurate with the market for precipitated calcium carbonate.

Metallic Magnesium

Magnesium has acquired importance as an industrial metal only in the last few years, although magnesium compounds are wide spread and abundant components of the earth's crust. Recently, however, many difficulties in production have been overcome and a considerable demand has been established. Its field of application is growing daily and although present consumption is largely for armament purposes, it is probable that normal requirements will expand sufficiently in the near future to assure continued expansion without artificial stimulation.

The supply of raw materials from which magnesium may be recovered is practically inexhaustible; most important are magnesite, dolomite, sea water, salt springs, and salt deposits. The last two are the source of the magnesium metal produced in Germany and the United States, whereas the first two are used elsewhere. As yet magnesium has not been extracted from sea water commercially, other than a small scale in Japan, but recent success in the preparation of various magnesia products and magnesium salts from this source assures its feasibility.

Three methods are at present used for the extraction of magnesium; (1) electrolysis of fused chlorides, (2) electrolysis of the oxide in solution in molten fluorides, and (3) direct reduction of the oxide by carbon in an electric carbon arc furnace. The first is the most important from the point of view of present production; the last, however, has proved highly satisfactory, especially where magnesite or dolomite are the raw materials, and several plants have been built within the last year to use this process. The second, although popular some years ago, has been largely superseded by the others.

The electrolytic process is employed exclusively in Germany and the United States, magnesium being extracted from potash-waste liquor and carnallite in the former and from brine-springs in the latter. Electrolysis is likewise used in Italy and Russia, and by certain plants in Great Britain, France, and Japan, and a variety of source-materials is being drawn upon, including carnallite, lake brine, sea-water bittern, magnesite, and dolomite. Where magnesite and dolomite are used they are first calcined and converted to magnesium chloride by treatment with hydrochloric acid. In general the actual process comprises three steps: (1) conversion of magnesium chloride salts to anhydrous form and admixture with other chloride salts; (2) electrolysis of fused bath in a cell at low voltage, and (3) purification of the metal. Details of operating practice are widely different but in general temperatures range from 450 to 750 deg. C., cell voltage from 2 to 8 volts, current from 10,000 to 20,000 amperes, and current efficiency from 85 to 90 per cent. The energy required to produce 1 kg. of metal is in the order of 18 to 20 Kw-Hrs.

and the product may be up to 99.99 per cent pure.

The recently developed electrothermic process has been adopted in several countries within the past two years, notably Great Britain, Japan, and Austria. In addition magnesium has been produced electrothermally on an experimental scale from Washington magnesite. The following description of the process is quoted from the Minerals Yearbook, 1938 (Ref. 10, p. 638):

> "Three parts of high-purity dead-burned magnesite are mixed with one part of coal dust and subjected to a temperature of about 2300 deg. C. in an electric furnace with three electrodes, where the magnesium oxide is reduced to magnesium vapor. The metallic vapor with excess coal dust passes through a flue, into which almost pure hydrogen is introduced by jets from a surrounding pipe, and then into a cooler with a temperature of 150 to 200 deg. C. The product consists of magnesium powder, coal dust, and a small quantity of magnesium oxide which next passes through a closed warm conveyor into an enclosed briquet machine. The briquets are heated to 750 to 950 deg. C. in a small electric furnace under partial vacuum, from which the magnesium is distilled and condensed in the form of small pellets. The pellets drop into a hopper of hydrocarbon oil of high boiling point. The metal is separated from the oil, remelted, and cast into ingots. Magnesium of 99.97 per cent purity is produced. Fritz Hansgirg, originator of the Austrian process, states that the total power consumption is 11 kw-hr. per pound of magnesium metal. The over-all recovery is probably better than 80 per cent of the magnesium content of the calcined magnesite."

Metallic magnesium is silvery white in color and one-third lighter in weight than aluminum. It is somewhat malleable when cold but extremely so if heated to 350-450 deg. C. It can be easily cast into moulds and worked into various forms. The chief limitation to the use of magnesium and its alloys at present is the reactive nature of the metal which causes it to oxidize readily in a humid atmosphere, or corrode in contact with certain solutions. Extremely pure metal, such as that obtained by the electrothermic process, shows a relatively high resistance to oxidation, and some alloys are practically as stable as other common industrial metals. Again, considerable advances have been made in methods of surface treatment to resist corrosion, two of the most common being immersion in nitric acid-sodium dichromate solution or in selenious acid or acidified sodium selenite.

For most construction work magnesium must be alloyed for sufficient strength, the common commercial alloys being confined to those with aluminium and zinc containing a small amount of manganese. Certain more complex alloys involving cadmium, copper, silver, etc. are used for special purposes. Sand and die castings, forgings, rolled sheet, and extruded structural members are being produced today for a variety of uses including crank cases, pistons, transmission bodies, gear cases, hub caps, aircraft and automobile parts, vacuum cleaners and typewriter parts, gun and rifle parts, and parts for cameras, binoculars, radio-equipment, portable pneumatic tools, bread slicing and wrapping equipment, textile machinery, packaging equipment, type-welding equipment, automatic hammers, etc.

New extrusion alloys have been recently developed and their use extended to various structural members. Magnesium rolled sheet has recently been used by printing concerns for etching plates, and a special alloy extensively employed by the electrical industry for bus bars.

Magnesium is widely used as a deoxidizer in the manufacture of non-ferrous castings, for the dehydration of oils, as a catalyst in several chemical processes, for the production of intense light for photography, in certain explosives such as ammonal, in the thermit reduction process, and in fireworks, flares, star shells, etc.

As mentioned, a variety of raw products are used for the extraction of metallic magnesium; magnesite and dolomite being important sources in several countries. Little information has been published, however, in respect to processes or purity requirements of the raw materials involved. One large manufacturer gives the following specifications for magnesite to be used in the electrothermic process: material to be deadburned with a MgO content of 93 to 94 per cent and ignition loss of not over 0.5% but preferably 0.3%. The ferrous oxide content is most important and should not exceed 0.5% although up to 1% is permissible. Lime is next in importance and should be as low as possible, preferably not over 1.5%. Silica is allowable up to 3.5% and alumina to 0.5% to 1%.

None of the hydromagnesite sampled is sufficiently pure to meet the above requirements, although the Atlin material approaches them fairly closely. Beneficiation tests, however, have shown the possibility of materially increasing the purity of the hydromagnesite, and relatively pure magnesia can probably be prepared by recarbonation. Again the requirements of certain users may not be as stringent as those above. In general, therefore, the hydromagnesite of British Columbia may prove of value as a source of metallic magnesium should its manufacture be contemplated in the province.

World production of magnesium in 1937 was estimated (Ref. 10) to be 18,000 metric tons, of which Germany produced 10,000, United States 2059, United Kingdom 2000, France 1500, Japan 1200, Switzerland 700, USSR 400, Austria 80, and Italy 66. Estimates for 1938 are not complete but world production has probably increased to at least 21,000 tons, with new operations contemplated in Japan, United Kingdom, Italy, and the United States. Magnesium metal, 99.8 per cent pure and in carload lots, is quoted at 30 cents per lb. on the New York market. It is estimated that high-purity magnesium can be produced for 15 cents per pound at most, and possibly with quantity production at as low as 10 cents from Washington magnesite on the basis of wholesale power charges of $17.50 per kilowatt year.

Chemical and Other Uses

Although the major uses of magnesite and magnesitic products have been discussed, a few minor ones remain which are worthy of mention.

Crude magnesite has few uses other than for the manufacture of the products already discussed. It has been employed, however, in the sulphite paper process, as a source of carbon dioxide gas, and finely ground as a filler in various products including paints and fertilizers. In the last connection the value of magnesium as a plant and animal food is being realized more and more, with the probable result that increasing amounts of magnesite, dolomite, and magnesium salts will be used in the manufacture of fertilizers as time goes on. In a few instances epsom salts are made by treating magnesite with sulphuric acid, and magnesium chloride with hydrochloric acid. The amount of crude magnesite sold in the United States and Canada is small, only 1952 tons being sold as such during 1937 in the former country, with an average value of $14.96 per ton.

The largest part of the caustic magnesite produced is used as a chemical accelerator in the manufacture of rubber. Although in general the requirements are similar to those for oxychloride cement, the magnesite need not be burnt as hard for this purpose but must be practically free from manganese. The selling price of caustic-magnesite ranges from $35.00 to $45.00 per ton f.o.b. mines.

Basic magnesium carbonate is used in considerable quantities by the rubber, ink, salt, and pharmaceutical industries. In rubber manufacture it is utilized largely in the production of mechanical goods and in the manufacture of printer's ink to produce a dull finish and hold the vehicle. About 1 per cent of basic magnesium carbonate is added to common salt to make it free-flowing. In the pharmaceutical and toilet preparation industries large quantities of basic magnesium carbonate as well as magnesium oxide and hydroxide are used in the manufacture of tooth powders and pastes, ointments, face powders, antacid preparations, etc. Certain chemicals such as magnesium citrate, fluosilicate, etc. are also made from the carbonate. Basic magnesium carbonate is quoted at 6 1/4 cents per lb. f.o.b. works.

The main uses of magnesium hydroxide and magnesium oxide are in the chemical and pharmaceutical industries. Milk of Magnesia, consumed in relatively large quantities, is a suspension of hydrous magnesium hydroxide prepared either by the reaction of epsom salts and caustic soda or by the dispersion of special grades of hydrated magnesia. Magnesium hydroxide is a more satisfactory neutralizer than caustic soda, and can replace caustic soda and litharge to advantage in the sweetening of gasoline. It is also highly efficient in the removal of hydrogen sulphide from gases, and is valuable in the synthesis of alcohols. Special grades of magnesium oxides have proved experimentally to be more efficient than decolorizing clays for the oil industry.

Magnesium chloride has a variety of uses including bleaching and the manufacture of cotton goods.

Magnesium oxide, U.S.P., light, in barrels is quoted at 42 cents a pound, and magnesium chloride, in drums, at $36.00 per ton on the New York market.

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