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POTASH DEPOSITS, ROCK SALT, AND BRINES IN MANITOBA

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TABLE OF CONTENTS

Tables

Illustrations

PART I: POTASH DEPOSITS IN MANITOBA

INTRODUCTION

Potash deposits of economic importance have been outlined recently along the western boundary of Manitoba. Although potassium minerals were found in the province as early as 1951 in the Calstan Daly 15-18-10-27W well, it was not until exploration in Saskatchewan had revealed large potash deposits that serious exploration for potash was undertaken in the bordering part of Manitoba. The potash deposits occur in the Middle Devonian Prairie Evaporite formation at depths in Manitoba ranging from 2,560 to more than 4,000 feet.

The deposits were formed by the precipitation of potassium salts from highly concentrated sea water within the Middle Devonian Elk Point basin. This basin extended about as far east as the Virden area and thus potash beds lie beneath a narrow crescent-shaped area along the south part of the western boundary of Manitoba (Fig. 1).

The only companies that have carried out exploration for potash deposits in Manitoba are S.A.M. Explorations Ltd. and Tombill Mines Limited. S.A.M. Explorations Ltd. acquired a Crown Potash Permit covering several townships along the Manitoba-Saskatchewan boundary, southeast of the area near Esterhazy, Saskatchewan where withdrawals are held by International Minerals and Chemical Corporation (Canada) Limited. The first potash test well in Manitoba, S.A.M. Binscarth 7-15-19-29W, showed that the potash beds extended into the province. Further land was acquired by S.A.M. Explorations Ltd. and 2 more test wells, S.A.M. Lazare 6-29-17-29W and S.A.M. Binscarth 13-6-19-29W, were drilled, both of which intersected potash beds. The property was optioned to Tombill Mines Limited in 1959 and further drilling was carried out by that company.

Because of the regional southwestward dip of the Prairie Evaporite formation and the generally higher elevation of Saskatchewan, the potash deposit in Manitoba occurs a few hundred feet closer to the surface than most of the deposits in Saskatchewan. The main potash zone in Manitoba, consisting chiefly of halite and sylvite, ranges from 6 to 8 feet thick, grades 25 per cent K_2O or better, and contains small amounts only of carnallite ($KCl.MgCl_2.6H_2O$) and clay. A salt bed 60 to 85 feet thick covers the potash bed except along its subcrop belt; a substantial "salt back" is considered essential for the successful mining of potash beds. These factors make the Manitoba potash deposit a potential commercial asset.

ACKNOWLEDGEMENTS

The writer is indebted to S.A.M. Explorations Ltd. for permission to use the results of their exploration work. In particular, much of the material presented on the grade and extent of the main potash zone in their 3 exploratory wells is taken directly from several reports compiled by R. V. Tomkins for the company and filed with the Manitoba Mines Branch.

POTASH

The potassium content of a substance is calculated usually in terms of equivalent K_2O (potash), even though few of the natural minerals or commercial salts contain this compound.

USES

Almost 95 per cent of the world production of potash is used in fertilizers. Potassium, nitrogen, and phosphorus are 3 elements essential to plant growth; the chief function of potassium is to promote the metabolism of the plant. In addition, potassium reduces the susceptibility of some plants to a number of diseases, enhances the quality of fibre plants, strengthens stalks, promotes the growth of large kernels, and improves the keeping qualities of fruits and vegetables (Johnson, 1933).

Many of the natural potash minerals can be added directly to the soil as plant food. However, if they contain impurities such as clay, or are mixed with other minerals (e.g. halite), it is necessary to refine them. Sylvite can be separated from a mixture of sylvite and halite by flotation. The ore is finely ground and reagents are added which float the halite and depress the sylvite. The commonest form in which potash is marketed for fertilizer is "muriate of potash", which should contain 95 per cent potassium chloride and grade a minimum of 60 per cent K_2O; for some soils or crops other forms, such as potassium sulphate, are required.

Many other applications of potash which consume only a fraction of the volume processed as fertilizer are nevertheless very important and account for a large proportion of the total value of potash consumed. Most of the applications are of a chemical nature for which various salts of potassium, such as the carbonate, bichromate, chlorate, nitrate, and cyanide, as well as potassium hydroxide and elemental potassium, are produced. These products are prepared usually from potassium chloride that contains less than 1 per cent impurities. This relatively pure potassium chloride is obtained by a process of solution and fractional crystallization. When a solution of water completely saturated with both halite and sylvite is cooled, the capacity of the liquid for sylvite is decreased, but there is little change in its capacity for halite. Thus a selective extraction of potassium chloride is possible; the recovered product may average more than 99 per cent pure KCl.

The chief chemical and industrial uses of potassium compounds are in the manufacture of glassware, soaps and detergents, matches, explosives, television tubes, photographic chemicals, insecticides, and other products. Potassium compounds are used also in dyeing, tanning, metallurgy, and electroplating.

MARKETS FOR POTASH

As soils in many of the agricultural areas of the world become deficient in potassium through intensive and prolonged cultivation, a steady rise in the demand for potash should result and markets should be available for any new production. Also, such countries as India and China which are raising their standards of living are considered potential importers of large amounts of potash. To date, Canada has imported all the potash it has consumed; in 1958 this was estimated to be (Bartley, 1958):

Fertilizers:	149,972 tons K_2O;	value: $3,707,059
Potash chemicals:	9,171 tons K_2O;	value: $1,558,719

It is expected that in the future most of the Canadian markets will be filled by potash from western Canada.

The chief producers of potash are the United States, Germany, and France, with some production from Russia, Spain, and Israel. World production of potash in 1957 was 8.7 million tons of K_2O, of which United States production accounted for 44.1 per cent. The majority of the United States production comes from Carlsbad, New Mexico, where the reserves of high-grade ore are gradually being depleted. Over the next few decades it is expected that exports of potash from western Canada will gradually displace the United States sources in supplying an expanding market.

Prices for potash fertilizers and chemicals have remained relatively constant for the past 15 years. The price quoted for agricultural muriate of potash containing a minimum of 60 per cent K_2O was $25.60 per ton (granular, bagged), as of December 29, 1958 (Bartley, 1958). It takes about 2 1/2 tons of ore to provide one ton of product.

MINERALS OF POTASH DEPOSITS

Potassium-rich minerals are among the last to be deposited during the evaporation of sea water. In advanced stages of evaporation the brine is enriched in the ions Na^+, Ca^{2+}, K^+, Mg^{2+}, Cl^-, and SO_4^{2-}. Various minerals are formed by different combinations of these ions. The most common minerals of potash deposits are listed in Table I.

TABLE I: MINERALS OF POTASH DEPOSITS

Mineral	Properties	Remarks
Anhydrite, $CaSO_4$	H*: 3-3.5; G*: 2.9; usually massive, granular; white, greyish or bluish; vitreous to greasy luster; subtranslucent.	Usually in separate bands or beds; rarely mixed with halite or dolomite.
Carnallite, $KCl.MgCl_2.6H_2O$	H: 2.5; G: 1.60; when pure, 16.9 per cent K_2O; milk-white, salmon, red; shining, greasy luster; conchoidal fracture; strongly phosphorescent.	Distinguished by its bitter, burning taste.
Halite, NaCl ("Rock salt")	H: 2.5; G: 2.1-2.6 (2.16 when pure); vitreous luster; colourless, white, reddish, bluish; transparent to translucent; perfect cubic cleavage; conchoidal fracture.	Commonly in cubes; saline taste, not bitter.
Polyhalite, $K_2SO_4.MgSO_4.$-$2CaSO_4.2H_2O$	H: 2.5-3.0; G: 2.78; 15.6 per cent K_2O; compact or fibrous masses; flesh or brick-red colour.	Has been mined in Germany.
Sylvite, KCl	H: 2.0; G: 1.98; 63.1 per cent K_2O; in cubes; colourless, white, bluish, or yellowish red; transparent to translucent; vitreous or greasy luster.	Taste resembles that of halite, but is bitter.

* H: hardness; G: specific gravity.

Halite and sylvite commonly occur together as a mechanical mixture which is called "sylvinite"; it can have wide variations in the proportion of sylvite to halite.

In addition to the above minerals, numerous rarer compounds may be present in potash deposits. Kainite, $MgSO_4.KCl.3H_2O$, occurs usually in granular masses and also as crusts; it can be white, dark flesh, or red. Langbeinite, $K_2SO_4.2MgSO_4$, is colourless, white, red, or yellow and has a greasy to vitreous luster; it is found in important quantities in the potash deposits of New Mexico, along with sylvite and carnallite. Both kainite and langbeinite occur in the potash deposits at Stassfurt, Germany.

The Prairie Evaporite potash deposits consist mainly of sylvite mixed with halite; carnallite is locally abundant. Bartley (1957) notes that minor amounts of polyhalite and leonite ($MgSO_4.K_2SO_4.2H_2O$) occur in the Saskatchewan potash deposits.

GEOLOGY AND ORIGIN OF EVAPORITIC POTASH DEPOSITS

The major potash deposits of the world have been formed by the precipitation of salts from sea water that has been concentrated by evaporation within a partially or totally enclosed basin. The Prairie Evaporite formation, in which the western Canadian potash deposits occur, was deposited during Middle Devonian time in the Elk Point basin - a large negative area which covered most of central Saskatchewan and bordering areas in Manitoba, North Dakota, and Montana (inset, Fig. 4). The outlet of this basin generally is considered to have been to the west, through Alberta, and to have been restricted by barrier reefs. However, Baillie (1953, p.55) notes that no evidence of shoreline conditions has been found on the northeast side of the basin and it is possible that a similar reef-restricted outlet existed there.

If the outlet connecting a basin with the open sea becomes restricted, and if the rate of evaporation of water from the basin exceeds the rate of inflow of fresh water, the concentration of dissolved solids in the brine within the basin will increase gradually. If this concentrated brine is prevented from escaping, evaporite minerals eventually will be precipitated. The order in which these minerals are deposited depends upon their solubility and concentration in the brine. Calcium carbonate is the first mineral to be precipitated and is followed by calcium sulphate, either as anhydrite or gypsum. When the concentration of the brine has increased to 10 times the normal salinity of sea water, sodium chloride will be precipitated.

If the outlet of the basin is further restricted, or if the basin is isolated from the open sea, the rare cations within the brine, especially K^+ and Mg^{2+}, become concentrated and potassium and magnesium salts may be precipitated. These salts are extremely soluble; to be preserved they must be covered rapidly by other deposits such as clay or halite.

During the period of evaporite deposition, intermittent changes in the restriction of the basin may result in the formation of several layers of potash minerals separated by beds composed predominantly of halite.

Post-depositional changes within potash deposits are believed to be widespread, especially in deposits that have been deeply buried or folded. In the Stassfurt deposits, much folding has occurred and low-grade metamorphism has caused the formation of new mineral assemblages. The Prairie Evaporite formation has undergone deep burial only, with little or no deformation. Measurements in some of the oil wells indicate that the temperature at a depth of 3,000 feet in southwestern Manitoba is between 85°F and 100°F. Temperatures of this order may be sufficient to cause partial recrystallization of

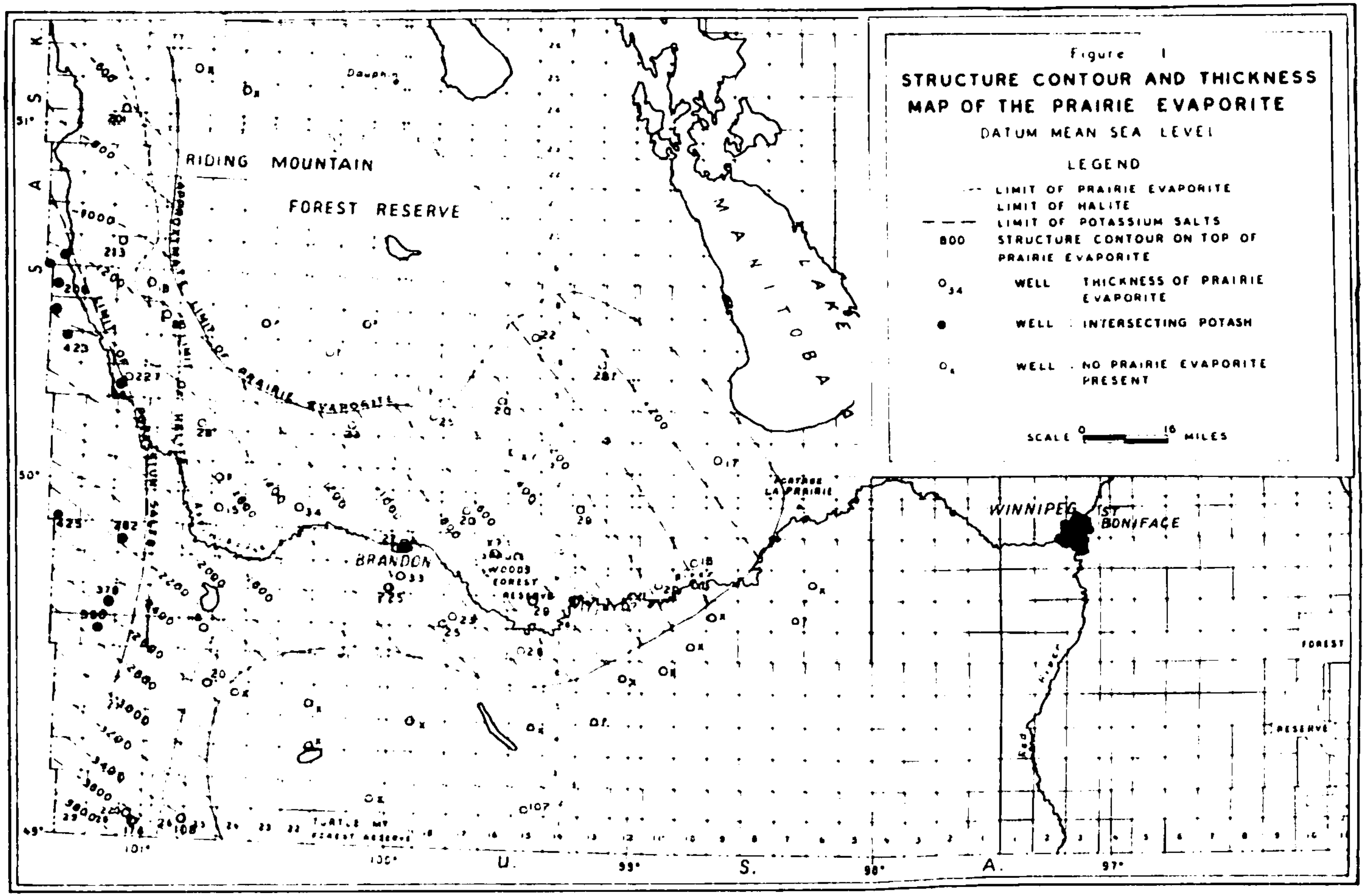
Figure 1
STRUCTURE CONTOUR AND THICKNESS MAP OF THE PRAIRIE EVAPORITE
DATUM MEAN SEA LEVEL
LEGEND
LIMIT OF PRAIRIE EVAPORITE
LIMIT OF HALITE
LIMIT OF POTASSIUM SALTS
800 STRUCTURE CONTOUR ON TOP OF PRAIRIE EVAPORITE
WELL THICKNESS OF PRAIRIE EVAPORITE
WELL INTERSECTING POTASH
WELL NO PRAIRIE EVAPORITE PRESENT
SCALE 0 16 MILES
RIDING MOUNTAIN
FOREST RESERVE
LAKE MANITOBA
BRANDON
WINNIPEG
ST BONIFACE
SASK
U. S. A.
FOREST
RESERVE
101°
100°
99°
98°
97°
51°
50°
49°

the deposit, especially if some connate water is trapped within the formation.

Shortly after their deposition, potash deposits may be subjected to solution and redeposition. Crystals of large size may be formed and some parts of the deposit may have an increased insoluble content whereas other parts, where redeposition occurred, may have a low insoluble content. Probably the major post-depositional changes in the Manitoba potash deposit have been solution and redeposition immediately or shortly after precipitation, as this deposit is characterized by coarse crystals and a low insoluble content.

POTASH OCCURRENCES IN MANITOBA

LITHOLOGY OF THE ELK POINT GROUP

The Prairie Evaporite formation is part of the Elk Point group of Middle Devonian age. The Elk Point group includes in ascending order the Ashern, Elm Point, Winnipegosis, and Prairie Evaporite formations (Baillie, 1953).

The Ashern formation consists mainly of brownish red and brick-red argillaceous dolostone and dolomitic shale. In the subsurface the formation is 10 to 50 feet thick. The Elm Point formation is a light-coloured mottled limestone which is not distinguished from the Winnipegosis formation in the subsurface. The Winnipegosis formation is composed of pale yellowish brown saccharoidal dolostone and contains many reefs of the bioherm type. The formation ranges from a normal thickness between 100 and 150 feet to as much as 400 feet where reef structures are present. Anhydrite is common in the upper part of the formation.

In the vicinity of the Manitoba-Saskatchewan boundary the Prairie Evaporite formation consists primarily of coarsely crystalline halite 500 feet in thickness. Thin layers of potash minerals occur within the top 100 feet of the halite section. To the east of the subcrop belt of the potash zone, thick beds of anhydrite occur near the top of the halite zone. No halite has been intersected east of Oak Lake. On the shelf area east of the Elk Point basin, where the Prairie Evaporite thins from 150 to 12 feet, anhydrite is predominant; as the formation thins, the underlying Winnipegosis formation thickens (see Figs. 1 and 2). Along the eastern shelf of the basin, the upper part of the Winnipegosis formation is thought to be the facies equivalent of the Prairie Evaporite formation to the west.

Covering the Elk Point group is the basal argillaceous member, called the "2nd red", of the Middle Devonian Dawson Bay formation.

POTASH DEPOSITS IN THE PRAIRIE EVAPORITE

The potash zone of the Prairie Evaporite formation has been intersected in at least 9 of the deeper wells along the west boundary of the province. On the basis of its location, one other well, Dome Naco Lazare 12-34-16-29W, probably intersected the potash zone, but no conclusive evidence is available as neither core nor a gamma ray log was taken.

Because of their easy solubility, potash minerals are rarely preserved in chip samples. To obtain information on the potash deposit, special techniques are employed. The potash deposit can be cored if diesel oil is substituted for the regular drilling fluid. A gamma ray log of the well will indicate the presence of potash beds. Because of a relatively high content of the radioactive isotope K^{40}, a potash bed causes a large deflection in the gamma ray curve; the degree of deflection is proportional to the amount of potassium within the bed (Fig. 3).

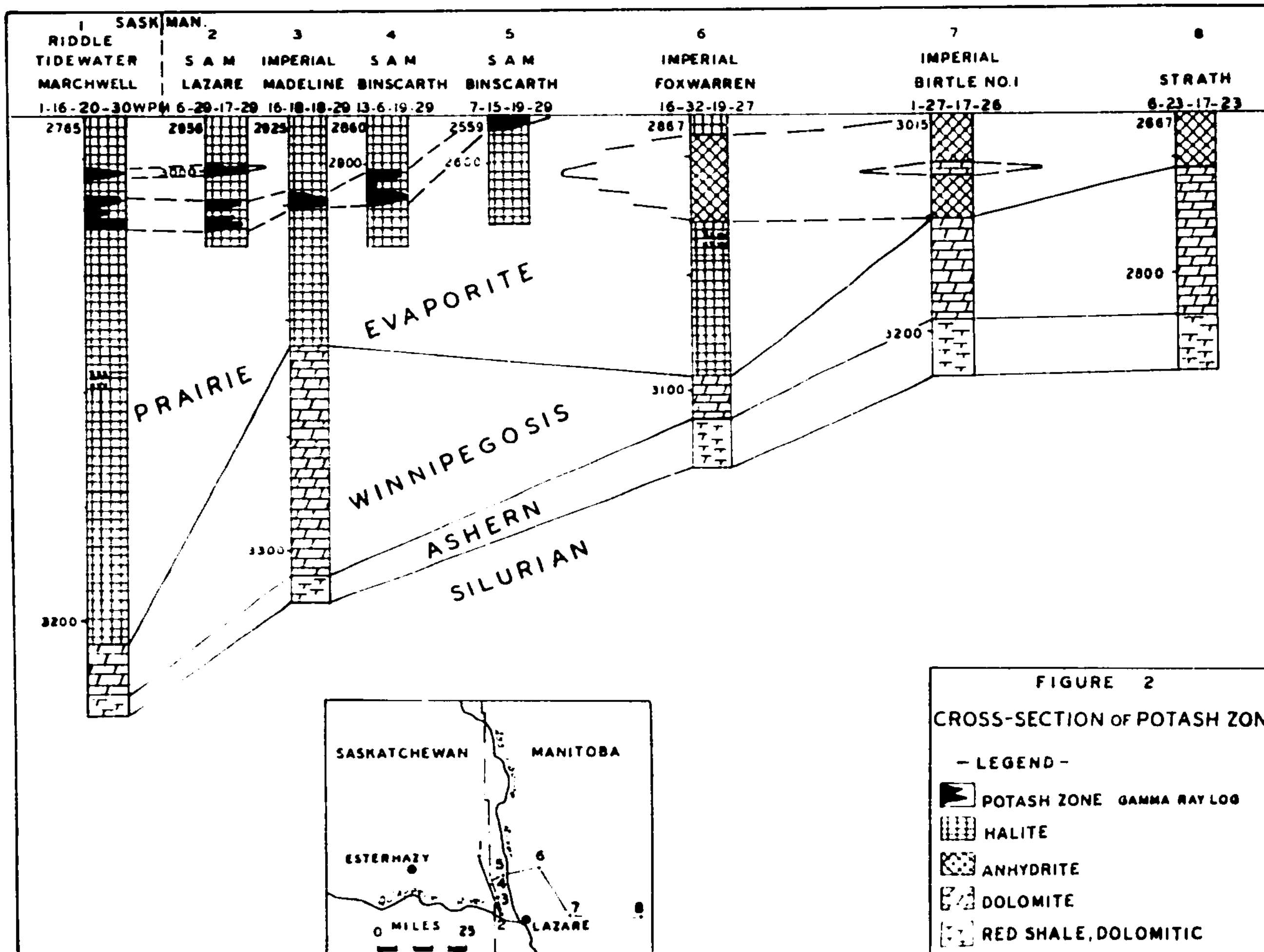

FIGURE 2

CROSS-SECTION OF POTASH ZONE

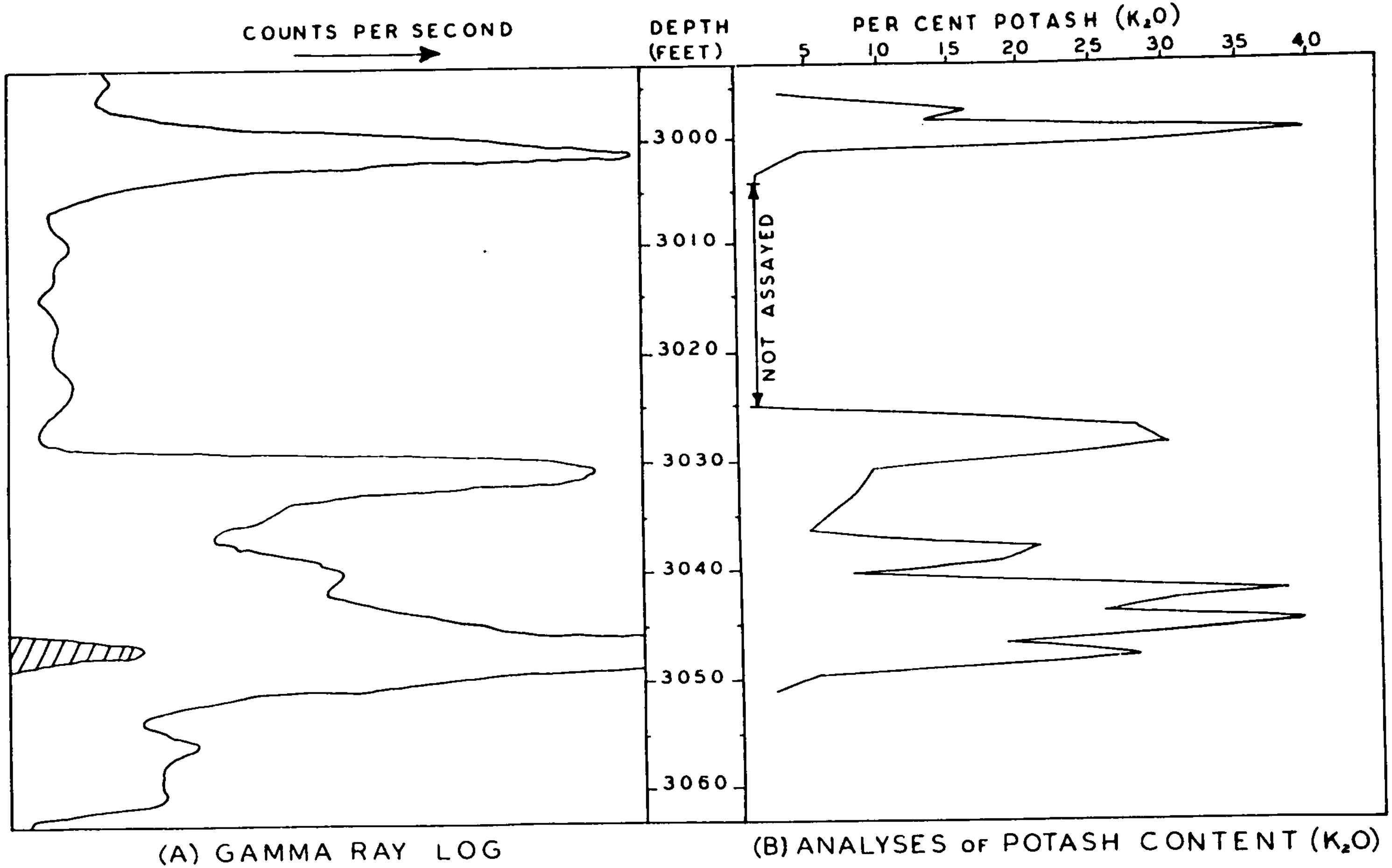

Figure 3. Comparison of gamma ray deflection with potash content for S.A.M. Lazare 6-29-17-29W.

TABLE II: RESULTS OF DRILLING

Well Name	Depth to top of Prairie Evaporite		Thickness of Saltback	Potash Zone(s)	Grade: % K_2O	Remarks
	Subsurface	Subsea				
S.A.M. Binscarth 7-15-19-29W	2559.5 *	-1207.5*	0*	2559.5-2566?*	36.3% over 3.5 feet of recovered core	Core lost at base of potash zone; thickness unknown (6.5 feet?).
S.A.M. Binscarth 13-6-19-29W	2855	-1257	67	2922-2931	24.7%	Also 3 feet of 12% K_20 at 2917-2920.
Imperial Madeline 16-18-18-29W	2918	-1321	75	2993-2999 **	unknown	Core is from 60 feet above the potash zone.
S.A.M. Lazare 6-29-17-29W	2956	-1375	85	2998.5-3000.8 3026.0-3029.5 3040.8-3049.0	33.3% 29.0% 27.4%	Main potash zone is 3040.8-3049.0; grades 26.1% K_20 as sylvite; richest section grades 29.4% over 5.2 feet.
Homestead Birdtail 10-8-15-27W	3102	-1567	0	3102-3110 **	strong gamma ray deflection	Probably within subcrop belt of the potash zone.
Calstan Elkhorn 7-8-11-29W	4080	-2297	36	4116-4122 ** 4149-4154 **	strong deflection moderate deflection	Potash zone not cored.
Calstan Daly 15-18-10-27W	3760	-2140	30	3790-3797 ** 3824-3827 **	strong deflection moderate deflection	First well to intersect the potash zone in Manitoba.
Calstan Ewart Prov.4-14-8-28W	4140	-2529	15	4155-4164 ** 4195-4208 **	strong deflection weak deflection	Analysis of core showed 14.6% KCl at 4245 feet, below the indicated potash beds, but no gamma ray deflection.
Calstan Linklater 2-21-7-28W	4340	-2722	22	4362-4370 **	strong deflection	Gamma ray log indicates lower-grade zone about 4400-4408

* All depths and thicknesses in feet

** Depths estimated from gamma ray logs

Exploration Results

The results obtained from the 9 wells intersecting the potash zone are listed in Table II. The data from these 9 wells indicate a potash bed or beds ranging in thickness from 6 to 9 feet beneath a crescent-shaped area extending from township 21 to township 4 along the western boundary of Manitoba (Fig. 1). In the northern part of this area the main potash bed ranges in depth from 2,560 to 3,100 feet and, in the southern part, from 3,800 to 4,360 feet. The grade of the potash in the southern part is unknown, but the gamma ray logs of the 4 wells there all show strong deflections across the potash zone. Two layers of potash minerals are indicated in this southern area, the lower layer being thinner and of lower potash content; the upper higher-grade layer is possibly an extension of the middle potash zone of Saskatchewan, as suggested by a study of the isopach maps by Goudie (1957) of the 3 Saskatchewan potash zones.

The main potash deposit in the northern part of the area, primarily because of its shallower depth, is of greater economic interest. The grade of the ore there is 25 per cent K_2O or better, with thinner sections within the potash bed grading between 30 and 40 per cent K_2O. The thickness of the salt back varies between 67 and 85 feet, except along the subcrop belt of the potash bed where the salt back has been eroded. The depth to the main potash zone depends of course on the elevation of the surface and would be shallowest in wells drilled in river valleys. Both the Assiniboine and Qu'Appelle rivers flow through the area and their valley floors are 200 to 250 feet below the regional elevation of about 1,600 feet above sea level.

Exploration in Saskatchewan has indicated that the highest-grade potash deposits are situated in or near local sub-basins within the main Elk Point basin. One of these sub-basins occurs northeast of Esterhazy (25 miles west of S.A.M. Binscarth 13-6-19-29W), and drill results indicate that the Manitoba deposits occur in a southeastward extension of this sub-basin (Fig. 4). Three main potash zones have been intersected in most of the Saskatchewan deposits; the main potash zone in the northern area of Manitoba correlates with the lowest of the 3 Saskatchewan zones, and a thin potash bed in the salt back may be a remnant of the middle zone. The middle and upper zones are of commercial importance in some places in Saskatchewan, but either are too thin to be economic or do not occur in the northern area of potash occurrences in Manitoba.

Petrography of the Potash Zone

Several drill cores from the Prairie Evaporite formation are available for study; some of these contain sections of the potash beds. The most complete section is from the S.A.M. Lazare 6-29-17-29W well; a detailed description of this core is given in Appendix I (page 27).

The Salt Back

The S.A.M. Binscarth 13-6-19-29W well and the S.A.M. Lazare well intersected respectively 67 and 85 feet of salt above the main potash zone. The third S.A.M. well, S.A.M. Binscarth 7-15-19-29W, intersected the main potash zone along its subcrop belt, where the potash zone is in contact with the overlying Devonian second red bed, with no intervening salt.

The salt back consists primarily of coarse transparent crystals of halite with interstitial red carnallite masses and green or brown clay particles. The halite crystals form over 90 per cent of the section. A few sylvite crystals occur

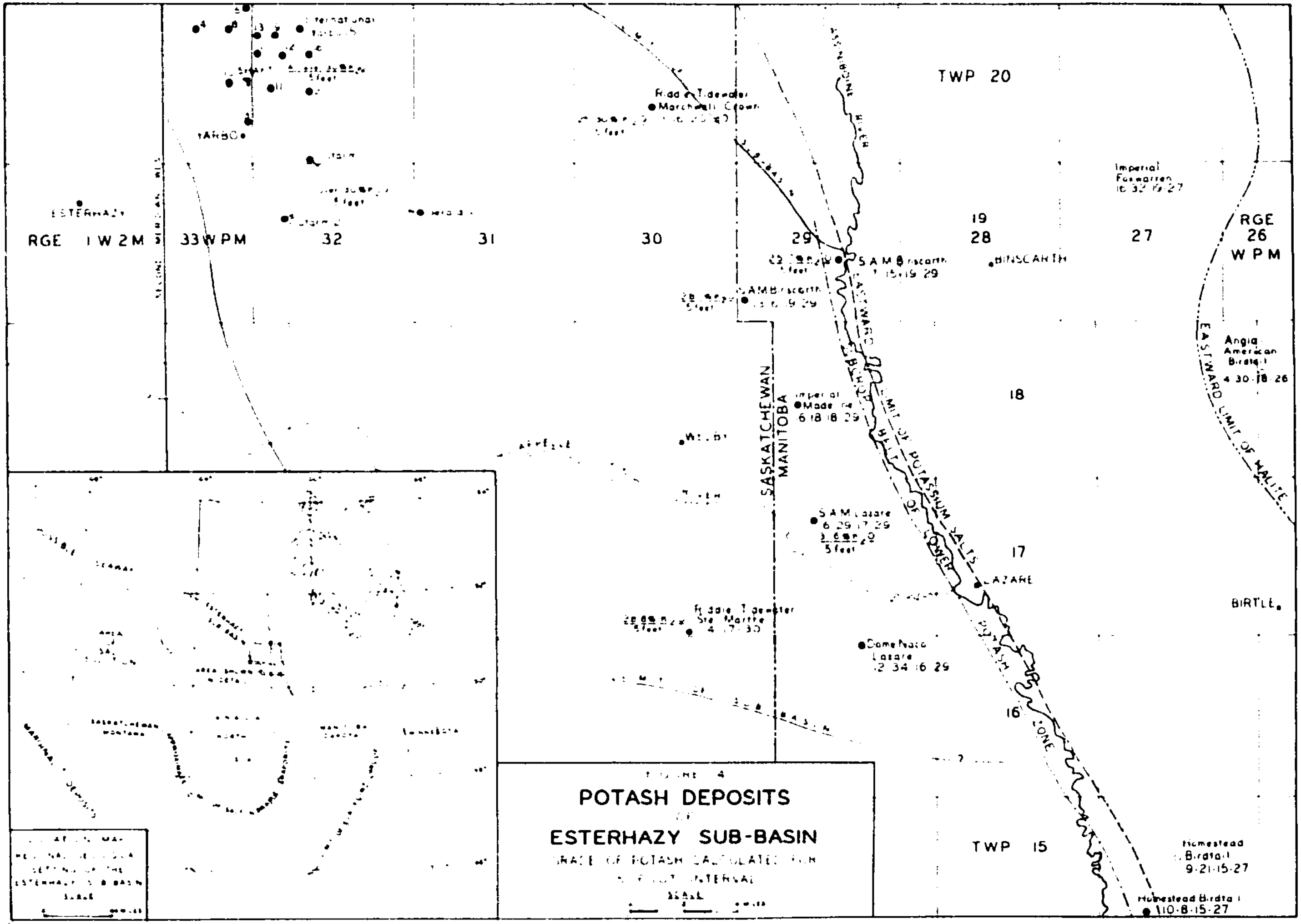

FIGURE 4

POTASH DEPOSITS OF ESTERHAZY SUB-BASIN

at intervals and the halite associated with them is translucent, pale bluish white. The carnallite ranges from small patches to irregular masses more than an inch across. Some sections are enriched in carnallite, whereas others consist of almost pure, clear halite. The clay occurs interstitially and also as small inclusions within the halite crystals. Some clay bands are present.

Both the S.A.M. Binscarth 13-6-19-29W well and the S.A.M. Lazare well intersected a few thin potash beds within the salt back. The thickest of these beds was intersected 44 feet below the top of the salt in the S.A.M. Binscarth well. The bed consists of clear honey-coloured halite with crystals of milky sylvite up to 1/2 inch across; some inclusions of grey clay are present in the halite. This section was not assayed; its thickness, as estimated from the gamma ray log, is about 3.5 feet. What is believed to be an extension of this bed was intersected in the S.A.M. Lazare well 42.5 feet below the top of the salt. The bed consists of milky halite crystals and clear to slightly brownish cubes of sylvite; orange to translucent red carnallite is abundant. The section contains some scattered green clay particles. It assayed 27.7 per cent K_2O for a thickness of 2.3 feet. This thin potash bed may be a remnant of the middle potash zone of Saskatchewan as it correlates with this zone in other holes in the Esterhazy sub-basin.* Other thin potash-rich beds occur in the salt back of the S.A.M. Lazare well (see Appendix I).

The Main Potash Zone

The main potash zone was intersected in each of the 3 S.A.M. wells. In all these wells, the zone consists of a mechanical mixture of sylvite and halite crystals with small amounts of carnallite and clay. In detail, however, significant differences exist in the thickness, grade, and mineral content of the potash zone in the individual wells. The probable cause of these differences is the position of the wells with respect to the extension of the Esterhazy sub-basin. For example, S.A.M. Binscarth 7-15-19-29W well is near the edge of the basin, whereas the S.A.M. Lazare well is thought to be close to the axis of the sub-basin. The 3 sections are described in detail below.

In the S.A.M. Binscarth 7-15-19-29W well, the potash zone was intersected directly beneath the second red bed. The gamma ray log indicates that the main potash zone is about 6.5 feet thick in this well. However, potash core was recovered only from the top 3.5 feet of this zone. Only 4 feet of core were recovered from the 19-foot interval immediately below; this lower core consists predominantly of halite and thus is not from the main potash zone. The 3.5 feet of core recovered from the potash zone consists of a mixture of sylvite and halite crystals; it is very clean with only minor carnallite and very little clay. This section assayed 36.3 per cent K_2O as sylvite for the 3.5 feet; the upper 2.5 feet of this section assayed close to 40 per cent K_2O as sylvite, the highest assay reported from the Manitoba portion of the potash deposits.

The main potash zone in the S.A.M. Binscarth 13-6-19-29W well has a thickness of 9.2 feet, and an average grade of 24.7 per cent K_2O, of which 23.2 per cent is present as sylvite and 1.47 per cent as carnallite. The potash is concentrated in the upper 4 feet, which assayed 30.9 per cent total K_2O. The upper part consists of a matrix of translucent sylvite with large milky halite crystals; carnallite occurs at the crystal interfaces, but the clay content is very low. The 2.5 feet of core immediately below the high-grade part assayed 15.8 per cent total K_2O; this section contains more carnallite, some clay, and

* R.V. Tomkins, personal communication.

less sylvite than the upper part. The lowest 2.7 feet of the zone consists of a mixture of large sylvite and milky halite crystals, but the proportion of sylvite to halite is less than in the upper part of the zone. This lowest section assayed 23.25 per cent total K_2O.

The S. A. M. Lazare well is situated nearer the axis of the Esterhazy sub-basin, and in this well the main potash zone assayed 26.12 per cent K_2O as sylvite for a thickness of 8.2 feet. The amount of K_2O present as carnallite is only 1.28 per cent, giving a total K_2O content of 27.40 per cent. The bed consists mainly of sylvinite in which the sylvite and halite crystals are mixed in approximately equal proportions. The halite occurs as coarse milky blue to white crystals; the sylvite is greasy, transparent to translucent, and usually forms a matrix in which the halite crystals are embedded. Red carnallite is present as scattered large masses and stringers, but occurs mainly in the upper half of the bed. The clay content is very low. A detailed description of the core from this well is given in Appendix I.

The Manitoba deposits differ from those of Saskatchewan, other than the deposits of the Esterhazy sub-basin, in their coarse texture and in the low content of clay. As discussed previously (page 8) these features are possibly the result of solution and redeposition of the potash deposits of the Esterhazy sub-basin.

Extent of the Deposits

The deposits in the northern part of the Manitoba potash area occur in a southeastward extension of the Esterhazy sub-basin, and the 3 S.A.M. wells indicate that the deposits underlie an area of about 35 square miles (Fig. 4). In October 1959, further drilling by Tombill Mines Limited in the vicinity of the S.A.M. Lazare well was nearing completion. Information from the new wells is not yet available.

The potash deposits in the southern part of the area cannot be correlated definitely with those of the Esterhazy sub-basin, but may be a southeastward extension of the middle potash zone of Saskatchewan. However, more information from the area between the two occurrences is required before a definite correlation can be made.

PART II: ROCK SALT AND BRINES IN MANITOBA

INTRODUCTION

Common salt is produced either by evaporation of concentrated brines or from beds of rock salt. To date in Manitoba salt has been produced only by evaporation of brine.

Several flowing brine springs occur along the west shore of Lake Winnipegosis. The largest springs are near Dawson Bay and flow out of the Middle Devonian Winnipegosis formation. The total maximum content of dissolved solids in these brines varies between 50,000 and 60,000 parts per million parts of solution (ppm), too low for present day commercial production of salt. However, for many years prior to the completion of the railway from eastern Canada in 1881, up to 1,000 bushels of salt per year were produced by evaporation of these brines. A history of the early salt operations and a description of the brine springs are given by Cole (1915) and Cameron (1948).

At present, salt is produced only by the Canadian Salt Company Limited at Neepawa. Salt is precipitated by the vacuum pan evaporation process using subsurface brines recovered from 2 wells at the town of Neepawa. The brines have been tapped at 2 horizons: the upper, at a depth of 1,160 feet, from a porous zone in the Souris River formation, and the lower, at a depth of 1,453 feet, from the Winnipegosis dolomite. The source formations have been determined by a comparison of the sample log of the Neepawa #2 well (9-33-14-15W) with the logs of neighbouring wells, as shown in figure 5. These brines have a total dissolved solid content of 170,000 to 180,000 ppm, of which NaCl forms more than 85 per cent. The concentration has remained essentially constant from the time of first production in 1932 to the present. Production now is about 23,000 tons of salt per year. The combined chlorides of calcium, magnesium, and potassium, in dry form, are recovered as a by-product (see also Cameron, 1948).

The only formation in Manitoba known to contain beds of rock salt is the Middle Devonian Prairie Evaporite. The thickness and extent of this formation, as estimated from limited well data, are shown in figure 1, which is a revision of the Manitoba Mines Branch stratigraphic map No. 9 by Fleming (1956). Over 500 feet of evaporites composed mainly of halite occur beneath the south part of the Manitoba-Saskatchewan boundary, but the halite thins rapidly to the east and none has been intersected east of Oak Lake (township 8, range 24W). The occurrence of potash minerals in the upper part of the halite has been discussed in Part I of this report. If the potash deposits are mined, it is possible that some rock salt will be produced as a by-product. In some parts of the world where subsurface beds of rock salt occur, artificial brines are made by introducing water into the salt beds and recovering the resulting brine. This process has not been tried in Manitoba.

ROCK SALT AND BRINES

USES

Salt is used in 3 forms: as a brine, as evaporated salt, and as rock salt. The proportion of each used was:

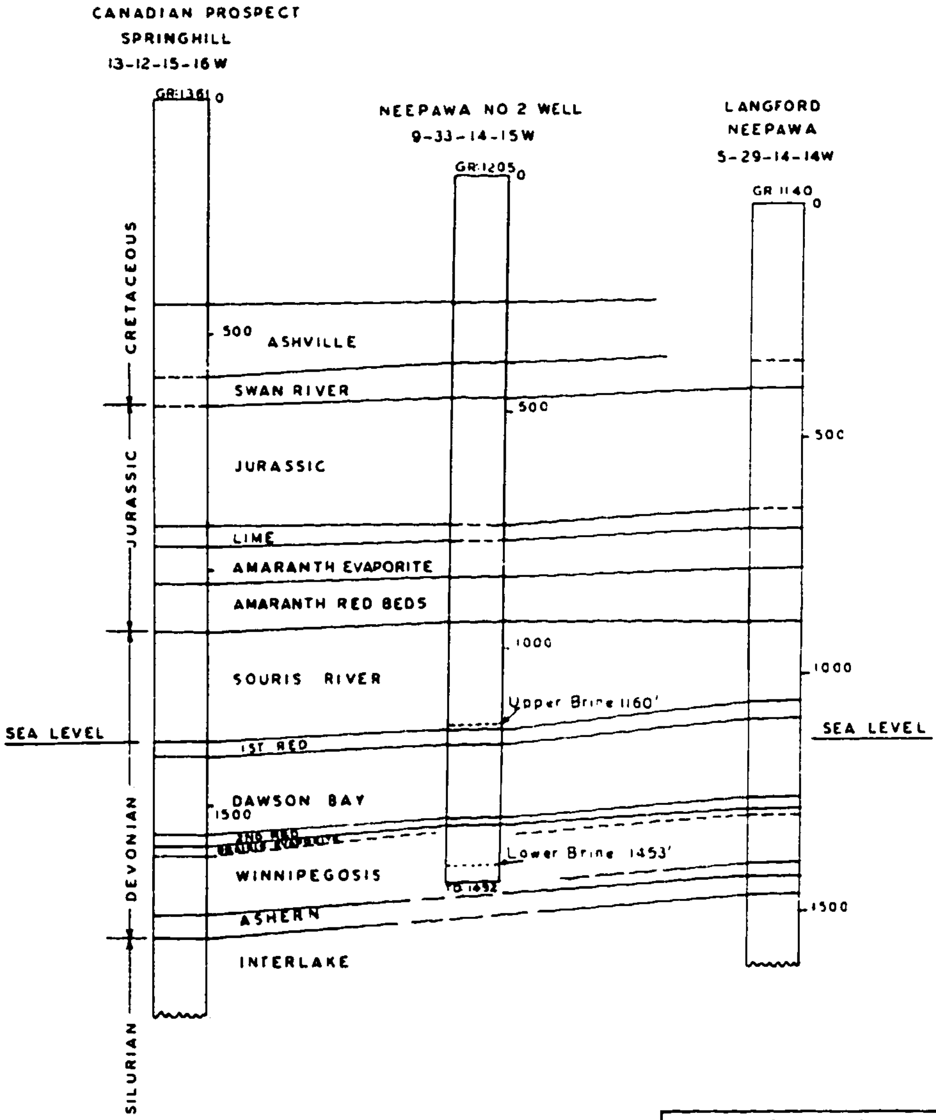

Figure 5

BRINE HORIZONS AT NEEPAWA

CORRELATION BY: H R McCABE

	Canada (1958)	United States (1952)
Brines	47%	58%
Evaporated salt	20%	19%
Rock salt	33%	23%

In the United States 70 per cent of the salt production is consumed in the manufacture of chemicals -- compounds (e.g. soda ash, sodium hydroxide, hydrochloric acid) and elemental sodium and chlorine. Salt is used also in metallurgy, ceramics, refrigerating agents, agriculture, medicine, food preparation, and in the home. Less than 3 per cent is used in purified form as table salt.

In Canada, in addition to most of the above uses, 3 to 4 per cent of the salt production is used by the pulp and paper industry, and much of the rock salt is crushed and used for ice and dust control on highways.

In addition to sodium chloride, natural brines may be a source of bromine, iodine, or the chlorides of calcium, magnesium, and potassium.

PRODUCTION AND VALUE

The value of the 2,375,192 tons of salt produced in Canada in 1958 was $14,989,542, or an average value of $6.31 per ton. Of this, eastern Canada produced 2,252,355 tons (with an average value of $5.43 per ton) and western Canada 122,837 tons (average value $22.46 per ton). The 20,560 tons of salt produced in Manitoba in 1958 were valued at $617,150, or $30.01 per ton, in the processed form (preliminary estimate).

BRINES IN MANITOBA

ORIGIN AND SOURCE OF THE BRINES

Brines have been intersected in most of the subsurface formations in Manitoba. Their extensive distribution suggests that they are connate sea waters trapped within the formations at the times of deposition. The brines are most easily recovered from porous and permeable zones, called aquifers, which are composed usually either of sandstone or of porous limestone.

If normal sea water were trapped in a formation, the concentration of the brine would be 35,000 ppm. Several theories have been proposed to explain the highly concentrated brines found trapped in some formations. Subsurface waters may pass through and dissolve part of a formation of rock salt. The original sea water may have been a brine concentrated within a basin of evaporation. Subsurface evaporation of trapped brines may occur (Washburne and Lahee, 1934), especially with deeply buried brines at increased temperatures. Each of these 3 processes could produce concentrated brines.

There is abundant stratigraphic evidence that the solution of subsurface rock salt has occurred in several parts of the Williston Basin. The Prairie Evaporite is the only formation with a significant thickness of halite in the Manitoba part of the basin, but many other beds of halite are present in the deeper parts of the basin to the south and west of Manitoba. These include: the Davidson evaporite, a member of the Upper Devonian Souris River formation; several beds of rock salt called the Charles evaporites, of Mississippian age; and, near the centre of the basin, evaporite beds of Permian and Triassic (?) age. It may be significant that the brines of both producing horizons at Neepawa are related to basinward salt deposits -- the upper horizon to the Davidson evaporite, and the lower horizon to the Prairie Evaporite -- although no rock salt is present in the Neepawa area. One mechanism suggested (Milner, 1956) for the production and circulation of concentrated brines within the Middle Devonian formations is that meteoric water has entered the formation at a relatively high elevation on the southwest or west side of the basin, circulated downward through a porous zone to the centre of the basin, dissolved part of the halite, and, because of the hydrostatic pressure, moved upward to the surface on the east side of the basin. Evidence that this process has occurred includes large areas of salt solution in central Saskatchewan and the estimated deposition (Cole, 1938) of over 50,000 tons of salt per year from 84 salt springs in Manitoba alone. The process is probably operating at the present time.

The concentrated brine formed by the solution of rock salt could be confined by impermeable barriers such as clay beds or tight limestone to a single zone; migration between formations would be difficult.

Enriched brines with no apparent connection with rock salt formations are probably connate waters concentrated either before or after the deposition of the enclosing rock.

Correlation of the concentrations determined from drill stem tests show that the concentration within a formation increases downward from its outcrop belt to the deeper parts of the basin. Dilution by meteoric water is the probable cause of the low concentrations near the surface. Also, the maximum concentrations of brines within a sequence of formations increases, in general, with the geological age of the formation. Washburne and Lahee (1934) have suggested that this feature may be caused by progressive subsurface evaporation of water.

DRILL STEM TESTS

Samples of some of the subsurface brines which have been intersected in oil well drilling have been recovered by drill stem tests. Careful sampling techniques are required to prevent dilution or contamination of the samples. Usually records are made of the pressure in the interval tested and of the amount and nature of the water recovered.

Most of the analyses of brines recovered from drill stem tests in Manitoba were made in the Analytical Laboratory of the Manitoba Mines Branch; some were supplied by oil companies. The ions whose concentrations were determined directly are Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^{-}, and CO_3^{2-}. The amount of Na^{+} was calculated from the concentration of the other ions, but this method made no specific allowance for K^{+} which was included as its sodium equivalent in the concentration reported for Na^{+}. The results are reported as ionic concentrations which give the ppm of each ion in the sample (Graham, 1945). Iodine and bromine are determined for some brines but the concentration of these ions has not been measured for the Manitoba drill stem tests.

The results of the drill stem tests from Manitoba wells are on file at the Petroleum Engineering Division, Mines Branch, Department of Mines and Natural Resources in Winnipeg. Several hundred analyses of formation brines are now available. Tables in appendices II and III list the data for drill stem tests which showed over 200,000 ppm of dissolved salts. Included in the tables are the ionic concentrations, specific gravity, pH value, resistivity, source of formation, and productivity, where these data are available.

In figures 6, 7, and 8 the drill stem test results have been plotted separately according to their source formation. Only those formations have

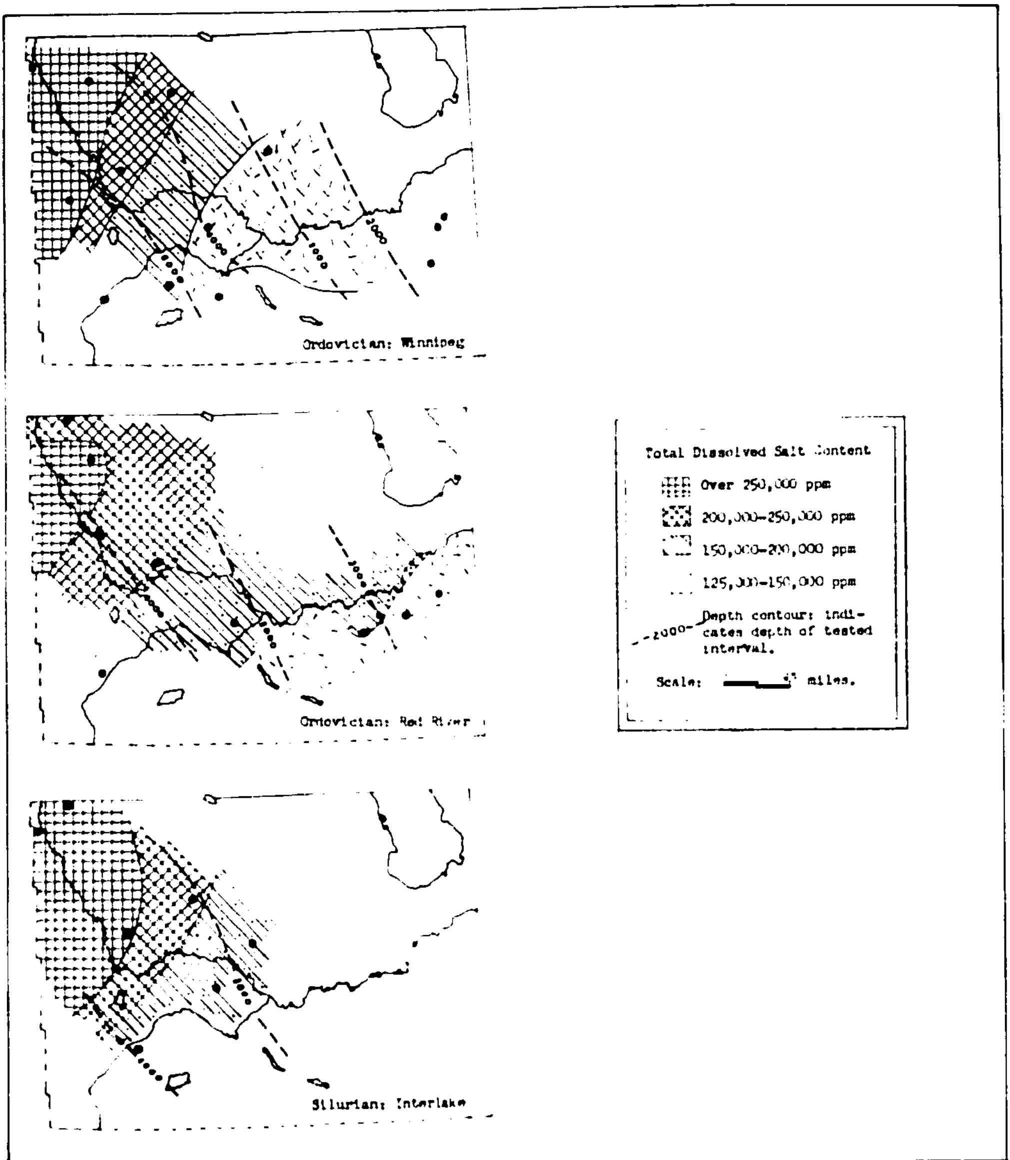

Figure 6. Brine concentrations in the Winnipeg, Red River, and Interlake formations, southwestern Manitoba.

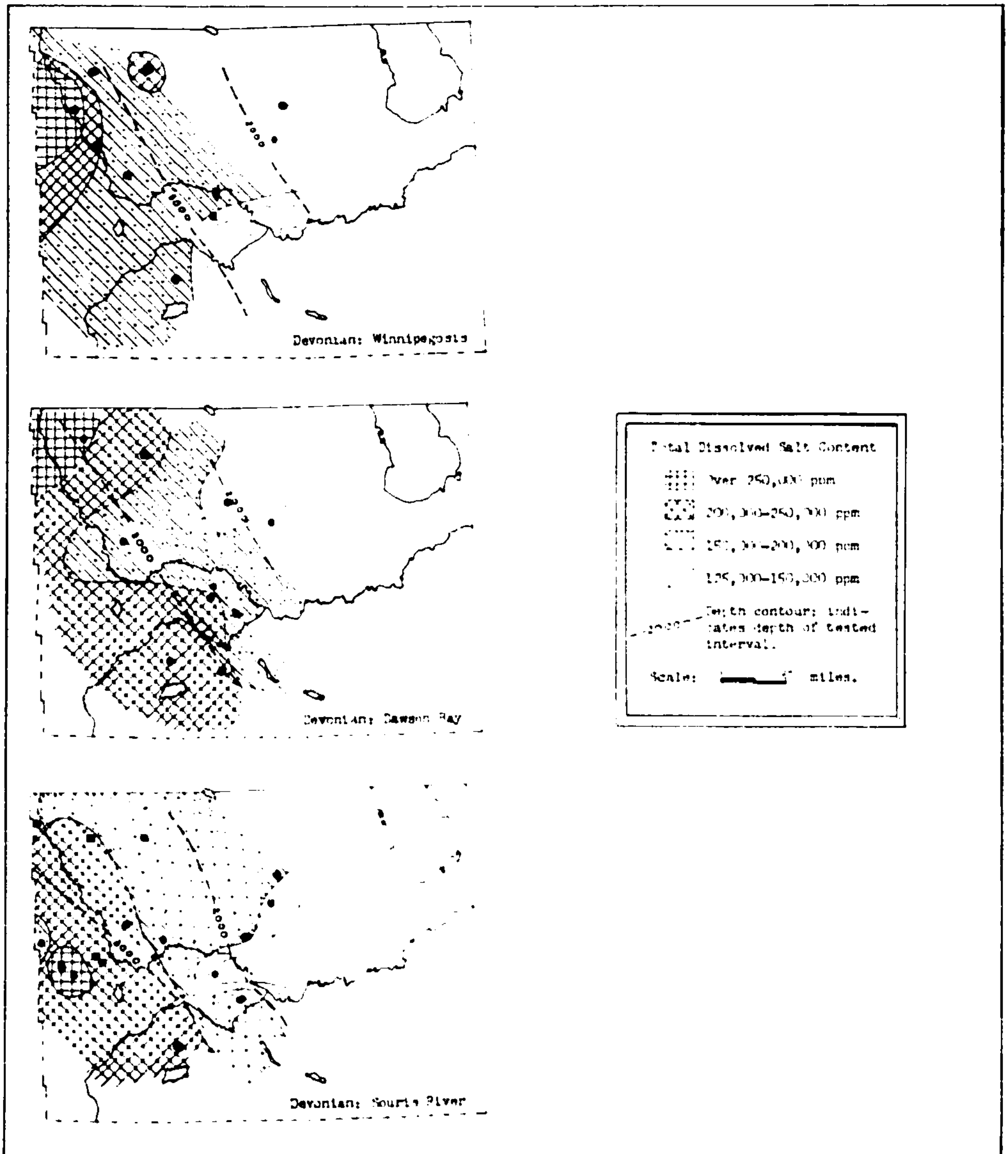

Figure 7. Brine concentrations in the Winnipegosis, Dawson Bay, and Souris River formations, southwestern Manitoba.

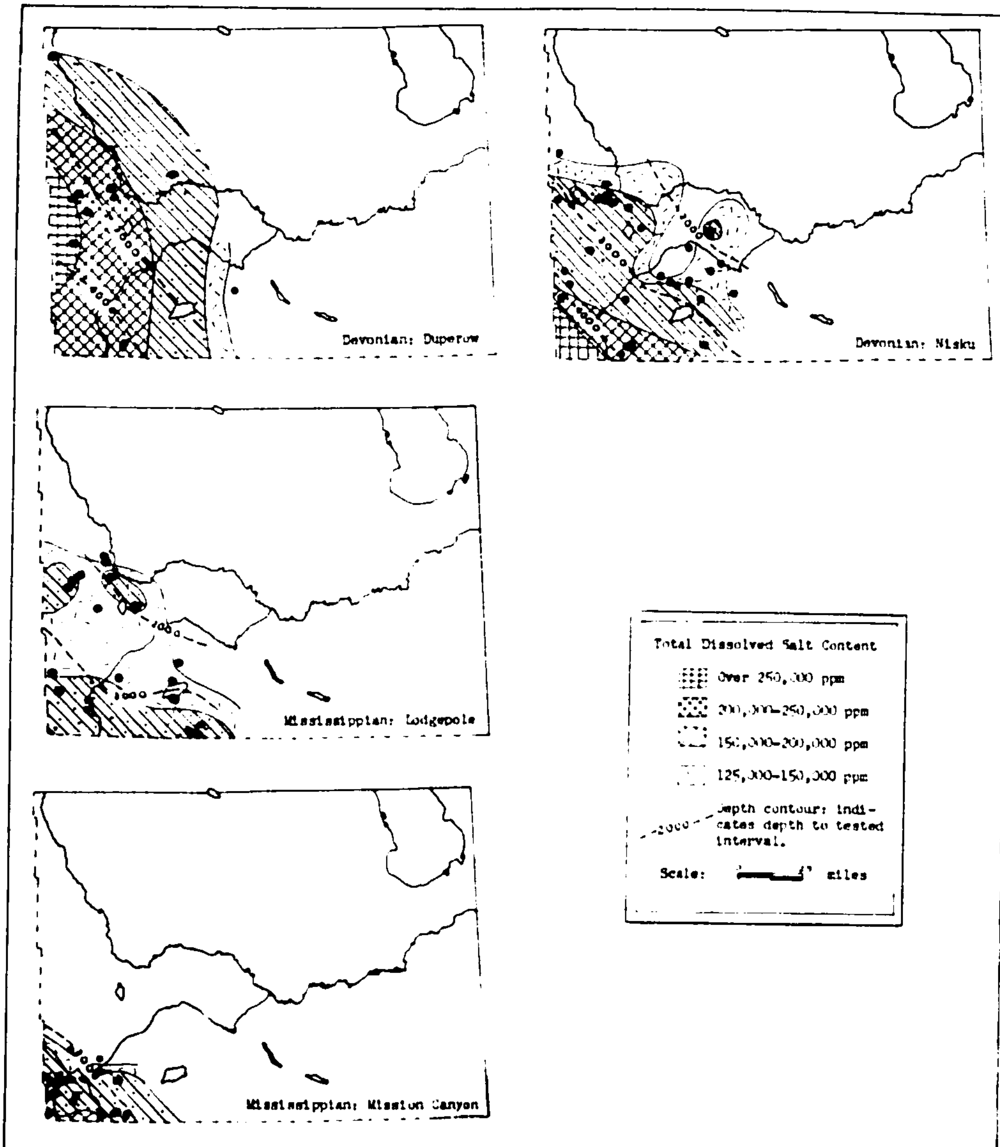

Figure 8. Brine concentrations in the Duperow, Nisku, Lodgepole, and Mission Canyon formations, southwestern Manitoba.

been included for which sufficient data are available to indicate a pattern of concentration of the brines. On the maps, only those analyses which showed over 125,000 ppm have been plotted. As the richest brines are probably limited to a well-defined horizon within a formation, brines from other horizons within the same formation may differ greatly in their dissolved salt content. The maps show only the general trend of the increase in the maximum or near maximum salt content of the most concentrated brine within each formation.

The relative proportions of some of the ions in the subsurface waters differ notably from those of normal sea water. These differences are most marked in the concentrations of Ca^{2+}, Mg^{2+}, SO_4^{2-}, and CO_3^{2-} ions. Many theories have been proposed to account for these differences (Washburne and Lahee, 1934); some workers have suggested there may be a relation between the Ca^{2+} and Mg^{2+} ion concentrations and the degree of dolomitization of the enclosing sediment. This process may govern also the concentrations of the CO_3^{2-} and the SO_4^{2-} ions.

CONCLUSIONS

The brine distribution maps show that for each formation mapped the content of dissolved solids in the formation brines increases basinward, and that in general the concentrations of the brines within the older formations are greater. The probable causes of these features have been discussed on page 19. However, it should be pointed out that the figures used are the maximum obtained for each formation and probably represent one or two concentrated brine horizons within the formation. Numerous other analyses of brine samples from the same formation show low concentrations, in some cases lower than that of normal sea water. Thus if commercial production is contemplated, it would be necessary to tap one of the concentrated brine horizons.

The commercial possibilities of the brines and rock salt deposits are controlled by many variable factors. For brines, these include market demand and price; the nature and amount of recoverable salts, including bromine and iodine; as well as the concentration, depth, and productivity of the brine. Rock salt could be extracted either in its natural form as a by-product of potash mining, or as a brine by solution in water followed by pumping of the artificial brine to the surface.

The market for Manitoba production can be considered to cover the eastern part of the Prairies, as well as Northwestern Ontario. The production of salt in Manitoba has risen from 16,000 tons in 1950, with an average value of $22.75 per ton (processed), to an estimated 20,560 tons in 1958 with an average value of $30.01 per ton (processed). Current production is estimated at 23,000 tons per year. Consumption should increase as the prairie region becomes more industrialized. The chemical industry could be an important consumer of salt brines, and, although the use of rock salt for dust and ice control on highways has received some criticism, it may create an additional market for this material.

APPENDIX I

CORE DESCRIPTION OF S. A. M. LAZARE 6-29-17-29W

Depth (K.B. 1582')	Rock Description	Thickness in Feet
	Devonian	
Second Red Bed		
2952-2956	Brick red shale; stringers and lenses of brown shale; clusters of halite crystals at 2955.0 and throughout the shale; at 2956 halite mixed with shale fragments.	4.0
Prairie Evaporite Formation		
2956-2963	Lost core, probably halite.	7.0
2963-2970.8	Halite, coarse grained, transparent; red carnallite around crystal boundaries; carnallite enriched in narrow bands; scattered clay inclusions.	7.8
2970.8-2971.6	Halite, translucent coarse crystals, slightly purplish, in a matrix of translucent greasy sylvite (about 30 percent); scattered green clay inclusions.	0.8
2971.6-2975.2	Halite, coarse, clear to translucent; carnallite in clear interstitial masses and small red grains.	3.6
2975.2-2975.6	Banded core: upper 0.2 feet, clear halite; next 0.1 foot, halite with layer of red carnallite at base; bottom 0.1 foot, greenish brown and red shale stringer.	0.4
2975.6-2987.8	Halite, mainly clear; coarse, red carnallite in masses up to 1 inch across; numerous brown clay inclusions and stringers with carnallite-filled cracks; 2981.9-2983.2: translucent halite with large red carnallite masses; five 1- to 2-inch bands enriched in red carnallite between 2984.5 and 2987.2.	12.2
2987.8-2994.0	Carnallite, resinous salmon and clear, in large masses, as a maxtrix, with embedded clear to translucent halite; some clay; 2991.8-2994: carnallite 20 to 30 per cent.	6.2
2994.0-2995.0	Lost core, assumed same as above.	1.0
2995.0-2997.0	Halite, clear to translucent; interstitial red carnallite.	2.0
2997.0-2997.9	Halite, milky; sylvite, clear; both as coarse crystals in red to orange translucent carnallite.	0.9
2997.9-2998.5	Halite, milky and clear; resinous carnallite masses; abundant greenish clay.	0.6
2998.5-3000.8	Sylvite, clear to slightly brownish cubes; milky halite crystals; abundant orange to translucent red carnallite; scattered green clay particles.	2.3
3000.8-3026.0	Halite, large clear and translucent crystals; orange, salmon, and purplish-red carnallite in varying amounts; green and brown clay.	25.2
3026.0-3029.5	Sylvite, mainly translucent and milky, also clear; halite, milky or blue crystals, also transparent; central part predominantly sylvite; lower foot mainly halite; red carnallite; large grey-green clay patches; halite and sylvite very coarse grained: 1- to 2-inch crystals.	3.5
3029.5-3040.8	Halite, clear, transparent, and faintly bluish; sylvite, translucent, greasy, in smaller crystals (about 3/8 inches across) forming about 12 per cent of section; enriched 3037.0-3039.0; abundant resinous red to shiny black carnallite; green clay abundant in upper half of section.	11.3
3040.8-3049.0	Main potash bed: sylvite, greasy, translucent to transparent, mainly as a matrix; halite, milky-bluish to white, in coarse cubes; sylvite and halite occur well mixed in about equal proportions as sylvinite; red carnallite in coarse masses and stringers, mainly 3041.5-3044.5; very low clay content especially 3040.8-3045.0.	8.2
3049.0-3059.7	Halite, slightly translucent bluish to clear transparent; scattered small sylvite crystals; red to salmon carnallite, interstitial; minor clay.	10.7
2952.0-3059.7		107.7 feet

APPENDIX II: Analyses of Drill Stem Tests

(1) No.	Well Name	Location	Zone	Interval	K.B.	Resistivity (2)	pH	Sp.Gr.	Ca	Mg	Na + K (as Na)	Chlorides	Sulphate	HCO_3 (3)	Total Concentration (Calculated)	No.
1	Royalite Turtle Mtn.	4-36-1-21	Nisku	3673-3685	2286			1.141	2,360	860	74,960	120,200	2,720	170	201,270	1
2	Imperial Calstan Hernefield	1-30-1-25	Duperow	4155-4185	1551	0.06	6.4	1.150	8,772	1,652	73,884	132,250	2,458	418	219,222	2
3	Anglo Ex Dando	3-32-1-25	Nisku	3907-3944	1554				9,860	1,432	73,676	134,059	1,527	146	220,700	3
4	Calstan Waskada	9-13-1-26	Nisku	3949-3965	1534	0.0505	6.9	1.152	10,734	2,027	81,382	149,640	919	110	244,756	4
5	Imperial Copely	11-18-1-29	Mission Canyon	3647-3673	1574				4,557	1,319	72,699	122,897	2,405	244	204,121	5
6	Calstan Pierson Prov.	2-29-2-29	Nisku	4360-4375	1578				18,273	4,854	71,354	155,896	605	134	251,316	6
7	Landa et al Wicks	1-8-3-29	Mission Canyon	3483-3495	1588				3,943	1,297	72,815	120,713	3,129	85	201,982	7
8	Calstan Pierson Prov.	4-11-3-29	Mission Canyon	3305-3310	1564	0.053	5.5	1.136	3,796	1,426	71,826	119,500	2,732	266	199,411	8
9	Western Orthez	13-36-4-19	Dawson Bay	3103-3123	1628				2,905	917	77,095	123,140	4,192	238	208,677	9
10	Imperial Calstan Eunola	4-26-4-29	Nisku	4015-4060	1615	0.08	6.0	1.173	13,252	1,078	75,839	142,250	1,551	315	234,125	10
11	Landa Warnez	5-13-5-22	Dawson Bay	3585-3639	1635	(Top)			4,725	1,585	74,470	125,687	2,839	116	209,422	11
12	Landa Warnez	5-13-5-22	Dawson Bay	3585-3639	1635	(Bottom)			3,989	912	78,103	128,235	2,573	91	213,903	12
13	Amerada Lauder Prov. M-F	9-35-5-25	Winnipeg	5285-5380	1425	0.057	6.6	1.146	5,656	1,065	76,405	129,750	1,608	60	214,514	13
14	Phillips East Tilston	5-12-5-29	Nisku	3800-3901	1582		5.0	1.157	11,273	1,815	78,077	144,750	1,223	40	237,158	14
15	Calstan Linklater	2-21-7-28	Duperow	3589-3605	1618		7.1	1.178	10,505	2,481	93,846	169,764	933	110	277,583	15
16	Calstan Linklater	2-21-7-28	Duperow	3771-3787	1618		7.0	1.174	7,975	1,988	95,233	165,816	1,188	85	272,242	16
17	Dome Brandon	3-5-9-19	Dawson Bay	2519-2537	1374	0.06	5.0	1.137	3,022	954	75,544	121,750	3,918	60	205,228	17
18	Calstan Woodnorth Prov.	5-15-9-27	Souris River	3628-3646	1598		6.5	1.180	5,488	1,328	104,609	173,536	1,751	75	286,749	18
19	Calstan South Virden SWD	3-11-10-26	Duperow	2750-2776	1441	0.058	6.8	1.164	6,357	2,509	83,062	145,250	1,841	140	239,087	19
20	Calstan South Virden SWD	3-11-10-26	Souris River	3250-3282	1441	0.058	4.5	1.160	4,087	2,161	83,008	139,250	3,114	49	231,644	20
21	B. A. Union Grose Virden SWD	7-27-10-26	Duperow	2630-2665	1450	0.057	5.0	1.134	3,291	1,315	72,380	118,500	3,707	125	199,255	21
22	B. A. Union Grose Virden SWD	7-27-10-26	Duperow	2765-2800	1450	0.052	4.5	1.161	5,781	2,104	84,954	146,000	1,858	66	240,730	22
23	B. A. Union Grose Virden SWD	7-27-10-26	Souris River	3235-3270	1450	0.052	4.5	1.161	3,659	1,236	89,476	146,000	2,798	61	243,199	23
24	Calstan Daly	15-18-10-27	Winnipeg	5334-5368	1614				6,098	718	94,600	162,000	10,050	10	274,076	24
25	Cdn-Sup Daly SWD #1	NW 4-10-28	Duperow	3245-3281	1681	0.060	7.0	1.164	6,384	2,208	89,893	154,908	1,860	90	255,297	25
26	Cdn-Sup Daly SWD #1	NW 4-10-28	Souris River	3724-3760	1681	0.057	6.5	1.167	7,296	1,380	94,249	160,866	1,803	90	265,638	26
27	Calstan Daly WIW	8-14-10-28	Nisku	2716-2744	1636	0.052	5.0	1.147	5,284	1,896	77,317	132,500	2,160	83	219,198	27

APPENDIX II: Cont'd.

No.[1]	Well Name	Location	Zone	Interval	K.B.	Resistivity (2)	pH	Sp.Gr.	Ca	Mg	Na+K (as Na)	Chlorides	Sulphate	HCO_3 (3)	Total Concentration (Calculated)	No.
28	Dome Harding	4-27-11-22	Souris River	2484-2499	1381	0.056	5.0	1.134	2,505	866	73,255	116,500	4,624	80	197,789	28
29	Dome Harding	4-27-11-22	Red River	3448-3460	1381	0.054	6.0	1.144	2,691	1,945	76,209	125,750	2,963	90	209,602	29
30	Imperial Blossom	3-17-12-24	Souris River	2905-2945	1550				4,320	1,087	82,292	135,636	2,804	67	226,206	30
31	Imperial Blossom	3-17-12-24	Interlake	3675-3700	1550				3,692	962	100,593	162,569	2,538	92	270,446	31
32	Imperial Blossom	3-17-12-24	Winnipeg	4470-4511	1550				5,708	738	80,435	134,652	2,212	61	223,806	32
33	Homestead Birdtail	10-5-15-27	Winnipegosis	3256-3283	1535				3,094	986	96,308	154,076	3,476	439	258,379	33
34	Homestead Birdtail	9-21-15-27	Elk Point	3271-3301	1540	(Top)			2,184	764	121,773	190,472	4,356	390	319,941	34
35	Homestead Birdtail	9-21-15-27	Elk Point	3271-3301	1540	(Middle)			3,005	1,158	98,565	158,080	3,422	201	264,431	35
36	Homestead Birdtail	9-21-15-27	Elk Point	3271-3301	1540	(Bottom)			2,932	1,144	98,106	157,473	3,146	85	262,886	36
37	Dome Strathclair	8-34-16-21	Jurassic Lime	1380-1420	1991	0.052	6.0	1.157	4,344	946	87,326	143,060	2,847	85	238,505	37
38	Dome Strathclair	8-34-16-21	Winnipeg	3807-3852	1991	0.059	6.0	1.141	2,546	1,042	76,908	122,750	4,588	75	207,871	38
39	Cdn-Sup Strath	6-23-17-23	Dawson Bay	2512-2524	1862	0.064	5.0	1.143	2,318	1,155	75,770	121,000	4,492	60	204,765	39
40	Cdn-Sup Strath	6-23-17-23	Winnipegosis	2704-2726	1862	0.061	5.5	1.151	2,567	1,293	84,803	136,500	3,464	120	228,686	40
41	Imperial Birtle	1-27-17-26	Souris River	2746-2775	1791				2,594	1,022	74,309	118,894	4,303	201	201,323	41
42	Imperial Birtle	1-27-17-26	Red River	3754-3760	1791				2,823	832	97,688	155,290	3,675	165	260,473	42
43	Imperial Birtle	1-27-17-26	Winnipeg	4128-4154	1791				2,873	845	110,458	175,307	2,806	104	292,393	43
44	Anglo Am Birdtail	4-30-18-26	Dawson Bay	2807-2823	1808				2,510	847	96,615	153,106	3,732	122	256,932	44
45	Imperial Madeline	16-18-18-29	Souris River	2499-2517	1597				6,002	1,404	74,141	126,779	3,038	92	211,456	45
46	Imperial Madeline	16-18-18-29	Interlake	3469-3505	1597				2,236	983	116,779	184,406	3,285	195	307,884	46
47	Imperial Madeline	16-18-18-29	Winnipeg	4284-4310	1597				4,282	817	94,355	153,470	2,657	110	255,691	47
48	Imperial Foxwarren	16-32-19-27	Interlake	3230-3295	1821				2,375	829	112,015	176,521	3,747	183	295,670	48
49	Imperial Foxwarren	16-32-19-27	Red River	3628-3658	1821				4,344	1,505	86,296	143,158	2,705	49	238,057	49
50	Imperial Foxwarren	16-32-19-27	Winnipeg	4057-4073	1821				3,777	866	99,321	160,385	2,669	85	267,103	50

(1) Numbers correspond with those used in Appendix III, they do not refer to licence number of well.

(2) Measured in ohms/M^2M at 68°F.

(3) The carbonate (CO_3) content for each of these tests was nil.

APPENDIX III

DRILL STEM TEST RECOVERY

Abbreviations:

DST: drill stem test	HP: hydrostatic pressure
OP: opened	FP: flowing pressure
SI: shut in	SIBHP: shut in bottom hole pressure
REC: recovery	FBHP: flowing bottom hole pressure
GIP: good initial puff	sw: salt water
SIP: shut in pressure	sul: sulphurous

No. *	Well **	DST	Recovery
1	Royalite Turtle Mtn	3673-3685	OP 130 min. REC 360' sw. SIP 1125. FP 175.
2	Imperial Calstan Hernefield	4155-4185	OP 1 hr. SI 1 hr. REC 270' muddy sw. SIBHP 1890. FBHP 25-75. HP 2350.
3	Anglo Ex Dando	3907-3944	OP 45 min. Good strong blow throughout. REC 1815' sw.
4	Calstan Waskada	3949-3965	OP 1 hr. REC 3300' sw; some slightly sul.
5	Imperial Copely	3647-3673	OP 30 min. SI 30 min. REC 3330' sw.
6	Calstan Pierson Prov	4360-4375	OP 1 hr. REC 630' muddy sw.
7	Landa et al Wicks	3483-3495	OP 30 min. REC 10' sw.
8	Calstan Pierson Prov	3305-3310	OP 1 hr. REC 150' oil and gas cut mud; 210' sul sw.
9	Western Orthez	3103-3123	OP 45 min. SI 30 min. REC 480' sw.
10	Imperial Calstan Eunola	4015-4060	OP 67 min. REC 1590' sw.
11, 12	Landa Warnez	3585-3639	OP 1 hr. REC 3100' sw.
13	Amerada Lauder Prov	5285-5380	OP 30 min. SI 30 min. REC 4200' muddy sw.
14	Phillips East Tilston	3800-3901	OP 1 hr. SI 75 min. REC 2690' muddy sw.
15	Calstan Linklater	3589-3605	OP 30 min. Fairly strong air blow; decreased slightly toward end of test. REC 1500' sul sw.
16	Calstan Linklater	3771-3787	OP 30 min. Fairly strong air blow throughout test. REC 570' sw.
17	Dome Brandon	2519-2537	OP 1 hr. SI 15 min. REC 1800' sw.
18	Calstan Woodnorth Prov	3628-3646	OP 30 min. Good air blow decreased toward end of test. REC 30' mud and 1800' sw.
19	Calstan South Virden SWD	2750-2776	OP 1 hr. SI 30 min. REC 1800' sw.
20	Calstan South Virden SWD	3250-3282	OP 45 min. SI 15 min. REC 1380' sw.
21	B.A. Union Grose Virden SWD	2765-2800	OP 45 min. REC 580' very muddy sw.
22	B. A. Union Grose Virden SWD	2630-2665	OP 50 min. REC 350' muddy sw.
23	B. A. Union Grose Virden SWD	3235-3270	OP 45 min. REC 2800' sw.
24	Calstan Daly	5334-5368	OP 1 hr. REC 480' sw.
25	Cdn Sup Daly SWD #1	3245-3281	OP 1 hr. GIP. Medium blow decreased to end of test. No gas. REC 1560' muddy sw. HP 1950. FP 150-900. SIP 1300.
26	Cdn Sup Daly SWD #1	3724-3760	OP 1 hr. Strong blow decreased. No gas. REC 2450' sw. HP 2150. FP 400-1225. SIP 1550.
27	Calstan Daly WIW	2716-2744	OP 1 hr. SI 30 min. REC 2200' sw. HP 1575. FP 1050. SIP 1135.
	Dome Harding	2484-2499	OP 1 hr. SI 15 min. REC 690' sw.
29	Dome Harding	3448-3460	OP 1 hr. SI 15 min. REC 780' sw.
30	Imperial Blossom	2905-2945	OP 30 min. REC 1350' muddy sw.
31	Imperial Blossom	3675-3700	OP 20 min. REC 1230' sw.
32	Imperial Blossom	4470-4511	OP 20 min. REC 3360' sw.
33	Homestead Birdtail	3256-3283	OP 45 min. SI 15 min. REC 570' sw.
34-36	Homestead Birdtail	3271-3301	OP 20 min. Strong blow. REC 760' sw. HP 2050. FP 650.
37	Dome Strathclair	1380-1420	OP 1 hr. REC 240' watery mud.
38	Dome Strathclair	3807-3852	OP 62 min. SI 15 min. REC 2650' sw.
39	Cdn Sup Strath	2512-2524	OP 30 min. SI 30 min. REC 1600' muddy sw.
40	Cdn Sup Strath	2704-2726	OP 30 min. SI 30 min. REC 1156' muddy sw.
41	Imperial Birtle	2746-2775	OP 1 hr. REC 100' mud, 390' gassy sw.
42	Imperial Birtle	3754-3760	OP 1 hr. REC 40' mud, 980' gassy sw.
43	Imperial Birtle	4128-4154	OP 50 min. REC 45' mud, 3150' sw. Initial strong air blow.
44	Anglo Am Birdtail	2807-2823	OP 1 hr. Strong initial puff, strong air blow for 20 min. gradually dying to faint at end of test. REC 1860' sw. HP 1400. FP 775.
45	Imperial Madeline	2499-2517	OP 1 hr. REC 60' mud, 750' dead sw.
46	Imperial Madeline	3469-3505	OP 50 min. REC 3300' sw, 180' gassy mud.
47	Imperial Madeline	4284-4310	OP 1 hr. REC 810' gassy sw, 150' mud.
48	Imperial Foxwarren	3230-3295	OP 1 hr. REC 2070' sw, 5' mud.
49	Imperial Foxwarren	3628-3658	OP 1 hr. REC 775' sw, 5' mud.
50	Imperial Foxwarren	4057-4073	OP 45 min. Very strong blow; dead in 30 min. REC 3200' sw., 10' mud.

* Numbers correspond to those used in Appendix II.

** The complete well name, which includes the location, is listed in Appendix II.

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