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SALT IN EAST-CENTRAL ALBERTA

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Salt In East-Central Alberta

ABSTRACT

Rock salt (sodium chloride) deposits of commercial thickness and purity underlie a large area in east-central and northeastern Alberta, extending into extreme northwest parts of the province. The deposits form part of the Middle Devonian Elk Point Group which contains four mappable salt units called (from oldest to youngest): lower Lotsberg, upper Lotsberg, Cold Lake and Prairie Evaporite Salts. All but the Prairie Evaporite Salt lie wholly within the study area (east-central Alberta), although a separate deposit of Cold Lake Salt exists in northern Alberta. The salt deposits attain a maximum aggregate thickness of nearly 1,400 feet in east-central Alberta, thinning gradually (depositionally) in all directions except northeast, where all of the deposits except the lower Lotsberg Salt are truncated due to post-depositional solution of the beds.

The thickest, most extensive salt units are the upper Lotsberg and Prairie Evaporite Salts, which exceed 500 and 700 feet at their respective depocenters. The younger and more shallow Prairie Evaporite Salt ranges in depth from 700 feet in the northeast part of the study area to 6,000 feet in the southwest. It is a "normal", first-cycle, marine evaporite deposit containing a normal proportion of soluble and insoluble impurities interbedded with or dispersed within the halite beds. The upper Lotsberg Salt is from 600 to 1,000 feet deeper than the Prairie Evaporite Salt but is more favorable for industrial use owing to its superior chemical quality. Both the Lotsberg and Cold Lake salt deposits have a complex history of solution and recrystallization, part of which occurred in nonmarine waters, subsequently resulting in abnormally small amounts of impurities in the rock salt.

Within the Lotsberg and Cold Lake successions non-salt strata are rare; thus, solution-mining recoverability of the salt is greatly enhanced. Notably lacking are interbeds of anhydrite, reflected in $CaSO_4$ concentrations commonly less than 0.1 weight per cent, about one tenth of the amount considered normal for rock salt. Magnesium and potassium salt concentrations also are consistently very low, whereas in the Prairie Evaporite Salt they tend to increase towards the top of the deposit and also laterally southeastward.

Exploitation of the salt deposits in east-central Alberta has continued since 1938, with production in 1969 of more than 150,000 tons valued at $2.4 millions. Increasing industrial development in Alberta undoubtedly will lead to increasing demand for salt, mainly to meet the expanding requirements of the chemical industry. Greater indirect use of salt beds for storage of liquified petroleum gas (LPG) and natural gas (in man-made caverns) also is foreseen, and improved solution mining techniques may lead ultimately to magnesium and bromine extraction through selective brining of beds rich in these elements.

INTRODUCTION

Common salt, sodium chloride, has a multitude of domestic and industrial applications which accord it possibly the greatest familiarity of all solid chemical compounds. It is found abundantly in nature in solid form and as brine, and has a history of exploitation that dates from antiquity. The mineral term for naturally occurring sodium chloride is *halite*. In the form of massive, bedded deposits it is known as *rock salt*. Rock salt rarely consists entirely of halite but includes variable amounts of anhydrite, dolomite,

limestone, shale, other sulfates and chlorides, and "potash" minerals. These impurities may be present in minute amounts as inclusions in halite or in larger amounts as irregular partings and beds interstratified on various scales with halite. Associations of these rock types are called *evaporites* in reference to their mode of deposition through the concentration of saline waters by evaporation.

Salt is essential to animal existence, and accordingly is consumed in amounts which tend to remain fixed in proportion to the population. Far greater, however, is the amount of salt used for industrial purposes, notably in the chemical industry, and this amount has shown remarkable growth in recent years. In all likelihood this growth will continue, and the Province of Alberta, richly endowed with rock salt deposits, can be expected to benefit from the expanding use of salt as a basic raw material for industry.

Purpose and Scope of Investigation

In recent years the Research Council of Alberta has received many requests for information on the widespread salt deposits that underlie much of Alberta from groups and individuals concerned with the industrial use of salt. The information sought is not generally to be found in the voluminous geological literature which deals primarily with regional stratigraphic implications of Alberta's salt formations. Those interested in industrial exploitation of salt need to know, for example, the chemistry of the salt deposits, and the precise nature of interbedding of salt and other strata as a measure of recoverability of the deposits.

With such needs in mind, a study was undertaken by the Research Council to define the salt deposits of east-central Alberta in terms that would be useful to existing and potential salt and chemical industries as well as those interested mainly in the stratigraphy of the deposits for petroleum exploration purposes. This report presents the results of the study based on subsurface data from more than 300 wells that have partly or completely penetrated the salt-bearing strata of east-central Alberta and adjacent parts of Saskatchewan. The data have been synthesized for presentation on maps to show the distribution and thickness of each of four salt formations, and the purity, depth, and "brinability" of those considered most suitable for exploitation[1].

Of necessity, the basic well data are interpretations largely of mechanical logs, supplemented with the results of examination of drill cuttings and core from wells for which these are available. Accuracy and consistency in the interpretation of the logs (many of which are old and of poor quality) were

[1] The well data are available on request to readers wishing to make their own interpretations suited to their particular need, but are not included with the report.

achieved through comparisons with carefully standardized correlation sections, lithologically calibrated with the aid of scattered core control to assist in resolving the evaporite successions of each well into salt, shale, anhydrite, and dolomite down to bed thicknesses of two feet. Details of this kind determine the "brinability" of a salt section (i.e. the thickness of salt that can actually be recovered by solution mining).

Data on the chemical composition of the salt deposits were obtained from analyses of salt cores. Although sparse, imperfectly preserved, and generally incomplete, the cores nevertheless provide enough information for a reasonably reliable appraisal of the quality of salt in each deposit.

Location and Geography of Area

The area of study is outlined in figure 1 and shown in detail in figure 3. In general, it embraces that portion of Alberta (herein called east-central Alberta) extending from the City of Edmonton eastward to the provincial boundary and northward to the latitude of the Town of Fort McMurray, and includes also a narrow, adjoining segment of Saskatchewan. Specifically, it is bounded by longitudes 108 and 116 degrees west and latitudes 53 and 57 degrees north.

These boundaries were chosen for both geographical and geological reasons: to include the salt-bearing part of Alberta best situated with respect to large potential markets (particularly that in pulp manufacture), and to embrace as much of each deposit as possible for portraying in maximum detail on a conveniently scaled base map. Accordingly, three of the four deposits are entirely delimited within the subject area (see Fig. 3). The fourth, vastly more extensive in one dimension, transcends the north and south area boundaries, though its east and west limits remain within the subject area.

Physiographically east-central Alberta is part of the Interior Plains; it has little local relief beyond that formed by the valleys of the Athabasca and North Saskatchewan Rivers (the primary drainage arteries of the area) and their major tributaries. The southern half is settled agricultural prairie land interspersed with wooded areas, with an established network of first-class roads and railways radiating from Edmonton — the capital city of Alberta. By contrast, the northern half is largely unsettled bushland, extensively covered with swamp and muskeg, and lacking in good roads apart from a single all-weather highway connecting Fort McMurray, the most northerly and largest community in this part of the area, with Edmonton to the south. The only railway is a single line also leading to Fort McMurray from Edmonton.

Previous Investigations

The earliest reference to the presence of rock salt deposits in Alberta is by Cole (1915, p. 83), who mentions two wells drilled near Fort Mc-

Murray between 1907 and 1912 which reportedly penetrated thick beds of salt. However, no drilling samples from these wells were kept, and confirmation of the deposit's presence was not obtained until 1920, when rock salt was first recovered as core from depths less than 700 feet in a test well drilled at the Fort McMurray townsite (Allan, 1921). Once the existence of rock salt had been proven, deposits underlying the Fort McMurray area received considerable exploratory attention, which culminated in 1937 with the building of a salt recovery plant at Fort McMurray. The history of exploration and development of these deposits up to 1937 is documented by Allan (1929, 1937, 1943), who directed the earlier test drilling and played a significant part in establishing a salt industry in Alberta.

The extent of the salt deposits at Fort McMurray was unknown until deep drilling for oil and gas in east-central Alberta, which got underway about 1944, disclosed the presence of similar deposits in the area east of the City of Edmonton. However, the relationship of these deposits to those at Fort McMurray was not ascertained for some time. Crockford (1949) detailed the drilling that had penetrated salt up to that time and concluded that it was insufficient to furnish correlative data, though it outlined a salt basin which appeared to be continuous from southeast Alberta to Fort McMurray. However, McGehee (1949) was able to present correlations based on intensive stratigraphic studies of selected wells to demonstrate that the thick salt deposits east of Edmonton were at least partly equivalent to the northerly Fort McMurray deposits.

As deep drilling progressed in the 1950's, a host of stratigraphic workers followed McGehee and, through their resultant efforts, evolved the stratigraphy of the salt deposits to its present state of understanding as expressed in a paper by Grayston, Sherwin, and Allan (1964). This paper reviews the significant contributions of earlier workers and includes a bibliography of publications dealing with the stratigraphic aspects of Alberta's major salt deposits.

The discovery of salt by deep drilling in Alberta was paralleled at approximately the same time in the neighboring province of Saskatchewan by the finding of what subsequently was shown to be the same continuous basin. Far more exciting, however, was the coincident discovery of extensive potash mineralization in the Saskatchewan salt deposits, the first published account of which was given by Cole (1948). In succeeding years the continuing search for oil and gas together with exploratory drilling for potash (which led eventually to commercial development) generated a vast amount of data on the Saskatchewan potash deposits. These data formed the bases of scores of studies on various geological aspects of the potash, all of which aided directly or indirectly in the geological understanding of laterally equivalent salt in Alberta. The recent works of Klingspor (1966), Harding and Gorrell (1967), and Holter (1969) on the deposition, distribution, and

richness of the potash zones contain reference to most of the work published on potash since the initial contribution by Cole (*ibid.*). Studies on the geochemistry, mineralogy, and petrology of the evaporite deposits have yielded significant information on depositional processes, most of which is given in papers by Schwerdtner (1964), Wardlaw (1964, 1968), Wardlaw and Schwerdtner (1966), and Wardlaw and Watson (1966).

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STRATIGRAPHY AND DISTRIBUTION

The major salt deposits of Alberta are part of a group of strata of Middle Devonian age called the Elk Point Group. Salt of other ages is not present in the study area, although younger (Upper Devonian) salt deposits are found in the province. The Upper Devonian deposits are confined to small areas in southeastern Alberta, are generally less than 100 feet in total thickness, and are economically unimportant in comparison with Elk Point salts, which are of vast extent and reach a maximum aggregate thickness of nearly 1,400 feet. The discussion below concerns only the Elk Point Group salt deposits.

Regional Stratigraphy

Elk Point is the name given by McGehee (1949) to a cyclic succession of evaporite, carbonate and clastic rocks lying between the eroded surface of Lower Paleozoic and Precambrian rocks and overlying Upper Devonian carbonates. The Elk Point strata extend in a broad belt from North Dakota and Montana northwestward across the Prairie Provinces as shown on figure 1. The isopach pattern of the Elk Point beds (Fig. 1) reflects chiefly the varying thicknesses of the evaporite sediments, which, except in northernmost Alberta, consist primarily of salt. Thus, the thickest deposits of salt are to be found in east-central Alberta (shown in outline as the area of study), where the Elk Point Group attains its maximum thickness in the Prairie Provinces of nearly 2,000 feet.

The Elk Point Group is divisible into distinct upper and lower subgroups, each with a characteristic basinal framework and depositional history that influenced the distribution and quality of its salt deposits. The limits of salt in each subgroup are plotted separately in figure 1.

The lower Elk Point Subgroup is restricted largely to east-central and northern Alberta, except for a slight projection into Saskatchewan. Elsewhere in the Elk Point basin it is represented only by a thin regolith of red dolomitic shales (Grayston *et al.*, 1964). Its depocenter is in east-central Alberta, where the thickness reaches 1,200 feet and accounts for the over-all thickening of the Elk Point Group in that area (see Fig. 1). As many as three salt units are mappable in this subgroup.

The upper Elk Point Subgroup is much more widespread and uniform in distribution than the lower. Southeast of the subject area, through Saskatchewan and into Manitoba, it is virtually the sole representative of the Elk Point Group. It contains a single salt unit that extends over a very large area (Fig. 1) and records a cycle of evaporite deposition complete to the potash phase. The upper subgroup thickens regionally toward the northwest, but the salt effectively thins as it grades laterally into anhydrite

in this direction. Because most of this thinning takes place beyond 57 degrees north latitude, the bulk of upper Elk Point salt is found also in east-central Alberta.

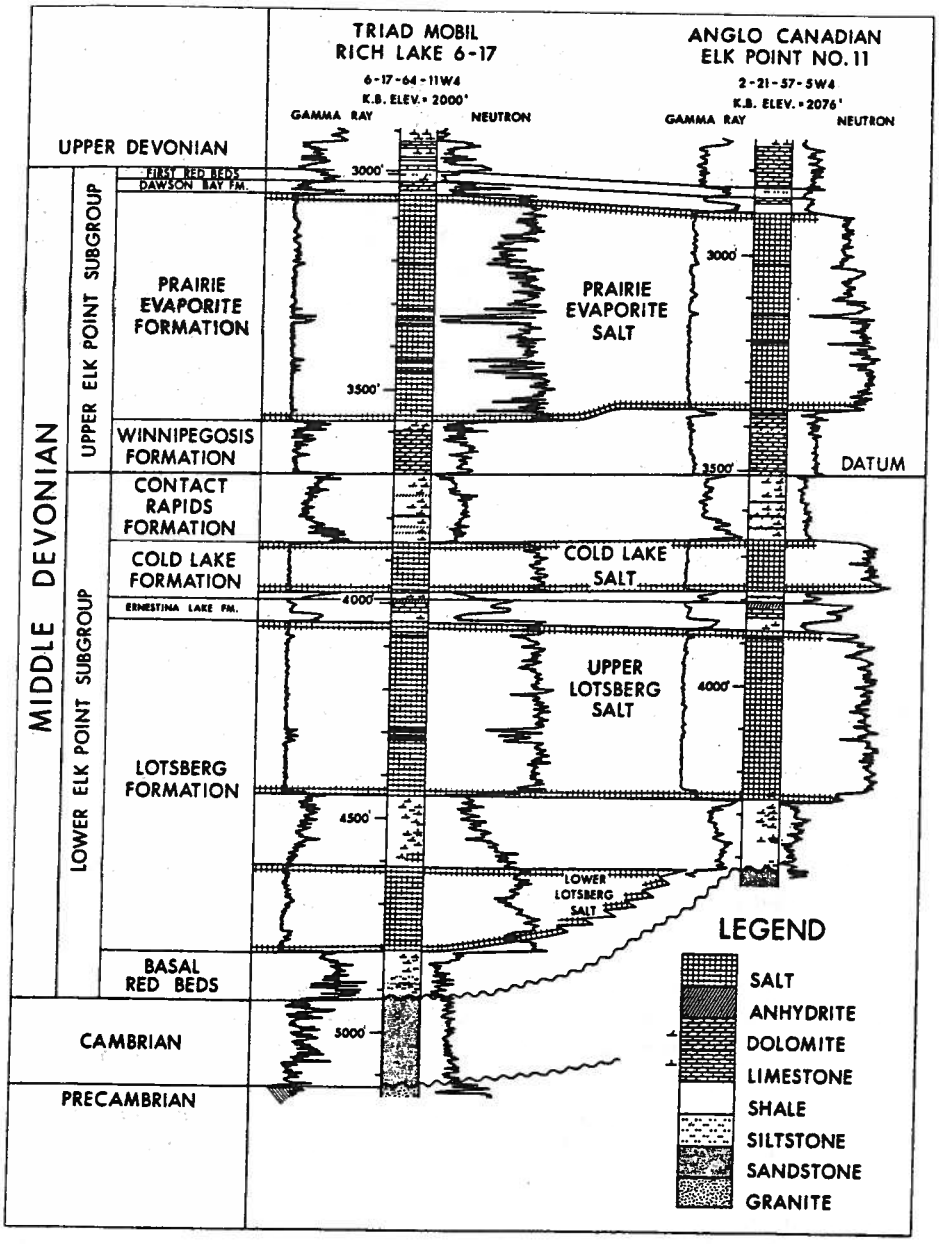

FIGURE 2. Typical well log sections of the Elk Point Group in east-central Alberta.

Elk Point Group of East-central Alberta

The succession of strata in the Elk Point Group of east-central Alberta is typified by the two well log sections illustrated in figure 2. One of the wells, Anglo Canadian Elk Point No. 11, was drilled in the locality from which the group derives its name, and was adopted by Crickmay (1954) as the type section of the Elk Point Group. Its designation as such is unfortunate, inasmuch as the well penetrated only two salt units in the lower Elk Point Subgroup. Consequently, a well which penetrated all three salts, Triad Mobil Rich Lake No. 6-17, is included for comparison in figure 2.

The nomenclature, divisions, and subdivisions of the Elk Point Group given in figure 2 have gained general acceptance among geologists since they were systemized by Grayston *et al.* (1964) and thus are used in this report. However, certain minor difficulties arise when dealing exclusively with the salt units as is done here. Because the salt units are the defining elements of their host formations, they are not themselves named; however, for convenience in description they have been given names. Thus, the Lotsberg Formation contains two mappable salt units, which are called lower Lotsberg Salt and upper Lotsberg Salt. The Cold Lake and Prairie Evaporite Formations contain single salt units, herein called Cold Lake Salt and Prairie Evaporite Salt. These names are informal[1] but expedient for the purposes of this report, which is concerned mainly with the economic aspects of the salt deposits rather than the stratigraphic implications.

Generalized lithologies of the formations constituting the Elk Point Group are given diagrammatically in figure 2. Precise descriptions can be found in Grayston *et al.* (1964) and need not be repeated in this report, except for those aspects that pertain to the discussion of the salt deposits.

The boundary between upper and lower subgroups of the Elk Point is placed at the base of the carbonate unit widely referred to as the Winnipegosis Formation. This horizon is easily recognized and correlated throughout the extent of Elk Point sediments, and serves as a datum for comparing the stratigraphic setting of upper and lower Elk Point salt deposits (Figs. 4 and 5).

Each salt deposit is shown in areal extent in figure 3. The salt limits are mainly depositional except along the northeast, where solution is responsible for abrupt termination of all but the lower Lotsberg Salt. The nature of the salt edges, and the comparative thicknesses of each deposit are indicated in the cross sections X — X′ and Y — Y′, figures 4 and 5. Detailed distribution maps and explanations of each salt deposit are presented below.

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[1] Although informal, these names have the word "salt" capitalized to avoid possible ambiguity where the word is meant in reference to the deposit as opposed to the rock(salt) that comprises the deposit.

Lower Lotsberg Salt

The oldest and deepest of the Elk Point salt deposits is the lower Lotsberg Salt. Its distribution is shown in figure 6, which is an isopach map of the "net" salt within the unit (i.e. excluding non-salt interbeds). The thickness of salt reaches a maximum of 200 feet at the depocenter, and tapers gradually to a feather edge on all sides, though much more rapidly toward the southeast. The limits and thickness variations are entirely depositional, reflecting the configuration of the Elk Point salt basin in the beginning stage of its development.

The rock salt consists mainly of clear, very coarse crystalline halite, commonly reddish tinted, and containing variable amounts of red shale[1] inclusions dispersed through the crystal aggregate. Shale is present also as discontinuous interbeds at some localities, but these and other non-salt strata are rare; the "net" salt isopachs of figure 6 are essentially coincident with gross thickness contours of the salt unit.

Significantly, only clastic rocks are associated with lower Lotsberg Salt. Anhydrite and other normal evaporite associates are conspicuously lacking. The salt rests on a unit of red silty shales grading to sandstones called "Basal Red Beds", which is the basal formation of the Elk Point Group (Fig. 2), representing a transgressive near-shore facies. Red shales also overlie the lower Lotsberg Salt in an unnamed interval up to 200 feet thick that separates it from upper Lotsberg Salt. Commonly, these red shales contain minor amounts of intermixed salt.

Upper Lotsberg Salt

The upper Lotsberg salt deposit (Fig. 7) is similar in many respects to the lower but is much thicker and more extensive. The salt reaches a maximum net thickness of more than 500 feet at one point, though the average thickness is about 400 feet over a sizable area which is skewed southeastward from the geometric center of the deposit (Fig. 7). From this area the salt thins gradually to zero toward the southwest, west and northwest, but abruptly toward the southeast and northeast. Convergence of the beds accounts for the gradual westward thinning. The abrupt southeastward termination results from depositional onlap against a pre-Devonian erosional escarpment. However, northeastward thinning has resulted almost entirely from the removal of salt by subsurface solution. This solution was regional in scale, fostered by a prolonged period of subaerial erosion; it established

[1] The term "shale" is used rather informally throughout the text in reference to the argillaceous material associated with Elk Point salts. The terms "mudstone" or "claystone" are probably technically preferable inasmuch as this material is poorly compacted, commonly exists as fine, wispy inclusions or as irregular masses in the salt, and exhibits no distinct lamination or cleavage even when present as distinct beds.

the northeastern limit of the deposit along a fairly straight line, the direction of which approximates the strike of the southwesterly dipping beds. The nature of the salt edges (i.e. depositional or solutional) is symbolized on figure 3 and shown diagrammatically on the cross sections in figures 4 and 5.

Rock salt of the upper Lotsberg consists chiefly of clear, very coarse crystalline halite, commonly colorless but which may exhibit hues of pink or amber. Some halite crystals are extremely coarse, ranging up to several inches across; some exceed the dimensions measurable from core and may be more than a foot across. Red shale inclusions in the crystal aggregate occur conspicuously in many parts of the salt section, though in most places their volume is insignificant. Shale also is found in few interbeds, generally less than five feet thick, causing little interruption in the halite bed succession. As with the lower Lotsberg Salt, anhydrite and carbonate interbeds (normal constituents of an evaporite succession) are not present.

The rhythmic banding that characterizes many thick salt deposits is not seen in upper Lotsberg Salt. Moreover, the salt section displays no large scale cyclic aspect to its deposition nor any widespread uniformity in its bedding structure that would permit recognition and correlation of smaller depositional units within it. In fact, radioactivity log profiles plus the sparse amount of available core indicate that bedding on the whole is obscure, and that the few shale intervals present do not persist laterally for more than a few miles. This absence of well-defined and correlatable bedding plus the deficiency of carbonate and anhydrite suggests that upper Lotsberg Salt, though thick and extensive, is not a "normal" marine evaporite.

The upper Lotsberg Salt overlaps all but the extreme northwest tip of the lower Lotsberg (Fig. 3). Where the two are superimposed, the upper deposit rests on the intervening red shale unit, but in the areas of overlap it may lie on the red shales or may overstep these to lie directly on silty and sandy "Basal Red Beds" (Figs. 4 and 5). Normally, however, the unnamed red shale unit loses identity in the absence of the lower Lotsberg Salt and is considered as part of the "Basal Red Beds" unit.

Overlying upper Lotsberg Salt is a thin but remarkably widespread and uniform succession of strata consisting of a lower shale, a middle limestone, and an upper anhydrite. This succession is named the Ernestina Lake Formation. It ranges from 35 to 70 feet in thickness and its base forms the upper boundary of upper Lotsberg Salt except near the center of the deposit, where local scour of unknown origin has caused its removal along with some underlying salt. The scour depression, indicated in figure 7 by a closed isopach "thin" in townships 66 and 67, ranges 15 and 16, was filled with salt or feldspathic sandstone or both, preceded by deposition of shale up to a thickness of 20 feet. Thus, here even as elsewhere in the basin, the upper Lotsberg Salt is overlain by shale.

Cold Lake Salt

The Cold Lake Salt (Fig. 8) is the uppermost salt deposit of the lower Elk Point Subgroup. It is about the same size areally as the lower Lotsberg deposit and somewhat similar in shape (Fig. 3), but averages 50 feet less in thickness. Both deposits are roughly oblong in outline; however, the Cold Lake deposit has a north-south elongation, almost 90 degrees to that of lower Lotsberg, and thus does not extend nearly as far westward. The distribution of Cold Lake Salt is given in the "net" salt isopach map of figure 8.

The maximum thickness of salt is found in a small area along the western edge of the deposit (townships 66 and 67, ranges 15 and 16), where a north-trending channel has been scoured in sediments underlying Cold Lake and subsequently infilled with up to 215 feet of salt. This thickness is about 50 feet greater than at the depocenter of the main salt body. The "channel" salt is indicated in figure 8 to be continuous with the main body of Cold Lake Salt, but the true relationship of the two is uncertain except that the "channel" salt equates stratigraphically with the Cold Lake interval. The salt grades abruptly into coarse feldspathic sandstone (as noted in a core from one of the wells) that appears to be channel-fill material as well and which may flank the salt that accumulated in the channel center, thereby separating it from the main salt body. Due to insufficient well data, the exact limits and origin of this anomalous salt thickness cannot be ascertained. In any case, it represents only a local departure from the regional trend in the Cold Lake salt basin, and its influence on the general picture of salt distribution is minor.

The depocenter of the main Cold Lake salt body is situated in the southeastern portion of the deposit, straddling the Alberta-Saskatchewan border where the "net" salt thickness is slightly more than 160 feet. From this point thinning is both depositional and solutional as with the underlying upper Lotsberg deposit, but with a few minor differences. The sharp southward termination of the salt deposit is again the result of depositional onlap against a pre-Devonian escarpment. Westward thinning is also depositional, but in this case the salt thins from the top down primarily as a result of shale-out, and grades laterally into fine, red, terrigenous clastics (see Fig. 4). The rapid eastward thinning is caused by regional salt solution, the "solution edge" paralleling that of the upper Lotsberg, though displaced slightly westward in accordance with the higher stratigraphic position of Cold Lake Salt plus regional dip. Toward the north, thinning is gradual over a comparatively long distance, and is due mainly to bedding convergence.

Lithologically, the Cold Lake Salt is identical to the Lotsberg salts. It consists of clear, very coarse crystalline halite; the only visible impurities are minor amounts of red shaly material, either interstratified or dispersed

within the crystal aggregate. Red shales also form the upper and lower boundaries of the salt unit. The lower shale, a red dolomitic shale generally less than 20 feet thick, separates the Cold Lake Salt from the Ernestina Lake Formation. Above the salt, red shales grade upward into green and grey dolomitic shales and dolomite — sediments which form a characteristic succession called the Contact Rapids Formation. The salt also grades laterally into red shales of the Contact Rapids Formation as the western edge of the Cold Lake Salt is approached (Fig. 4).

Prairie Evaporite Salt

The upper Elk Point Subgroup contains only one salt unit, but it is the thickest and most extensive of the Elk Point salts. It is termed Prairie Evaporite Salt in this report, and its distribution is given in figures 9 and 10, in which it may be seen to be the only salt deposit not wholly contained by the area boundaries.

The Prairie Evaporite Salt differs in several respects from lower Elk Point salt deposits. One important difference is in lithology, the rock salt of the Prairie Evaporite containing a much larger proportion of interbedded non-salt material. Consequently, two maps are required to show the distribution of salt effectively.

The first map, figure 9, is a "net" salt isopach map similar to that used to display the distribution of salt in the lower deposits with their very low proportion of non-salt interbeds. However, such a map alone would give a misleading picture of the Prairie Evaporite salt distribution, for it would fail to indicate the true vertical distribution of the salt (i.e. whether in a single continuous interval or, in the other extreme, widely interspersed with non-salt strata over a much thicker interval).

The second map, figure 10, is presented for use in conjunction with figure 9, indicating in a general way the extent to which the salt succession is interbedded with non-salt strata. This map is a combined isopach and lithofacies map of the "gross" salt interval, which includes all strata between the base of the lowest and the top of the highest salt bed in the Prairie Evaporite unit. Essentially, three types of strata are found in the "gross" salt interval: salt, shale, and anhydrite. The facies pattern of figure 10 shows variations in the relative proportions of these rock types.

The Prairie Evaporite Salt (Figs. 9 and 10) is shown to extend north-northwestward across the map area, in a belt of approximately uniform width, to overstep both the north and south boundaries of the study area. The deposit is thickest along a northwest-trending axis, increasing from about 500 feet at the south boundary to about 700 feet at the north. Transversely, the deposit thins from this axis eastward over a very short distance as a result of salt solution. Westward, the thinning takes place over a long

distance, the salt terminating depositionally. The sharp eastward termination of the salt deposit is ascribed to the same salt solution process that terminated the Cold Lake and upper Lotsberg Salts. The solution edge parallels those of the lower salts as shown in figure 3, the edge of successively younger deposits being shifted progressively farther west.

On the other hand, westward thinning of the salt is entirely depositional, involving both facies change and bedding convergence. Figure 10 indicates the manner in which the salt changes facies towards the west and also demonstrates the decreasing over-all thickness of the salt unit. The combined effect of these two mechanisms is the "net" salt distribution given by figure 9.

In general lithology, the Prairie Evaporite Salt consists chiefly of halite, commonly medium crystalline in texture, but varying from fine to coarse. Brown is the dominant color of the halite, though modified in many parts of the salt section by hues of red, green, grey, or amber. White or nearly colorless halite is uncommon but is found at some localities. For the most part, the halite is translucent or semi-opaque as a result of finely dispersed impurities; clear, colorless varieties of the mineral are seen only in minor quantities, usually as large, isolated crystals in the rock salt mass.

The chief impurities of the rock salt are shale, anhydrite, and dolomite. In finely dispersed form these impurities (especially the anhydrite) are responsible for the brown coloration of the halite crystal mass. They are much more evident, however, in the form of interbeds in the salt section, ranging from very thin laminae to massive beds several tens of feet thick, although commonly between two and six feet.

As indicated by figure 10, shale is the dominant impurity everywhere except in the northwest corner of the map area, where facies change has effected a dominance of anhydrite. The anhydrite interbeds decline rapidly in number and thickness southward and are virtually absent in the south half of the study area. Dolomite interbeds are present in close association with anhydrite but volumetrically are of little importance in the study area.

A characteristic feature of the Prairie Evaporite Salt is a distinct and regular color banding in light and dark brown, which has been suggested by some (Allan, 1937; Wardlaw and Schwerdtner, 1966) to represent seasonal layering. This banding is arranged in a rhythmic manner — the darker bands are generally less than one inch thick with a thin (one to three millimeters) layer of anhydrite in the middle, and the lighter bands notably thicker, ranging up to five inches.

In addition to rhythmic color banding, which is a comparatively small scale feature, the Prairie Evaporite salt section also displays a rhythmic aspect in its gross stratification. The interbedding of shale and anhydrite

with halite forms a well-defined bedding succession that is correlatable *almost* on a bed-by-bed basis over large parts of the study area, and certain beds or marker horizons persist throughout the entire salt basin. With such widespread continuity of strata, the salt succession can be broken down regionally into discrete units of deposition, units which are repetitive in thickness and lithologic make-up, and which are taken to represent subcycles[1] within the major cycle of Prairie Evaporite salt deposition.

Four subcycles of regional character are recognized in the Prairie Evaporite Salt of the study area (Figs. 4 and 5). These are represented by stratal intervals of 80 to 150 feet in thickness. Each interval consists typically of a basal anhydrite bed 5 to 15 feet thick, overlain by massive bedded halite containing minor thin (commonly 1 to 5 feet thick) interbeds of shale. The interval terminates, usually in a thin shale band, at the base of another anhydrite bed. The lithologic succession varies from place to place, however, in accordance with the facies changes that are indicated in figure 10. Toward the west and northwest, the anhydrite beds become thicker and the shale interbeds more numerous; consequently, the subcycles become better resolved. Southward, the subcycles lose some of their distinctiveness as shale interbeds become fewer and anhydrite disappears altogether; nevertheless, they still can be identified on the basis of widely persistent marker horizons.

Potash, a major "impurity" in the Prairie Evaporite Salt southeast of the subject area (in Saskatchewan), appears to be lacking in east-central Alberta. Prairie Evaporite Salt is the product of a cycle of evaporite deposition that progressed (with several interruptions and reversals as noted above) essentially to completion. In the later stages of evaporation the sea water had in places become so concentrated that potash salts precipitated, but the main bulk of precipitation was restricted to southern Saskatchewan (Fig. 1) in the part of the basin farthest removed from the open sea. In Alberta, refreshening by normal marine waters from the northwest kept the concentration of the sea water below the level required for large-scale precipitation of potash minerals. Thus, apart from traces of carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$) scattered through the upper half of the salt section, potash has not been observed in the study area.

Prairie Evaporite Salt is underlain by carbonates of the Winnipegosis Formation, though in most places it is separated from the carbonate by a band of shale or anhydrite. In the northern part of the map area an interval of anhydrite up to 40 feet thick may be present at the base of the salt. The

[1] A "subcycle" arises from a temporary reversal in the progressive concentration of sea water, caused by an influx of fresher water into the evaporite basin. Precipitation of increasingly soluble salts is thus brought to a halt, but shortly resumes with a less-soluble precipitate from the diluted brine.

Winnipegosis has a reefoid aspect that reflects in the abrupt thickness variations the formation undergoes in certain parts of the area. Wherever reef growth has effected a thickening of the carbonate section, the overlying Prairie Evaporite Salt is thinned accordingly, as reef carbonates assume the stratigraphic position that would otherwise have been occupied by salt.

The salt is overlain generally by red and green dolomitic shales that constitute a unit known as the "Second Red Beds", the basal member of the Dawson Bay Formation (Fig. 2). Toward the north and northwest, the "Second Red Beds" phases out and the Dawson Bay becomes anhydritic, so that in the northern third of the map area the salt is overlain by anhydrite. Along the eastern (solution) edge of the deposit the salt is overlain also by anhydrite, but in this case the anhydrite represents "residue" from a higher part of the salt section now removed by leaching.

STRUCTURE

Elk Point Group strata of east-central Alberta are situated structurally on what is sometimes referred to as the east flank of the Alberta Syncline, in which the beds dip gently to the southwest, toward the Rocky Mountains, at a rate that increases as the mountains are approached. The structural setting of both lower and upper Elk Point Subgroups can be seen in figures 11 and 12.

The upper surfaces of Prairie Evaporite and upper Lotsberg salt deposits appear to be time-constant datum planes throughout most of the study area and therefore serve as reference surfaces on which true structure can be mapped. Inasmuch as these two deposits are the thickest and most extensive of the Elk Point salts, and hence most favorable for development, only they are presented on structure maps — upper Lotsberg Salt in figure 11 and Prairie Evaporite Salt in figure 12, representing the lower and upper Elk Point Subgroups respectively.

The structure pattern is virtually the same on both surfaces. The upper Lotsberg Salt has a slightly gentler dip, but the discordance is barely perceptible. Over most of the area the structure is that of an undisturbed homocline with a slope of 20 feet per mile in the northeast increasing to about 40 feet per mile in the southwest. The only deviation from this regional dip, apart from minor irregularities, is found along the eastern (solution) edge of both deposits, where solution and removal of salt has effected a flattening or reversal of dip along a band about 20 miles wide.

The structure data presented above have been combined with topography in figures 13 and 14 to show the depths of the two salt units below ground surface. Figure 13 is a depth-contour map to the top of the upper Lotsberg Salt, and figure 14 to the top of the Prairie Evaporite Salt. The depth to Prairie Evaporite Salt (the shallowest deposit) ranges from 700 feet at Fort McMurray to about 6,000 feet at Edmonton. The upper Lotsberg Salt is about 600 feet deeper at Edmonton, and due to a slight divergence of the two surfaces northeastward, about 1,000 feet deeper near the eastern margin of the Prairie Evaporite Salt.

ORIGIN OF THE SALT DEPOSITS

All major rock salt deposits have originated by precipitation from sea water, concentrated by evaporation in embayments partly or wholly cut off from the ocean. The simplest and perhaps most common form of cut-off occurs when differential downwarping within an embayment creates a basin isolated by a sill, i.e. a tract of the sea floor adjoining the ocean that does not subside but remains as a shallow barrier to free circulation of sea water between the ocean and the basin. A barrier also can be formed by a bar or reef, and if climatic conditions in the basin are such that the evaporation rate exceeds rainfall plus terrestrial run-off, an environment for the deposition of evaporites is created.

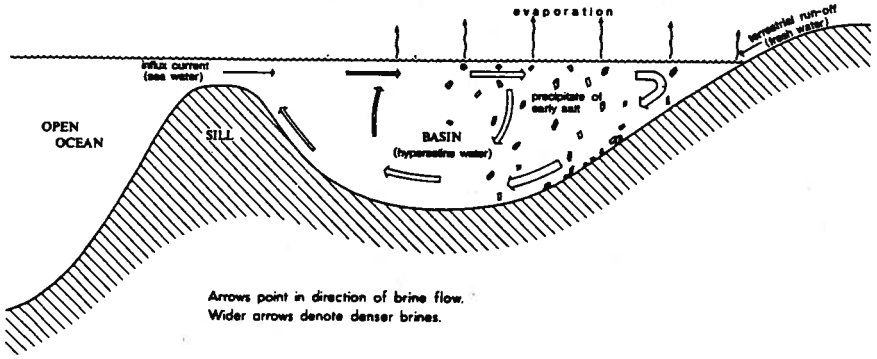


FIGURE 15. Simplified model of evaporite basin in early stage of development.

In the generally accepted evaporite model a continuous or intermittent influx of sea water across the sill replenishes water lost to the atmosphere (see Fig. 15). As evaporation proceeds, the concentration of dissolved salts increases on the surface to form denser brines, which then sink, and are prevented from returning to the ocean by the sill. Gradually, the basin brines become more saline, and salts begin to precipitate in a definite order dependent on the solubility product of each salt. Calcium carbonate and calcium sulfate are the first precipitates, followed by sodium chloride, and finally by magnesium and potassium salts. In nature, however, evaporite deposition is never undisturbed, and the observed successions of evaporites in many areas invariably indicate many interruptions and reversals in the progressive concentration of sea water. Furthermore, in nature the evaporite cycle rarely goes to completion (with dessication of the isolated sea), so that deposition of late-forming magnesium and potassium salts other than in trace amounts is quite rare.

The origin of Elk Point salt deposits conforms broadly with the general case described above. The depositional history of the Elk Point Group has

been discussed by many authors, and a summary of this history as it affected salt deposition is given below. Additional detail can be found in publications by Pearson (1963), Grayston *et al.* (1964) and Schmalz (1969).

Deposition of Elk Point sediments began in early Middle Devonian time with encroachment from the north of a sea — an extension of the boreal ocean — southeastward onto the emergent Interior Plains region. The "Basal Red Beds", a transgressive unit of clastic debris the red color of which reflects shallow water and oxidizing conditions, was the first deposit of this sea. The southward advance of the sea was halted about midway down Alberta and Saskatchewan by the northwest-facing Meadow Lake Escarpment (Figs. 1 and 5), a prominent topographic feature of that time marking the edge of a vast plateau area to the south that remained emergent throughout most of the lower Elk Point depositional period. The sea also spread westward in its advance and encroached upon the western borderland in two separate parts of Alberta as a result of relative downwarping to create two distinct subbasins. The first of these westward extensions was into central Alberta (the area of study in figure 1) where a thick accumulation of Lotsberg salts was received. A later extension into northern Alberta deposited Cold Lake Salt there as well as in the central Alberta subbasin. Although in figure 1 the two areas of lower Elk Point salt deposition are shown as separate, they are interpreted to have been connected via the main seaway lying to the east, for which all depositional record has been eroded.

The highly saline conditions of salt deposition resulted from restricted circulation between the boreal ocean and the lower Elk Point sea. The restrictive barrier, situated far to the northwest, is of uncertain nature and origin — probably a shallow sill between the basin and the ocean that became effective as a barrier following "Basal Red Beds" deposition. Salt accumulated under essentially constant conditions throughout Lotsberg time with only one major interruption: when clastic sedimentation predominated between the depositional intervals of lower and upper Lotsberg Salts.

A second evaporite cycle in early Elk Point time is indicated by carbonate and anhydrite deposits of the Ernestina Lake Formation, representing the early stages of the cycle when a sudden downwarp caused breaching of the barrier and freshening of the hypersaline water in the basin. However, hypersalinity subsequently was restored, and Cold Lake Salt was deposited to mark the end of salt deposition in early Elk Point time.

Lower Elk Point salts are associated closely with clastics having red bed characteristics suggestive of a shallow water, oxidizing environment (Schmalz, 1969, p. 819) in which the deposition of salt generally kept pace with subsidence and gave rise to widespread salt-flat conditions. At times

clastic material from the western borderland was swept into the basin to become thoroughly interspersed with the accumulating salt or, in rare instances, to replace salt deposition altogether.

The abnormally low bromine content of lower Elk Point salts (Wardlaw and Watson, 1966) indicates that at some point in their post-depositional history they were dissolved and redeposited *in situ* by fresh water. The time and the actual mechanics of this event are uncertain at best, and in fact several cycles of solution-deposition may be involved, but the event appears to have occurred before deposition of the overlying Prairie Evaporite Salt (*ibid.*, p. 271) and almost certainly the recycling water was initially fresh.

Following deposition of Cold Lake Salt, regional tectonic subsidence occurred over the Interior Plains, causing extensive flooding and a return to normal marine conditions. Thus began the third major evaporite cycle of Elk Point time with deposition of Contact Rapids sediments over the Cold Lake Salt. A gradual increase in water depth concomitant with subsidence is reflected in a change from red bed characteristics of the basal Contact Rapids upwards into dark grey and green mudstones, the first indications of widespread reducing conditions during Elk Point deposition (Schmalz, *op. cit.*, p. 819). By the end of Contact Rapids deposition, the sea had transgressed to its maximum limit, over the Meadow Lake Escarpment, and southeastward across the plateau area of Saskatchewan and beyond. In this vastly expanded sea a lengthy period of Winnipegosis carbonate deposition followed, with vigorous biologic activity giving rise to extensive reef banks within and around the margins of the basin. Thick biohermal reefs developed in places on these banks, flourishing particularly on the northwest flank of the basin where a coalescing series of bioherms gradually formed a barrier across northwestern Alberta between ocean waters and waters of the Elk Point sea. Eventually this barrier — the Presqu'ile reef complex — created the evaporitic conditions associated with Prairie Evaporite salt deposition.

The environment of Prairie Evaporite deposition generally is interpreted as one of deep water, the basin initially filled with brine to a depth at least as great as the thickness of evaporites (see Wardlaw and Schwerdtner, 1966, p. 340-1), which along the central axis of the basin ranges from 600 to 1,000 feet. As the brines underwent progressive concentration, the basin rapidly filled with evaporites and the brine depth decreased accordingly until with dessication this evaporite cycle essentially came to completion. The succession of evaporites, although showing many irregularities, broadly consists of basal dolomite and anhydrite passing upward into a thick section of halite, the upper part of which contains variable proportions of potash minerals. A lateral progression in salinities across the basin also is evident in the gradation from anhydrite deposition in northwestern Alberta to salt

in east-central Alberta and Saskatchewan (see Fig. 10), with the potash salts of Saskatchewan reflecting extreme salinities at the basin center.

With fill-up of the basin completed, shallow-water conditions again prevailed. The restrictive barrier was effectively destroyed, and an incursion of marine waters gave rise to red bed-carbonate sediments of the Dawson Bay Formation. A brief period of emergence followed, during which the brackish clastic sediments of the "First Red Beds" — Watt Mountain interval were deposited over the basin to mark the end of Elk Point deposition.

Elk Point salt deposition is generally believed to have extended much farther east than the present limit shown in figure 1. However, the original extent is not known because erosion and subsurface solution of the salt have destroyed the sedimentary record. Salt solution has been discussed at length by several writers, mainly with regard to local features in Saskatchewan and the unusual structural phenomena that have resulted from different times of solution (see Gorrell and Alderman, 1968, p. 301-12; Holter, 1969, p. 49-56). In Alberta, the effects of post-burial solution of Elk Point salt are mainly regional, and regional solution appears to have occurred mainly in a single episode coincident with pre-Cretaceous erosion. This episode began near the end of Carboniferous time — long after burial of the salt deposits — with regional uplift over the Interior Plains and tilting of the Carboniferous and older (including Elk Point) strata gently westward. The erosion that followed lasted over most of the region until Early Cretaceous time, resulting in truncation and partial removal of the tilted strata over a vast area east of their present limits. While this subaerial erosion was taking place, the soluble salt beds of the Elk Point Group underwent leaching at the surface and for a considerable distance downdip beneath overlying strata by surface and underground waters. Some salt leaching undoubtedly went on before and has continued since, but the bulk of it occurred during this period, causing the salt edges to recede basinward to their present positions, which in Alberta demarcate the very abrupt eastern termination of all the salt deposits except the lower Lotsberg.

RECOVERABILITY

Rock salt can be recovered by conventional underground mining or by solution mining methods. The latter is more commonly used, at least in Canada, where the majority of salt deposits are too deep for practical underground mining. In east-central Alberta the minimum depth at which salt is found is about 700 feet (at Fort McMurray — see Fig. 14); at this depth the salt could well be considered for underground mining. Elsewhere in the area, however, the depths are such that solution mining is the only practical method of recovery. This is especially true for the southern half of the study area, where the shallowest salt deposit ranges in depth from 2,500 to 6,500 feet (Fig. 14).

Solution mining has advantages over the conventional underground method quite apart from the fact that it permits recovery of salt from practically any depth. It is a simple operation, requiring only a substantial source of water along with the standard surface plant facilities. The basic technique involves drilling a well into the salt, lining the borehole with casing to the top of the salt bed, and running tubing inside the casing to the bottom of the salt interval to be mined. Water is then pumped down the tubing to dissolve the salt *in situ* and carry it up the annulus to the surface as brine. The technique varies among different operators, and several modifications have been developed over the years to improve the efficiency of salt recovery[1], although the principle essentially is unchanged. Few technical problems are encountered, and the maintenance involved in brine wells generally is minimal. The salt is recovered as brine, in which form it is used directly in its primary industrial applications, or the salt may be crystallized out of the brine by standard evaporation techniques. Solid salt recovered in this manner is very pure — generally much more so than conventionally mined rock salt, the purity of which depends to a greater extent on the purity of the deposit in place.

Inasmuch as the salt deposits throughout most of east-central Alberta are recoverable only by solution mining, it is essential that they be considered from the standpoint of "brinability". Clearly, no matter what the total thickness of salt at a given locality may be, if the salt beds are intercalated with beds of anhydrite, shale, or dolomite in such a manner as to prevent the proper development of a solution cavity, the salt may not be effectively recovered by brining. All salt formations commonly include

[1] A relatively recent advancement in solution mining is the hydraulic fracture-connected well system, in which two or more brine wells are connected underground through the salt layer along a hydraulically initiated fracture. Connected wells are operated as a unit, the water injected into one well and the brine recovered from the other(s). This method, now almost universally practised, results in greatly improved efficiency of recovery over the single well method of brining, while yielding a fully saturated brine from the outset of production.

some non-salt strata, and the proportion and thickness of these insoluble beds will determine whether the entire salt section or even a portion of it is brinable (i.e. suitable for solution mining as a unit interval).

Little concrete information is available on what thickness of non-salt interbeds can be tolerated in the brining of a salt section. However, the consensus of most operators is that any insoluble layer thick enough — depending on its lithology — to cause a significant constriction in the wall of the solution cavity imposes a hazard to the operation of the brine well, so that dolomite or anhydrite beds thicker than about 6 feet, or shale beds thicker than 10 feet, may as the cavity develops form protruding ledges that can break off suddenly and damage the tubing to such an extent as to force abandonment of the well. Beds thinner than these thicknesses normally will slough off the cavity wall as it recedes, and settle to the bottom without causing any problem. However, if thin beds of insoluble rock are intercalated with equally thin salt beds over an interval of 10 feet or more, that interval may behave as a single insoluble stratum and form a hazardous ledge, even though the non-salt interbeds may be less than a foot thick. Thus, the nature of the interbedding is also a determining factor in the brinability of a salt section.

For the purposes of this study, and based on the foregoing considerations, a thickness of 10 feet has been assumed arbitrarily as the limit for any insoluble stratum to be included in a continuously brinable salt section. Accordingly, if a 65-foot thick section were to contain 50 feet of salt with no non-salt interbeds except for a 15-foot layer of anhydrite in the middle, only one half of the salt thickness would be considered brinable in a single brining operation, i.e. the maximum thickness of brinable salt is only 25 feet. *Brinable salt* is thus defined as the net thickness of salt beds of an interval in the evaporite succession that can be solution-mined *as a unit.*

Brinable salt thicknesses in the upper Lotsberg and Prairie Evaporite salt deposits are given by means of a color pattern in figures 7 and 9, together with isopachs of net salt in the deposit. Although at any location more than one interval of brinable salt may be present in either deposit, only the thickest interval is presented on the map, so that the color pattern relates to the *thickest* brinable salt. The color code is devised to indicate *ranges* in thickness, with successive ranges increasing in a quasi-logarithmic manner (see map legends, Figs. 7 and 9), for meaningful isopach patterns of the actual brinable salt thickness would be impossible to construct.

The two remaining Elk Point salt deposits, lower Lotsberg and Cold Lake, have not been mapped in terms of brinability. Their net salt thicknesses also can be considered brinable thicknesses because of the virtual absence of non-salt interbeds over much of their extent. For this reason, and also because both deposits are thinner and less extensive than the

others (and probably less likely to be exploited), it is unnecessary to present brinable salt maps for these deposits.

The minimum thickness of brinable salt required for a successful brining operation depends on plant capacity and on the brining technique employed. Generally a salt bed less than 20 feet thick can be considered too thin for practical brining, at least by the single well method, because the shape and small size of the solution cavity would bring only a small area of salt in contact with the brine water. Difficulty would be encountered in achieving full saturation except by extremely slow circulation. In practice, a brinable salt should be at least 50 feet thick for a minimum-sized operation. A rule of thumb that might be used is "a minimum of one foot of salt for each ton required daily by the plant". However, if a multiple-well system is used in which the brine wells are connected underground, a lesser thickness may be acceptable, for the distance between connected wells is then added to the vertical (stratigraphic) thickness of salt to give the effective thickness of salt face exposed to the brining action.

CHEMICAL QUALITY

Data on the chemical composition of Elk Point salt deposits are given in appendices A and B. These data were obtained through chemical analyses of rock salt cores from the subject area, cores which originated largely from wildcat drilling in the late 1940's and 1950's in the search for petroleum. The cores are widely scattered, imperfectly preserved, and generally incomplete, inasmuch as their recovery often was more by accident than intent; consequently, they fail to provide for the systematic sampling required in a full evaluation of chemical quality. Nevertheless, the chemical data these cores furnish, if used in conjunction with the lithologic data interpreted from well logs, give a fair appraisal of the comparative quality of each salt deposit.

Methods of Analysis

The method of rock salt analysis used in this study is modified after analytical methods described in Kaufmann (1960, Ch. 15), in which NaCl is not determined directly but is obtained by difference after a quantitative determination of the impurities. Chip samples of rock salt cores were taken over selected intervals, crushed to pass a 40-mesh sieve, and analyzed by both water-solubility and acid-solubility methods, the former to indicate what brine composition would result from solution of the salt, and the latter to provide a complete chemical analysis of the salt including the insoluble impurities. The minerals that comprise the insoluble impurities were identified by X-ray diffraction techniques to ascertain how the chemical constituents are combined.

In the water-solubility method, determinations are made for calcium (Ca), magnesium (Mg), potassium (K), sulfate (SO_4), iron oxide (Fe_2O_3), "water insolubles", and moisture. These constituents are reported as such and in combinations as minerals in appendices A and B. NaCl is obtained by subtracting the total weight per cent of the mineral impurities from 100. The analyses were done exactly according to Kaufmann (*op. cit.*, p. 333-37) except for the constituents Mg, Fe_2O_3, and K. Mg was determined by standard EDTA titration (Rigg and Wagenbauer, 1964, p. 12, 13), or in some cases by atomic absorption with equally satisfactory results. For Fe_2O_3 the orthophenanthroline technique (*ibid.*, p. 13, 14) was used, although in all samples the amount was below the detection limit and Fe_2O_3 therefore is not reported in the water soluble analyses. K, an undetermined constituent in Kaufmann's procedure, was determined by flame photometer.

In the acid-solubility method, the salt is dissolved in dilute hydrochloric acid rather than water, so that most of the water-insoluble material also goes into solution. The same determinations are made, following the procedures in Kaufmann (*ibid.*, p. 344-49) but with the same exceptions as above. The difference in the concentrations of constituents for the two

methods establishes the composition of the "water insolubles". Acid-insoluble residue from the "water insolubles" normally is small in amount and was not chemically analyzed, although its mineral composition was determined qualitatively from X-ray diffraction powder patterns.

The mineral components of the salt are calculated[1] and reported on a dry basis in appendices A and B. Although some of these minerals are in fact hypothetical combinations of the chemical constituents, the presence of water-insoluble minerals $CaSO_4$, $CaMg(CO_3)_2$, $CaCO_3$, and $MgCO_3$ are all confirmed by X-ray identification. NaCl is determined indirectly in the water-solubility method as explained above. $CaSO_4$ is partially soluble in water and consequently appears in both water-soluble and acid-soluble constituents; however, the proportions are inconsistent so only the total amount is reported. Excess Mg and K are "leftovers" from the combining of constituents, and may in certain cases represent errors in the analyses, especially where the total exceeds 100. However, in most cases excess Mg undoubtedly comes from the clay mineral *chlorite* (an Mg, Fe, Al silicate) that was dissolved in the acid treatment (as evidenced by X-ray diffraction patterns of the water-insoluble and acid-insoluble residues). Acid-soluble iron, reported as Fe_2O_3, probably belongs mostly to chlorite as well (although traces of *hematite* [Fe_2O_3], another possible source, were detected in rare cases), and excess K may represent some partially dissolved feldspar or clay. Accordingly, the total weight per cent of the mineral components reported should always be slightly less than 100, thus providing an indication of the analytical accuracy.

Mineralogy

The mineral impurities in rock salt of the Elk Point deposits may be grouped into three categories; (1) water-soluble minerals, (2) water-insoluble minerals, and (3) the mineral *anhydrite* ($CaSO_4$), which is weakly soluble in water. The water-soluble minerals and anhydrite are the most important because it is they that determine brine quality. Water-insoluble minerals can in large part be left behind in the recovery of the salt. In a brining method of recovery they are excluded, and even where conventional underground mining is employed the salt can be selectively mined to minimize the insoluble content. In almost all the industrial applications of salt where its quality is critical, the salt is used in brine form; thus the

[1] In calculating the mineral equivalents of the chemically determined constituents, firstly SO_4 was converted to $CaSO_4$ and the unused Ca to $CaCl_2$. In a few cases where the quantity of SO_4 exceeded that needed to combine with Ca the excess was combined first with Mg to make $MgSO_4$, and the remainder (if any) converted to Na_2SO_4. Unused Mg was converted to $MgCl_2$, and K to KCl. For the water-insoluble constituents, SO_4 was converted to $CaSO_4$, and unused Ca combined with Mg to make $CaMg(CO_3)_2$; remaining Ca, if any, was converted to $CaCO_3$. Unused Mg was either converted to $MgCO_3$ (where identified by X-rays) or tabulated as excess. Excess K was tabulated.

primary consideration in an appraisal of rock salt quality is the content of soluble minerals and their effect on the chemistry of a derived brine.

Generally, the major impurity by far in rock salt deposits (according to Kaufmann, 1960, p. 188) is the mineral *anhydrite* ($CaSO_4$). This statement holds true for upper Elk Point salt, but definitely not for the lower Elk Point salts, the $CaSO_4$ content of which ordinarily is less than one tenth the normal amount. The mineral is widely distributed in halite beds as fine crystals or inclusions disseminated through the halite crystal mass. However, it is most evident and abundant as distinct beds interlayered with halite.

Anhydrite has a relatively low solubility in pure water but is considerably more soluble in NaCl brine, achieving its maximum solubility in a brine which is dilute rather than concentrated (see Kaufmann, *op. cit.*, p. 330, Fig. 2). Its solubility varies with NaCl concentration, temperature, and pressure (Blount and Dickson, 1969), and also with the amounts of other ionic impurities present in the brine (Madgin and Swales, 1956). The *rate* of solution in turn varies with the grain size and degrees of crystallinity and compaction of the anhydrite. Consequently, the $CaSO_4$ concentration in a brine derived from rock salt bears no direct nor consistent relationship to the amount present in the rock salt.

Experience in actual brining operations has shown, however, that brines from mature production wells customarily contain $CaSO_4$ in concentrations at or near its limit of solubility for the particular brine strength. Undoubtedly the explanation is the enormous size of the solution cavern and the very slow turnover of dissolving brine water, resulting in an extremely long period of contact (under considerable hydraulic pressure) between the salt section and the brine. Although the $CaSO_4$ content of halite beds may be only a fraction of its solubility limit, any anhydrite interbeds in the salt section also will be susceptible to solution as long as the brine is unsaturated with respect to $CaSO_4$.

The solubility limit of $CaSO_4$ in a fully saturated NaCl brine under normal conditions — 20 degrees centigrade and 1 atmosphere — is about 5.2 grams/kilogram H_2O (Madgin and Swales, *op. cit.*; Bock, 1961). This concentration corresponds roughly to 1.5 weight per cent of the solid salt. Most salt sections contain at least this proportion of anhydrite in combination as beds and as widely disseminated inclusions, so that if the salt is subjected to solution in a brining recovery operation, the $CaSO_4$ content of the brine eventually will come up to its solubility limit[1].

[1] Exceptions to this general rule are the extremely pure sections characteristic of many salt domes, the brines from which remain unsaturated in $CaSO_4$ indefinitely simply because it is not there to be dissolved. Similarily, salt formations with a history of depositional "recycling" could be expected to yield a low $CaSO_4$ brine, for in the course of recycling much of their normal impurity has been eliminated, including the anhydrite.

The soluble mineral impurities in the Elk Point salts as in most natural salt deposits consist mainly of chlorides of calcium, magnesium, and potassium. The first two are believed to be present as liquid inclusions of $CaCl_2$ and $MgCl_2$ in the halite crystals, representing entrapped brine from which the salt was crystallizing (Kaufmann, *op. cit.*, p. 189). Potassium is considered to be present as the mineral *sylvite* (KCI). Alternatively, these chlorides may exist in complex associations as hydrated salts or double salts; for example, traces of the mineral *carnallite* ($KCI \cdot MgCl_2 \cdot 6H_2O$) have been observed in some of the Elk Point cores. Precise mineral identification of the chloride impurities is difficult, and perhaps irrelevant, for the total content generally is less than 0.5 weight per cent in these rock salt analyses.

In addition to chlorides, water-soluble sulfates are found in some of the analyses of lower Elk Point salts. These are reported as Na_2SO_4 and $MgSO_4$, although the minerals actually present could not be identified owing to the minute amounts involved (generally less than 0.05 weight per cent). They are detected by a slight excess of SO_4 in the chemical analyses (see footnote, p. 25), an excess that is found only in lower Elk Point salts. According to Borchert and Muir (1964, p. 186), normal marine evaporites are always "sulfate deficient", meaning that the basin brines that gave rise to halite and later precipitates of the evaporite sequence were deficient in dissolved sulfate as a natural effect of the marine evaporitic environment (*ibid.* p. 73-6). This is revealed in a universal lack or shortage of Na-Mg sulfates in marine salt deposits, even though the early precipitating sulfate, $CaSO_4$, is commonly abundant. Therefore, the presence of minerals requiring a sulfate excess, however slight, is suggestive of a nonmarine environment, and supports other evidence that lower Elk Point salts are not normal marine evaporites.

The water-insoluble impurities are comprised chiefly of carbonates of probable evaporitic origin and clastic minerals of terrigeneous origin, being present as disseminated inclusions in halite as well as distinct beds. Of the carbonates, the dominant mineral is *dolomite* ($CaMg[CO_3]_2$) which is found in almost all the salt cores analyzed — in many cases as the sole carbonate impurity. The mineral *calcite* ($CaCO_3$) is virtually confined to lower Elk Point salts, and its presence seems to be characteristic of these salts. It is found consistently throughout the lower Elk Point deposits, invariably associated with dolomite, but only rarely is it detected in the upper Elk Point salt.

Among the carbonates, the mineral *magnesite* ($MgCO_3$) is least common. This mineral, though not uncommon in marine evaporites, has not been recorded previously in Elk Point evaporites to the writer's knowledge. Magnesite is restricted to the Prairie Evaporite Salt and to the upper few

feet of the evaporite section, sharing the habitat of potash salts. Thus, it would appear to be a late-forming mineral in the depositional sequence.

The clastic constituents — in the form of shale and siltstone — are represented in the analyses as the "acid insolubles" and were determined by X-ray diffraction techniques to consist mainly of quartz and clay minerals (illite and chlorite), with traces of feldspars. Commonly, the mineral *talc* (a magnesium silicate) is also detected in trace amounts in the "acid insolubles". This mineral is not considered to form part of the terrigenous clastics, and its presence in an evaporite mineral assemblage therefore is somewhat curious. Talc is recorded in evaporite deposits elsewhere, however. It apparently is widespread in evaporites of Permian age (Bailey, 1949; Stewart, 1949; Braitsch, 1962) and recently was found in Cambrian salts (Kolosov *et al.*, 1969). This report is believed to record the first finding of talc in Devonian evaporites.

Talc was detected by X-rays in about 90 per cent of the salt samples analyzed. It is present in all of the Elk Point salt deposits, but due to the minute quantities involved no attempt was made to study petrographically its mode of occurrence. However, studies made of talc in other evaporites describe it as being present in very thin plates mainly along the cleavage planes of halite crystals (Stewart, *op. cit.*, p. 666), and all who have written on the subject agree that the mineral is of secondary origin — deposited later than the salt. In all probability the talc in Elk Point salt formations has the same mode of occurrence and (secondary) origin.

Chemical Composition

In the foregoing section some differences in mineralogy were noted between salts of the upper Elk Point and lower Elk Point Subgroups, differences that have a marked effect on the relative purities of the salts as reflected in their chemical compositions. The results of the salt analyses therefore are presented separately for each subgroup.

Lower Elk Point

Chemical analyses of salt cores from lower Elk Point salt deposits (Lotsberg and Cold Lake) are given in appendix A. Cores are scarce, and complete core is available from only one location (Anglo Home C&E Elk Point No. 2; Lsd. 3, Sec. 14, Tp. 57, R. 6, W. 4th Mer.) where, unfortunately, the lower Lotsberg Salt is absent. An additional, continuous core of the upper Lotsberg Salt is available from the well, Chemcell Duvernay NaCl, in Lsd. 16, Sec. 27, Tp. 55, R. 12, W. 4th Mer. Other cores are few and of short intervals only.

The data, however limited, indicate that lower Elk Point salt deposits are all much alike chemically, and are essentially constant in composition both laterally and vertically throughout their extent. They are characterized by abnormally low concentrations of soluble impurities and $CaSO_4$, and in some analyses by an excess of SO_4 in the water-soluble fraction, indicating the unusual presence of Na-Mg sulfate minerals. The $CaSO_4$ content in most cases is less than 0.1 weight per cent, and the soluble impurities less than 0.05 weight per cent — about one tenth the amounts that might be regarded as normal for rock salt.

In figure 16 the concentrations of water-soluble Ca, Mg and K are plotted against stratigraphic position over continuous sections of Elk Point salts. The resulting profiles demonstrate the extremely low concentrations encountered throughout lower Elk Point salts, contrasting with those of the upper Elk Point (Prairie Evaporite) salt. Concentrations are given in weight per cent of water-soluble salts — i.e. on an "insolubles-free" basis — so that they also could be considered ionic concentrations of brine impurities (expressed as weight per cent of dissolved solids). The profiles thus give an indication of how brine quality might vary with selective brining of different intervals in the salt section, and what the average quality for the entire section might be.

The concentrations of soluble Mg and K in the lower salts generally are less than 0.002 and 0.005 weight per cent (as Fig. 16c shows, Mg frequently is even less than 0.001 weight per cent). The concentration of Ca is higher and tends to be rather erratic. Ca concentration is plotted separately in figure 16 by its presence (1) as highly soluble $CaCl_2$, and (2) as $CaSO_4$. The latter constituent has a limited solubility, which for an NaCl-saturated brine at 20°C amounts to a Ca concentration in the salt of 0.42 weight per cent. A vertical line plotted at this concentration in figure 16 marks the limit of solubility of Ca present as $CaSO_4$. Notwithstanding the one anomalous point which plots above the line in figure 16c, the concentration of Ca as $CaSO_4$ in lower Elk Point salts as a rule is far below this limit. In fact, in figure 16b $CaSO_4$ is not detected in many samples of that lower Elk Point salt section, thus no Ca profile is plotted. With respect to the Ca present as $CaCl_2$, the reverse situation exists between figures 16b and c. Commonly, in the latter section $CaCl_2$ is undetected, thus no profile of Ca as $CaCl_2$ is plotted. Ca concentrations in sections of the lower Elk Point salt, although consistently low, are so erratic that the profiles show no distinct stratigraphic trends.

Upper Elk Point

Chemical analyses of the upper Elk Point salt are presented in appendix B. This single deposit — Prairie Evaporite Salt — is thicker and more ex-

tensive than any of the lower Elk Point deposits. The number of analyses is greater because more cores are available. Several complete cores have been cut, and those few that are preserved in entirety were systematically sampled for analyses to provide data on *vertical* variations in chemical composition. These data are presented in figure 16, displaying variations in concentrations of the soluble impurities Ca, Mg, and K through the Prairie Evaporite salt section at different localities.

The available salt cores also include a number of short-interval "spot" cores from widely scattered localities and from all stratigraphic levels, but most commonly from the upper 50 feet of the salt section. These cores (of the upper 50 feet) were analyzed to furnish comparative data on *lateral* variations in chemical composition, the substance of which is presented in figure 17.

Upper Elk Point salt generally has a much higher concentration of impurities than do the lower salts. This can be seen in figure 16c, in which profiles of Ca, Mg and K concentrations are compared for different deposits of the same well location. In Prairie Evaporite Salt the impurities Mg and K undergo a general increase in concentration upward from minimal values at the base of the section, values which are, nevertheless, several times the average for lower Elk Point salts. The increase is considered to reflect progressive enrichment of the sea water in Mg and K during the Prairie Evaporite depositional cycle; however, because this cycle was far from an ideal evaporite cycle, the profiles are imperfect, showing several interruptions and reversals in the over-all tendency to increase towards the top of the succession. In figures 16a, d, profiles are presented for the Prairie Evaporite section at two other localities where, though even more irregular, the profiles also show a general increase upward.

The increase is best displayed in the K profile. The Mg profile and the profile for Ca present as $CaCl_2$ are considerably more irregular, influenced perhaps by sporadic precipitation of dolomite ($CaMg[CO_3]_2$), which by removing Ca and Mg ions would amplify fluctuations caused by intermittent freshening of the sea water. These two profiles tend to be subparallel, whereas the K profile behaves independently. The profile for Ca present as $CaSO_4$ is erratic, as concentrations in many cases exceed the limit corresponding to the solubility limit of $CaSO_4$ in NaCl-saturated brine.

The vertical increase in concentrations of soluble impurities is characteristic of Prairie Evaporite Salt, and is recapitulated in a *lateral* increase from the margins toward the center of the Prairie Evaporite basin (and the site of potash deposition). Figure 17 displays lateral variations of Mg and K in a 50-foot "slice" of Prairie Evaporite Salt, from minimum values in the northwest to maximum values in the southeast where potash salts are found. The slice chosen for this illustration is the upper 50 feet of the deposit, for

it alone has sufficient core data to yield a contour pattern. Presumably, a similar pattern would result for any slice of Prairie Evaporite Salt (or for the entire salt section), were sufficient data available. Inasmuch as the concentrations of impurities increase upward, those obtained in the upper 50 feet generally will be maximums for the deposit.

Discussion of Data

Significant observations on the chemistry of Elk Point salts are summarized as follows:

(1) soluble Mg and K concentrations undergo a general increase upward and also laterally southeastward in the upper Elk Point salt deposit (Prairie Evaporite Salt);

(2) both constituents are constantly low throughout the lower Elk Point salt deposits (Lotsberg and Cold Lake Salts), and lower than minimum values observed in the Prairie Evaporite Salt;

(3) Ca and SO_4 concentrations are higher in the Prairie Evaporite Salt by a factor of ten or more;

(4) lower Elk Point salts show a slight "sulfate excess" in some samples, manifested in the presence of Na-Mg sulfate minerals; Prairie Evaporite Salt is always "sulfate-deficient" (i.e. lacking in late-forming sulfates, although abundant in the early precipitate, $CaSO_4$).

These observations, together with lithologic phenomena presented in a preceding section and interpretations of geochemical trends published elsewhere[1] demonstrate that the lower Elk Point salt deposits are different in origin from the younger Prairie Evaporite Salt. The latter is a "normal", first-cycle, marine evaporite deposit, whereas the lower Elk Point salts have a complex history of solution and redeposition, at least part of which took

[1] Geochemical data concerning the distribution of bromine in Elk Point salts are summarized in the works of Wardlaw (1964, 1968) and Wardlaw and Watson (1966). Briefly, as salts are precipitated from progressively concentrated sea water, bromine ions do not form bromides but precipitate as a solid solution with chlorides. The ratio of bromine entering the chloride precipitate to bromine present in the parent brine is a constant and, for all chlorides, less than 1. Thus, as chloride precipitation proceeds, the brine is enriched in bromine, which is reflected by progressive enrichment of bromine in the precipitating chloride. The first chloride (halite) to crystallize has a fixed minimum bromine content. Succeeding halite will have increasingly more. However, if the halite subsequently is dissolved and reprecipitated, the bromine content is much reduced — all the more so if the dissolving water is fresh. Bromine profiles of the Prairie Evaporite Salt indicate it to be a more or less normal, primary evaporite deposit of marine brines. However, in the lower Elk Point salts the bromine content is so low that recycling by fresh waters is inherent in their origin.

place in nonmarine waters. This recycling had the effect of refining and purifying lower Elk Point salts to a large degree, to give them a definite increase in quality over the Prairie Evaporite Salt.

Figure 17 indicates that in Prairie Evaporite Salt the salt quality with respect to Mg and K improves northwestward and at its optimum (in the Athabasca-Slave Lake region) becomes comparable with the quality of lower Elk Point salts. However, the proportion of anhydrite and insolubles is substantially higher in the northwest (see Fig. 10), and this tends to offset the advantage of low Mg and K contents by way of (1) higher Ca and SO_4 contents, and (2) reduced recoverability. Most serious by far is the latter effect, wherein increasing numbers and thicknesses of non-salt interbeds disrupt the continuity of the salt section to an extent that "brinable" salt thickness can be reduced practically to zero. The higher content of Ca and SO_4 in fact matters little, because even in areas of minimal anhydrite content the Prairie Evaporite Salt generally contains enough to saturate a derived brine with $CaSO_4$.

The reverse situation prevails in the lower Elk Point salts. The notable lack of anhydrite interbeds throughout the extent of these deposits is reflected in chemical analyses (Appendix A), in which the $CaSO_4$ content ordinarily is found to be less than 0.1 weight per cent. This is far below the solubility limit of 1.5 weight per cent and effects a considerable quality advantage for lower Elk Point salts. The advantage is further enhanced by a lower Mg and K content throughout most of the study area, especially in the southern half (Fig. 17) where these impurities form concentrations in the Prairie Evaporite Salt many times higher than the 0.002 and 0.005 weight per cent commonly found in lower Elk Point salts.

For the primary industrial applications of salt, the critical impurities actually are Ca and Mg. These must be completely eliminated by chemical treatment of the brine, although SO_4 and K normally can be tolerated up to the levels they obtain in Elk Point salts. In this respect, upper and lower Elk Point salts are equally suitable for industrial use throughout the study area, because the Ca and Mg contents never approach quantities where removal would not be practical. However, inasmuch as the chemical treatment for removal becomes increasingly troublesome and costly with higher concentrations, the low Ca and Mg contents of lower Elk Point salts gives these deposits decided superiority as a raw material for industry.

No other soluble impurities are found in significant amounts in the Elk Point salts, with the possible exception of trace metal constituents. These are not troublesome in industrial use except in the "mercury-cell" process for caustic-chlorine generation, in which certain trace metals can be injurious if present in the salt above certain allowable limits. Trace metal constituents were determined spectrographically in a few samples and were found to be

more abundant in the "purer" lower Elk Point salts. Chromium and vanadium were detected only in lower Elk Point salts, and then only in some samples, in concentrations near the lower detection limits of 5 and 10ppm respectively. Strontium and titanium are present in all the salts but commonly in somewhat higher concentrations (up to 100ppm each) in the lower Elk Point samples. Zirconium was detected in some samples in concentrations near its lower detection limit of 10ppm, and copper, molybdenum and silver were detected as traces in all the salts. The only other trace metal detected (though in somewhat larger than "trace" proportions) is iron — essentially a water-insoluble constituent as determined from chemical analyses. (Soluble iron, a critical impurity in the major industrial applications, is below the limit of detection by chemical analysis [0.001 weight per cent] in all the Elk Point salts.)

ECONOMIC ASPECTS

History of Production

Natural salt deposits in Alberta have been exploited as far back as 1820, when the salt deposited around brine springs on Salt River in the extreme northern part of the province is recorded to have been harvested for trade (Allan, 1920, p. 92). As much as five tons of this salt were produced annually, supplying residents of the northwest (Mackenzie Basin) until recent times. The salt industry accordingly must rank as one of the oldest in Alberta.

The industry became commercially significant only after rock salt was discovered in the subsurface at Fort McMurray between 1907 and 1912. This led to the establishment in 1924 of the first commercial salt recovery plant in Alberta by a firm named Alberta Salt Company, Limited. The plant recovered salt in open grainer pans using brine from one of the discovery wells in which salt was penetrated at 1,400 feet. It operated intermittently until 1927, producing about 3,000 tons of salt, but had to close because of high transportation costs in moving the salt to railhead some eight miles away.

The railway was later extended to Waterways (about two miles out of Fort McMurray), and with further exploratory drilling a 200-foot bed of rock salt was located directly beneath railhead at a depth of 700 feet. In 1937, a salt plant was built at Waterways by a company called Industrial Minerals Limited. The plant, which recovered salt by solution mining and evaporation, was taken over the following year by Dominion Tar and Chemical Company, Limited and was operated until 1950, producing 228,000 tons of salt.

Discovery of very thick deposits of rock salt near the town of Elk Point in 1946 ultimately forced the shutdown of the Waterways plant, as a more favorably situated plant was established at Lindbergh, near Elk Point, in 1948. The firm that built and operated the plant was also named the Alberta Salt Company, and was formed by a consortium of oil companies that had discovered the salt while drilling for oil. The plant continues to operate, now under the name of the Canadian Salt Company, Limited (which purchased the Alberta Salt Company), and has undergone several expansions from its original capacity of 120 tons to the current 240 tons of salt daily. It produces evaporated salt for domestic and industrial use from brines obtained by brining a 450-foot section of Prairie Evaporite Salt at a depth of 2,600 feet.

By the early 1950's exploratory drilling for oil and gas had outlined the enormous extent of salt deposits in east-central Alberta, and in view of the general expansion of industry then taking place in the province, Western

Chemicals Limited decided to build a chloralkali plant — the first in Western Canada — to utilize the salt resources. The plant was built in 1953 at Duvernay, near the town of Two Hills, where natural gas, rail facilities, and water were available along with thick salt deposits. Its primary products were caustic soda and chlorine (generated electrolytically from salt by the "diaphragm-cell" process); it also produced muriatic acid, calcium chloride, and refined salt. Several plant expansions increased the daily capacity from an original 12 tons caustic soda and 10 tons chlorine to 85 tons caustic soda and 75 tons chlorine, for which 175 tons of salt were required daily. The salt was obtained by brining a 400-foot section of Prairie Evaporite Salt at a depth of 3,600 feet, and was used directly as brine.

In 1964, Western Chemicals was absorbed by Chemcell Limited, under whose name the plant currently operates. However, early in 1970 the electrolytic cell portion of the plant was closed, and the plant now produces or maintains facilities for producing high purity "electrolytic-grade" evaporated salt for market in the chemical and related industries. Production capacity of 300 tons daily can be met by brining a 340-foot section of upper Lotsberg Salt from a depth of 4,400 feet. The upper Lotsberg Salt is extraordinarily pure at this locality, yielding brine far superior in quality to the Prairie Evaporite Salt brine formerly used by the plant.

The most recent development of salt resources came in 1968, when Dow Chemical Company of Canada, Limited brought on stream a modern chloralkali plant at Fort Saskatchewan capable of producing 300 tons of caustic soda and of chlorine daily. At capacity the plant requires 600 tons of salt per day, obtained by brining both the Prairie Evaporite and upper Lotsberg salt deposits at depths of 5,400 and 6,100 feet. In both deposits the salt thickness is about 200 feet, with a 450-foot section of clastic and carbonate rocks between them.

The locations of currently operating salt plants are shown in figure 18. Although not mentioned in the foregoing discussion, one plant just outside the subject area at Unity, Saskatchewan has been operating since 1949. The plant produces evaporated salt for domestic and industrial use, brining a 400-foot section of Prairie Evaporite Salt at a depth of 4,100 feet. Current plant capacity is 400 tons of salt daily. The operator is Domtar Chemicals Limited (Dominion Tar and Chemical).

Salt production statistics for Alberta are given graphically in figure 19 starting from 1938 when commercial production began on a continuing basis. Yearly production is broken down into three main categories of use as indicated by the bars of the histogram (Fig. 19). The breakdown is an estimate only, based on known plant capacities and products, but it serves to compare the growth rates of these uses. Salt for other than chemical or

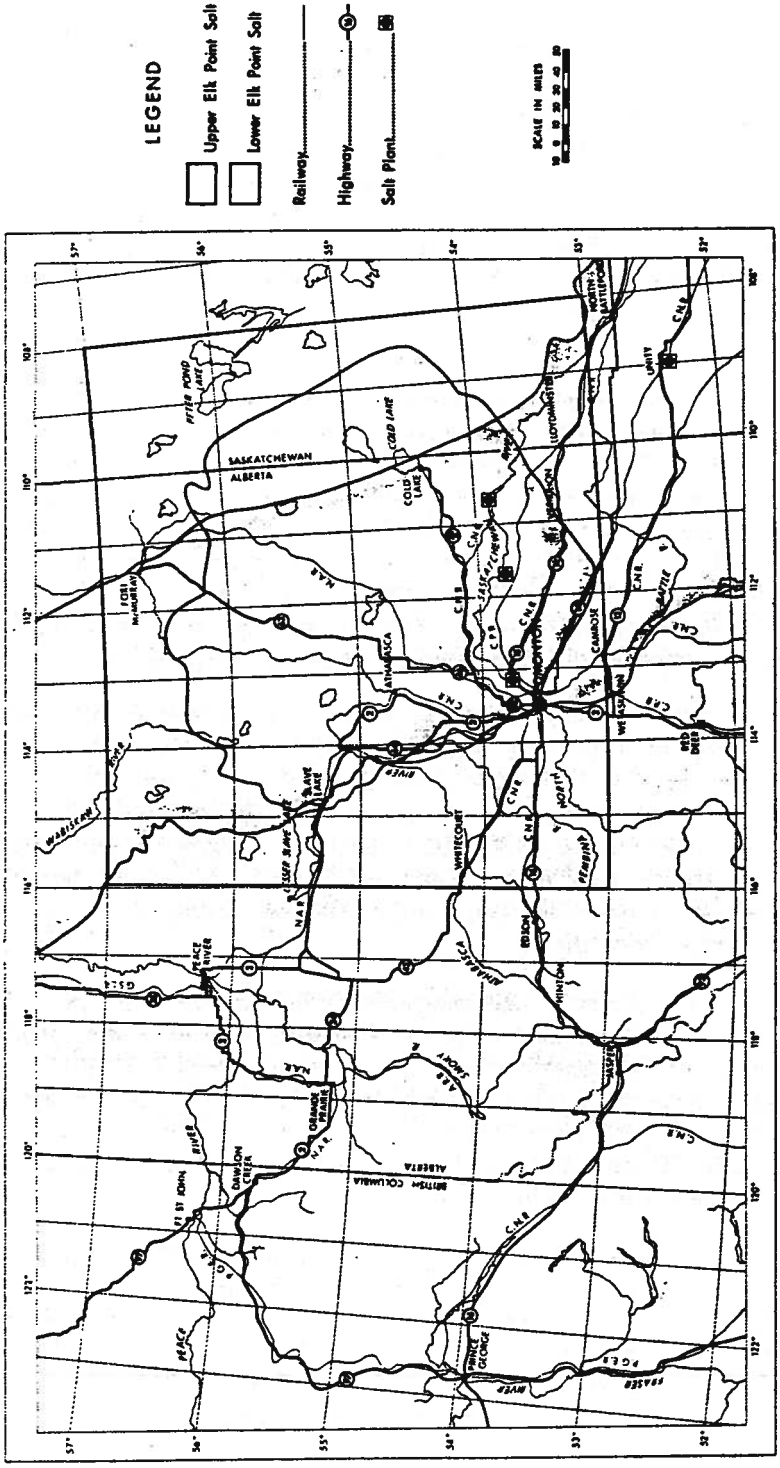


FIGURE 18. Distribution of salt in central Alberta with respect to major cities and towns, railways, main highways and surface water resources.

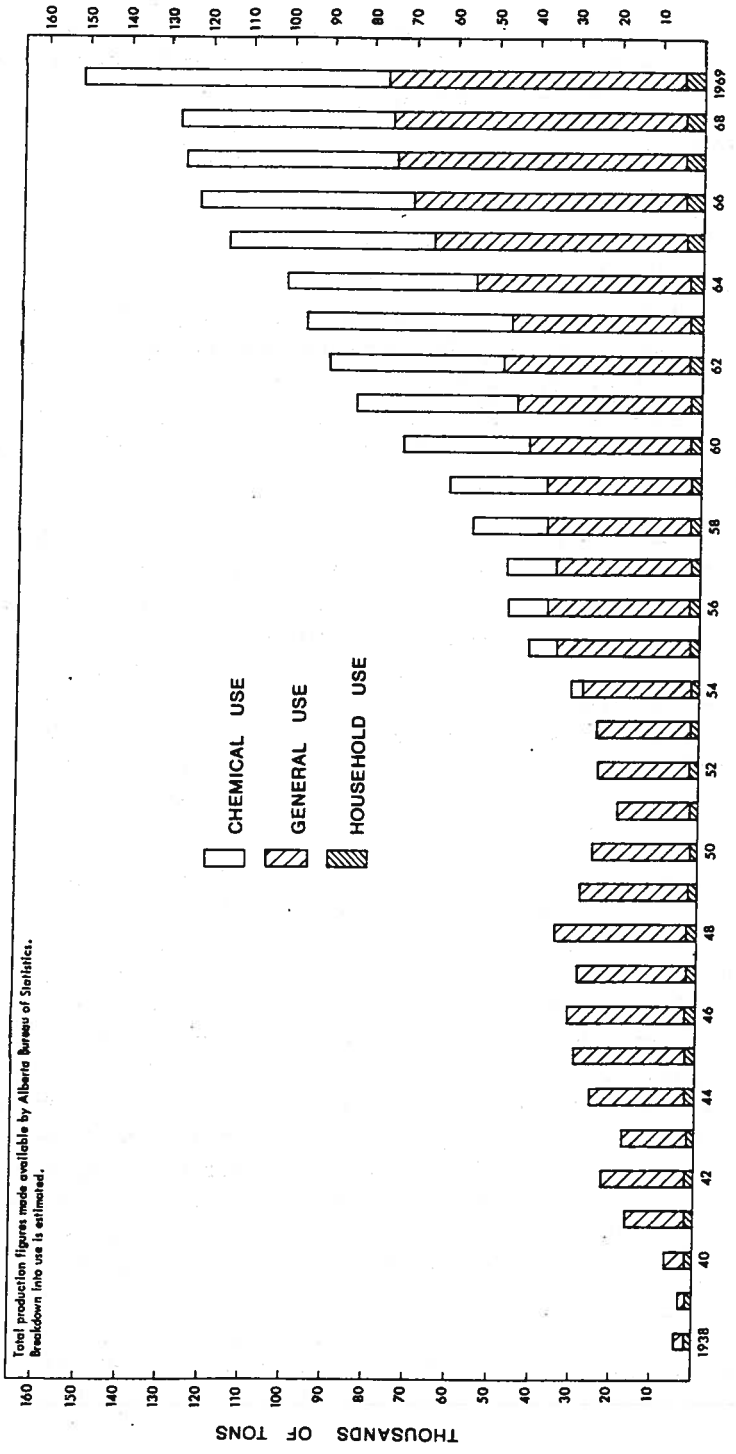


FIGURE 19. Salt production in Alberta for the period 1938-69.

household use is lumped into the category of "General Use", which includes a great variety of specific salt uses, the most important being for ice control on roads. The use of salt for de-icing came into prominence in Alberta in the early 1950's, and has steadily increased to where it currently accounts for more than half the amount of the "General Use" category.

In 1969 the production of salt in Alberta totalled 151,566 tons, valued roughly at $2.4 millions.

Future Exploitation

The salt resources of east-central Alberta are virtually unlimited. Tonnage reserves could be calculated with fair accuracy, but the figure would be astronomically high and quite useless; therefore, suffice it to say that salt is available in sufficient quantity for all of Alberta's foreseeable needs. Moreover, salt of such purity is available to meet any quality specifications now existing.

Most future exploitation of salt will continue to be by solution mining, and advancement in the technology in this field will play a major role in new developments. With more closely controlled leaching, the quality of salt brines and of salt recovered at localities where the salt section is impure could be considerably upgraded by selective solution mining. Along this line, the recovery of thin potash layers (see below) to the exclusion of unwanted soluble salts could become practicable and economically feasible, which in turn could lead to the extraction of magnesium and bromine from layers in the salt deposit rich in these elements (normally also the potash layers).

Further to the subject of potash, it was stated in a preceding section of the report that apart from traces of carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$) in the upper part of the Prairie Evaporite Salt, potash has not been observed in the study area. However, recent work by Holter (1969) indicates that the areal limit of potash mineralization in the Prairie Evaporite Formation of Saskatchewan extends a short distance into the study area in the extreme southeastern part (in Saskatchewan; see Figs. 1, 17). It does not extend into the Alberta portion of the study area, but immediately to the south of the area boundary there is some indication that potash mineralization, presently not of commercial significance, exists over a small tract of about twelve townships bordering Saskatchewan. The potash zone is 10 feet or less in thickness, almost certainly carnallitic, and deep (4,000 feet). Future potential for potash mining in Alberta[1] perhaps lies mainly in magnesium

[1] This potash potential exists solely in the Prairie Evaporite Salt. With respect to lower Elk Point salt deposits, it must be concluded on the bases of their chemistry, geochemistry and stratigraphy that no possibilities exist for potash mineralization.

extraction, inasmuch as carnallite (the suspected potash mineral) contains 30 per cent $MgCl_2$ and is a promising source of the $MgCl_2$ brine required with dolomite, the other primary raw material in the extractive process and one of abundance in Alberta.

One form of industrial utilization of salt deposits — though of indirect economic importance — is in the storage of liquified petroleum gas (LPG) and natural gas in underground salt caverns. This type of storage is likely to come into greater use in the future because of its very favorable cost advantage over surface storage ($1 to $2 per barrel compared with $20 to $25 per barrel for above-ground steel pressure tanks — Crow, 1963, p. 616). Advancement in the technology of solution mining, with more rapid and efficient development of solution cavities, will make it even more attractive in the future. Storage caverns currently are in use at two locations in Alberta, at Hardisty and at Hughenden, both just outside the south boundary of the study area.

The distribution of salt in the study area is shown in figure 18 with respect to the transportation network and surface water resources. Parts of the study area which specifically appear favorable for development of salt resources are (1) the area southeast of Lesser Slave Lake between Slave Lake and Athabasca townsites, (2) the area eastward from Edmonton to the eastern limit of salt, and (3) the area in the vicinity of Fort McMurray. The Slave Lake-Athabasca area is considered with respect to potential pulp mill markets in northwestern Alberta. The region east of Edmonton is where current developments are located, and where the deposits attain maximum thickness and purity. The Fort McMurray area is where a salt industry was first established in Alberta, which although shut down for many years has good prospects for redevelopment. Fort McMurray undoubtedly is destined to become an industrial center of the province in the foreseeable future; with a salt deposit present at depths less than 700 feet, this area is the only one in Alberta where underground mining of rock salt is practical.

With increasing industrialization of Alberta reasonably assured, the utilization of salt, a basic raw material of industry, is certain to progress at an increasing rate. At the very least, the rate of increase in production shown in figure 19 for the period 1959-69 can be anticipated for the immediate future, with the bulk of the increase resulting from expanding requirements of the chemical industry — chiefly in the fields of pulp and paper and petrochemicals manufacture.

Salt production other than for chemical use will increase as well, but likely at a lesser rate because of the limited potential for expansion of existing markets. For example, the market for road de-icing salt, which has expanded rapidly in the past decade, is now nearing saturation, and may

even show a decline should concern for environmental protection and over damage to concrete structures reflect on the use of salt on roads and its possible harm to the adjacent landscape. The salt industry, however, serves many markets in the "General Use" category, and undoubtedly will acquire others in coming years to offset the decline or loss of existing uses.

REFERENCES CITED

Allan, J. A. (1920): The mineral resources of Alberta; Res. Coun. Alberta Rept. 1, p. 87-102.

——— (1921): The mineral resources of Alberta; Res. Coun. Alberta Rept. 2, p. 102-17.

——— (1929): Salt and gypsum in Alberta; Trans. Can. Inst. Min. Met., Vol. 32, p. 232-54.

——— (1937): Salt deposits at McMurray, Alberta; Trans. Can. Inst. Min. Met., Vol. 40, p. 614-28.

——— (1943): Rock salt deposits at Waterways, Alberta; Res. Coun. Alberta Rept. 34, Pt. 2, p. 40-57.

Bailey, R. K. (1949): Talc in the salines of the potash field near Carlsbad, Eddey County, New Mexico; Amer. Mineral., Vol. 34, p. 757-59.

Blount, C. W. and F. W. Dickson (1969): The solubility of anhydrite ($CaSO_4$) in $NaCl-H_2O$ from 100 to 450°C and 1 to 1000 bars; Geochim. et Cosmochim. Acta, Vol. 33, p. 227-45.

Bock, E. (1961): On the solubility of anhydrous calcium sulphate and of gypsum in concentrated solutions of sodium chloride at 25°C, 30°C, 40°C, and 50°C; Can. Journ. Chem., Vol. 39, p. 1746-51.

Borchert, H. and R. O. Muir (1964): Salt deposits — the origin, metamorphism and deformation of evaporites; D. van Nostrand Co. Ltd., London, 338 p.

Braitsch, O. (1962): Entstehung und Stoffbestand der Salzlagerstätten; Springer-Verlag, Berlin, 232 p.

Cole, L. H. (1915): The salt deposits of Canada and the salt industry; Can. Mines Br. Rept. 325, 152 p.

——— (1948): Potash discoveries in western Canada; Trans. Can. Inst. Min. Met., Vol. 51, p. 83-99.

Crickmay, C. H. (1954): Paleontological correlation of Elk Point and equivalents; Ralph Leslie Rutherford Memorial Volume, Symposium, Western Canada Sedimentary Basin, Am. Assoc. Petroleum Geol., Tulsa, p. 143-58.

Crockford, M. B. B. (1949): Occurrences of common salt in Alberta; Res. Coun. Alberta Mimeo. Circ. 6, 17 p.

Crow, R. D. (1963): Salt cavern storage of LPG at Lowell, Michigan, and Hutchinson, Kansas; Symposium on Salt, Northern Ohio Geol. Soc., Inc., Cleveland, p. 616-20.

Gorrell, H. A. and G. R. Alderman (1968): Elk Point Group saline basins of Alberta, Saskatchewan, and Manitoba, Canada; Saline Deposits, Symposium, Geol. Soc. Am. Spec. Paper 88, p. 291-317.

Grayston, L. D., D. F. Sherwin and J. F. Allan (1964): Middle Devonian; Chapter 5 *in* Geological history of western Canada, Alberta Soc. Petroleum Geol., Calgary, Alberta, p. 49-59.

Harding, S. R. L. and H. A. Gorrell (1967): Distribution of the Saskatchewan potash beds; Trans. Can. Inst. Min. Met., Vol. 70, p. 174-79.

Holter, M. E. (1969): The Middle Devonian Prairie Evaporite of Saskatchewan; Saskatchewan Dept. Min. Resources Rept. 123, 134 p.

Kaufmann, D. W. (1960): Sodium chloride — the production and properties of salt and brine; Am. Chem. Soc. Monograph Ser. No. 145; Reinhold Publishing Corp., New York, 743 p.

Klingspor, A. M. (1966): Cyclic deposits of potash in Saskatchewan; Bull Can. Petroleum Geol., Vol. 14, No. 2, p. 193-207.

Kolosov, A. S., A. M. Pustyl'nikov, I. A. Moshkina and Z. M. Mel'nikova (1969): Talc in Cambrian salts of the Kan-Taseyevka depression; Doklady, Vol. 185, No. 1, p. 127-9.

Madgin, W. M. and D. A. Swales (1956): Solubilities in the system $CaSO_4$-NaCl-H_2O at 25° and 35°; Jour. Appl. Chem., Vol. 6, p. 482-87.

McCamis, J. G. and L. S. Griffith (1967): Middle Devonian facies relationships, Zama area, Alberta; Bull. Can. Petroleum Geol., Vol. 15, No. 4, p. 434-67.

McGehee, J. R. (1949): Pre-Waterways Paleozoic stratigraphy of Alberta plains; Bull. Am. Assoc. Petroleum Geol., Vol. 33, No. 4, p. 603-13.

Pearson, W. J. (1963): Salt deposits of Canada; Symposium on Salt, Northern Ohio Geol. Soc., Inc., Cleveland, p. 197-239.

Rigg, T. and H. A. Wagenbauer (1964): Analysis of silicate rocks: Pt. 1, Routine determination of major constituents; Res. Coun. Alberta Prelim. Rept. 64-1, 29 p.

Schmalz, R. F. (1969): Deep-water evaporite deposition: a genetic model; Bull. Am. Assoc. Petroleum Geol., Vol. 53, No. 4, p. 798-823.

Schwerdtner, W. M. (1964): Genesis of potash rocks in Middle Devonian Prairie Evaporite Formation of Saskatchewan; Bull. Am. Assoc. Petroleum Geol., Vol. 48, No. 7, p. 1108-15.

Stewart, F. H. (1949): The petrology of the evaporites of the Eskdale no. 2 boring, east Yorkshire: Pt. 1, The lower evaporite bed; Mineralog. Mag., Vol. 28, No. 206, p. 621-75.

Wardlaw, N. C. (1964): Bromide in some Middle Devonian salt rocks of Alberta and Saskatchewan; Third International Williston Basin Symposium, Billings Geol. Soc., North Dakota Geol. Soc., Saskatchewan Geol. Soc., p. 270-73.

_____ (1968): Carnallite-sylvite relationships in the Middle Devonian Prairie Evaporite Formation, Saskatchewan; Bull. Geol. Soc. Am., Vol. 79, p. 1273-94.

Wardlaw, N. C. and W. M. Schwerdtner (1966): Halite-anhydrite seasonal layers in the Middle Devonian Prairie Evaporite Formation, Saskatchewan, Canada; Bull. Geol .Soc. Am., Vol. 77, p. 331-42.

Wardlaw, N. C. and D. W. Watson (1966): Middle Devonian salt formations and their bromide content, Elk Point area, Alberta; Can. Jour. Earth Sciences, Vol. 3, p. 263-75.

Webb, J. B. (1964): Historical Summary; Chapter 16 *in* Geological history of western Canada, Alberta Soc. Petroleum Geol., Calgary, Alberta, p. 218-32.

APPENDIX A.

CHEMICAL ANALYSES

OF

LOWER ELK POINT SALT

(Concentrations expressed in weight per cent.)

Depth Interval	Moisture	Water Solubles				"Water Insolubles"	Acid Solubles					"Acid Insolubles"
		Ca	Mg	K	SO_4		Ca	Mg	K	SO_4	Fe_2O_3	
IMPERIAL ARDROSSAN NO. 1 (Lsd. 8, Sec. 17, Tp. 53, R. 21, W.4 Mer.)												
Upper Lotsberg Salt interval, 6456 to 6540 feet												
6534-6540	.011	.006	-	.007	.014	0.200	0.036	.013	.007	0.025	.004	0.070
CHEMCELL DUVERNAY NACL 16-27-55-12 (Lsd. 16, Sec. 27, Tp. 55, R. 12, W.4 Mer.)												
Upper Lotsberg Salt interval, 4395 to 4740 feet												
4403-4431	.039	.045	.001	.005	.096	2.852	0.565	.216	.010	0.191	.033	0.810
4431-4479	.034	.008	.001	.004	-	0.643	0.113	.043	.007	-	.010	0.175
4479-4541	.029	.013	.002	.004	-	3.159	0.575	.246	.012	-	.031	0.846
4541-4582	.029	.005	.001	.003	-	0.220	0.042	.016	.005	-	.004	0.068
4582-4617	.050	.041	.002	.005	.086	2.271	0.406	.182	.007	0.129	.027	0.646
4617-4638	.041	.003	.001	.003	-	0.038	0.006	.002	.004	-	.003	0.019
4638-4661	.034	.007	.001	.045	-	0.700	0.120	.056	.052	-	.015	0.207
4661-4677	.116	.036	.007	.008	.020	12.229	1.298	.765	.012	0.025	.001	6.563
4677-4708	.050	.093	.004	.006	.199	4.452	0.798	.355	.014	0.221	.057	1.588
4708-4736	.039	.006	.001	.004	-	0.532	0.090	.045	.006	-	.011	0.186
NUL FORT SASK. No. 7-10 (Lsd. 7, Sec. 10, Tp. 55, R. 22, W.4 Mer.)												
Upper Lotsberg Salt, top 6091 feet, base not penetrated												
6125-6127	.035	.004	.001	.006	-	0.460	0.080	.040	.008	-	.010	0.150
ANGLO HOME C & E ELK POINT No. 2 (Lsd. 3, Sec. 14, Tp. 57, R. 6, W.4 Mer.)												
Cold Lake Salt interval, 3554 to 3671 feet												
3554-3560	.033	.020	-	.006	.030	4.486	0.536	.296	.029	0.042	.157	1.659
3600-3610	.019	.012	.002	.005	.044	1.161	0.168	.033	.008	0.044	.016	0.679
3666-3671	.017	.008	.001	.003	.028	0.328	0.040	.010	.004	0.047	.016	0.171
Upper Lotsberg Salt interval, 3771 to 4173 feet												
3780-3790	.015	.040	-	.004	.093	3.533	0.656	.334	.015	0.167	.044	0.801
3836-3840	.017	.008	.002	.005	.038	1.377	0.232	.120	.007	0.054	.012	0.445
3875-3878	.012	.007	.001	.004	.030	0.251	0.048	.014	.005	0.054	.005	0.112
3940-3945	.027	.020	-	.006	.029	8.680	1.413	.807	.033	0.056	.117	2.212
3995-4000	.011	.009	.001	.004	.029	0.313	0.056	.017	.006	0.049	.004	0.122
4160-4163	.009	.401	-	.004	.881	5.193	1.859	.056	.008	3.614	.015	0.285
IMPERIAL GROSMONT NO. 1 (Lsd. 13, Sec. 17, Tp. 67, R. 23, W.4 Mer.)												
Upper Lotsberg Salt interval, 5519 to 5766 feet												
5536-5540	.037	.012	.005	.007	.041	3.178	0.489	.310	.013	0.099	.031	1.102
5545-5548	.025	.124	.004	.006	.272	1.651	0.481	.087	.008	0.724	.012	0.360
Lower Lotsberg Salt interval, 5957 to 6044 feet												
5957-5959	.029	.012	.002	.003	.068	4.874	0.826	.285	.012	0.068	.037	1.941
5962-5965	.016	.012	.002	.004	.054	0.197	0.040	.010	.005	0.068	.003	0.112
SOBC CALSTAN HONDO NO. 12-36-70-4 (Lsd. 12, Sec. 36, Tp. 70, R. 4, W.5 Mer.)												
Upper Lotsberg Salt interval, 6612 to 6656 feet												
6614-6615	.018	.040	.001	.014	.058	0.146	0.060	.060	.023	0.082	.001	0.092

*includes "acid insolubles" plus acid soluble Fe_2O_3

† presence confirmed by X-ray diffraction analyses of "water insolubles".

Calculated Mineral Composition (moisture-free basis)													
NaCl	$CaCl_2$	$MgCl_2$	KCl	$MgSO_4$	Na_2SO_4	†$CaSO_4$	†$CaMg(CO_3)_2$	†$CaCO_3$	†$MgCO_3$	Excess Mg	Excess K	Others*	Total
99.767	-	-	.013	-	-	0.036	0.098	.010	-	-	-	0.074	99.998
96.982	.014	.004	.010	-	-	0.271	1.631	.315	-	-	.005	0.843	100.075
99.323	.022	.004	.008	-	-	-	0.318	.090	-	-	.003	0.185	99.953
96.788	.036	.008	.008	-	-	-	1.852	.400	-	-	.008	0.877	99.977
99.756	.014	.004	.006	-	-	-	0.114	.030	-	-	.002	0.072	99.998
97.574	.014	.008	.010	-	-	0.183	1.367	.125	-	-	.007	0.673	99.961
99.944	.008	.004	.006	-	-	-	0.009	.002	-	-	.001	0.022	99.996
99.191	.019	.004	.086	-	-	-	0.418	.055	-	-	.007	0.222	100.002
87.608	.078	.027	.015	-	-	0.035	5.757	.025	-	-	.004	6.572	100.121
95.208	.028	.016	.011	-	-	0.313	2.664	.292	-	-	.008	1.646	100.186
99.439	.017	.004	.008	-	-	-	0.334	.027	-	-	.002	0.197	100.028
99.514	.011	.004	.011	-	-	-	0.296	.030	-	-	.002	0.160	100.028
95.439	.019	-	.011	-	-	0.060	2.246	.057	-	-	.023	1.817	99.672
98.767	-	-	.010	.010	.010	0.041	0.235	.262	-	-	.003	0.695	100.033
99.627	-	-	.006	.005	.007	0.054	0.068	.022	-	-	.001	0.187	99.977
96.323	.003	-	.008	-	-	0.237	2.534	.085	-	-	.011	0.845	100.046
98.577	-	-	.010	.010	.016	0.050	0.896	.055	-	-	.002	0.457	100.073
99.712	-	-	.008	.005	.013	0.058	0.097	.025	-	-	.001	0.117	100.036
91.244	.022	-	.011	-	-	0.079	6.123	.130	-	-	.027	2.330	99.966
99.644	-	-	.008	.005	.004	0.059	0.121	.032	-	-	.002	0.126	100.001
93.458	.091	-	.008	-	-	5.122	0.424	.564	-	-	.004	0.300	99.971
96.728	-	.008	.013	.015	-	0.123	2.086	-	-	.030	.006	1.133	100.142
97.905	.030	.016	.011	-	-	1.026	0.630	.077	-	-	.002	0.372	100.069
95.021	-	-	.006	.010	.046	0.041	2.148	.867	-	-	.009	1.979	100.127
99.708	-	-	.008	.010	.025	0.061	0.060	.022	-	-	.001	0.115	100.010
99.697	.044	.004	.027	-	-	0.116	0.046	-	-	.053	.009	0.093	100.089

APPENDIX B.

CHEMICAL ANALYSES

OF

UPPER ELK POINT SALT

(Concentrations expressed in weight per cent.)

Depth Interval	Moisture	Water Solubles				"Water Insolubles"	Acid Solubles					"Acid Insolubles"
		Ca	Mg	K	SO_4		Ca	Mg	K	SO_4	Fe_2O_3	
IMPERIAL IRMA NO. 1 (Lsd. 6, Sec. 14, Tp. 46, R. 9, W.4 Mer.) Prairie Evaporite Salt interval, 4294 to 4710 feet												
4335–4350	.236	.349	.051	.184	.677	4.579	0.834	.404	.180	0.732	.081	1.770
V.C.O. NO. 15 (Lsd. 6, Sec. 12, Tp. 49, R. 6, W.4 Mer.) Prairie Evaporite Salt interval, 3481 to 3903 feet												
3481–3541	.187	.351	.036	.169	.674	2.611	0.617	.250	.183	0.763	.064	1.190
BLACKFOOT DEVONIAN TEST SYNDICATE NO. 1 (Lsd. 12, Sec. 15, Tp. 50, R. 2, W.4 Mer.) Prairie Evaporite Salt, top 3365 feet, base not penetrated												
3367–3392	.143	.170	.039	.095	.352	0.713	0.261	.088	.092	0.420	.021	0.257
ANGLO CANADIAN BEAVERHILL LAKE NO. 2 (Lsd. 11, Sec. 11, Tp. 50, R. 17, W.4 Mer.) Prairie Evaporite Salt interval, 5100 to 5420 feet												
5100–5108	.144	.279	.013	.206	.619	0.593	0.296	.053	.204	0.651	.015	0.367
5152–5158	.057	.141	.008	.084	.307	0.385	0.228	.018	.082	0.493	.003	0.082
5234–5240	.081	.170	.009	.026	.351	0.387	0.228	.025	.027	0.412	.007	0.144
5293–5303	.127	.094	.015	.013	.147	0.355	0.136	.029	.014	0.190	.007	0.158
5345–5351	.170	.228	.020	.014	.427	1.067	0.349	.072	.017	0.445	.024	0.507
5406–5416	.057	.198	.005	.012	.458	0.954	0.396	.045	.013	0.605	.008	0.277
IMPERIAL ARDROSSAN NO. 1 (Lsd. 8, Sec. 17, Tp. 53, R. 21, W.4 Mer.) Prairie Evaporite Salt interval, 5782 to 6005 feet												
5790–5800	.052	.176	.013	.324	.377	1.512	0.287	.184	.343	0.456	.023	0.537
CHEMCELL CLOVER NACL NO. 10-17-53-23 (Lsd. 10, Sec. 17, Tp. 53, R. 23, W.4 Mer.) Prairie Evaporite Salt interval, 5976 to 6082 feet												
5986–5987	.057	.701	.014	.014	1.576	3.337	1.192	.330	.020	1.811	.033	1.177
5987–5991	.039	.717	.009	.016	1.637	3.521	1.355	.167	.019	2.447	.004	0.844
5992–5993	.071	.206	.011	.018	.417	6.064	0.938	.504	.028	0.459	.017	2.501
6009–6013	.037	.156	.009	.026	.330	0.655	0.247	.077	.027	0.378	.001	0.193
IMPERIAL PINEDALE NO. 1 (Lsd. 7, Sec. 28, Tp. 54, R. 16, W.4 Mer.) Prairie Evaporite Salt, top 4537 feet, base not penetrated												
4571–4591	.144	.349	.034	.089	.713	3.862	0.780	.317	.099	0.746	.058	1.556
IMPERIAL WILLINGDON NO. 1 (Lsd. 14, Sec. 14, Tp. 55, R. 15, W.4 Mer.) Prairie Evaporite Salt interval, 4180 to 4591 feet												
4200–4219	.184	.272	.043	.219	.563	2.830	0.561	.257	.222	0.569	.051	1.145
ANGLO HOME C&E ELK POINT NO. 2 (Lsd. 3, Sec. 14, Tp. 57, R. 6, W.4 Mer.) Prairie Evaporite Salt interval, 2805–3256												
2806–2815	.147	.645	.020	.120	1.390	5.518	1.222	.383	.125	1.639	.050	2.675
2848–2853	.141	.301	.024	.035	.604	0.883	0.373	.096	.037	0.661	.019	0.423
2888–2898	.175	.329	.030	.170	.679	1.869	0.541	.190	.179	0.702	.038	0.721
2938–2948	.125	.357	.024	.067	.733	0.993	0.449	.092	.070	0.766	.020	0.454
3006–3016	.061	.261	.011	.020	.540	1.188	0.553	.021	.022	1.176	.004	0.098
3051–3056	.271	.290	.039	.030	.449	4.115	0.621	.360	.044	0.479	.090	1.952
3098–3101	.091	.186	.016	.017	.361	0.269	0.212	.030	.018	0.403	.007	0.142
3140–3144	.068	.395	.009	.011	.848	1.024	0.589	.055	.012	1.167	.015	0.306
3216–3220	.049	.391	.006	.012	.835	0.846	0.557	.041	.013	1.173	.011	0.223
3253–3256	.054	.154	.007	.009	.318	0.508	0.255	.012	.009	0.501	.005	0.186

* includes "acid insolubles" plus acid soluble Fe_2O_3.

† presence confirmed by X-ray diffraction analyses of "water insolubles".

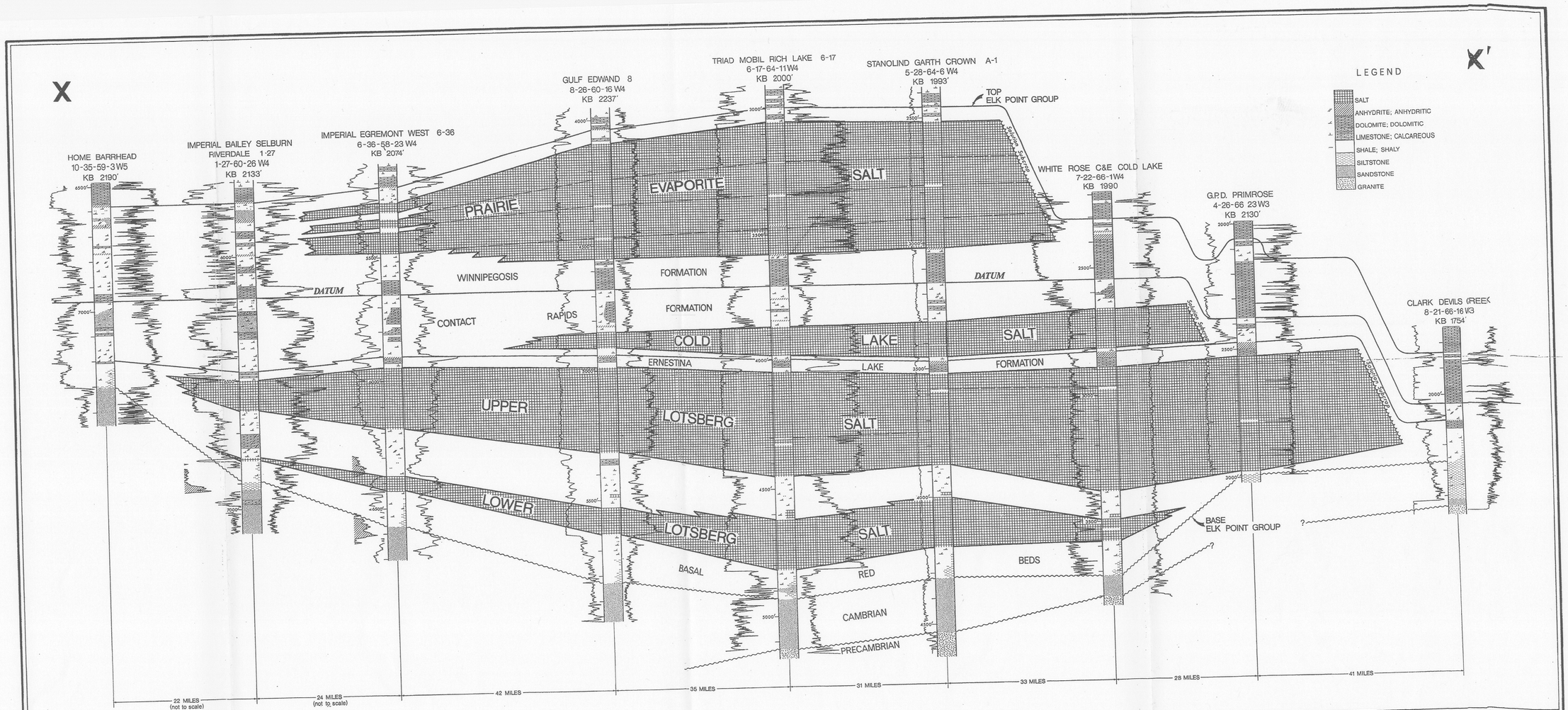
Calculated Mineral Composition (moisture–free basis)													
NaCl	$CaCl_2$	$MgCl_2$	KCl	$MgSO_4$	Na_2SO_4	†$CaSO_4$	†$CaMg(CO_3)_2$	†$CaCO_3$	†$MgCO_3$	Excess Mg	Excess K	Others*	Total
93.711	.186	.200	.352	-	-	1.039	2.130	-	-	.073	-	1.855	99.546
95.769	.194	.141	.323	-	-	1.083	1.056	-	-	.075	.014	1.256	99.911
98.387	.064	.153	.181	-	-	0.596	0.290	-	-	.011	-	0.278	99.960
98.025	.058	.051	.394	-	-	0.923	0.017	-	.132	-	-	0.383	99.983
98.952	.036	.031	.160	-	-	0.699	0.040	-	-	.005	-	0.085	100.008
98.964	.066	.035	.050	-	-	0.583	0.121	.017	-	-	.001	0.151	99.988
99.261	.091	.059	.025	-	-	0.269	0.106	.002	-	-	.001	0.165	99.979
98.081	.138	.078	.027	-	-	0.632	0.396	.067	-	-	.003	0.532	99.954
98.334	.019	.020	.023	-	-	0.857	0.303	.177	-	-	.001	0.285	100.019
97.231	.053	.051	.618	-	-	0.646	0.358	-	.430	-	.019	0.560	99.966
94.225	.119	.055	.027	-	-	2.568	1.809	-	-	.078	.006	1.211	100.098
93.997	.094	.035	.031	-	-	3.469	1.198	.100	-	-	.003	0.848	99.765
93.174	.089	.043	.034	-	-	0.651	3.287	-	-	.060	.010	2.520	99.868
98.742	.050	.035	.050	-	-	0.536	0.327	-	-	.025	.001	0.194	99.960
94.673	.144	.133	.170	-	-	1.059	1.922	-	-	.030	.010	1.616	99.757
95.676	.102	.168	.419	-	-	0.808	1.317	-	-	.041	.003	1.198	99.732
92.013	.180	.078	.229	-	-	2.326	2.180	-	-	.076	.005	2.729	99.816
97.961	.136	.094	.067	-	-	0.938	0.221	-	-	.043	.002	0.443	99.905
96.595	.127	.117	.324	-	-	0.997	0.933	-	-	.037	.009	0.760	99.899
97.602	.141	.094	.128	-	-	1.087	0.358	-	-	.021	.003	0.475	99.909
97.865	.100	.043	.038	-	-	1.667	0.075	.027	-	-	.002	0.102	99.919
94.740	.286	.153	.057	-	-	0.681	1.467	-	-	.128	.014	2.047	99.573
99.026	.097	.063	.032	-	-	0.573	0.037	-	-	.009	.001	0.149	99.987
97.602	.114	.035	.021	-	-	1.655	0.281	-	-	.009	.001	0.321	100.039
97.805	.119	.023	.023	-	-	1.663	0.115	-	-	.020	.001	0.234	100.003
98.938	.058	.027	.017	-	-	0.710	0.038	.042	-	-	-	0.191	100.021

Depth Interval	Moisture	Water Solubles				"Water Insolubles"	Acid Solubles					"Acid Insolubles"
		Ca	Mg	K	SO_4		Ca	Mg	K	SO_4	Fe_2O_3	
IMPERIAL FEDORAH NO. 1 (Lsd. 13, Sec. 22, Tp. 57, R. 23, W.4 Mer.) Prairie Evaporite Salt Interval, 5558 to 5756 feet												
5605-5614	.064	.310	.006	.011	.621	1.800	0.699	.054	.018	0.714	.032	0.460
IMPERIAL CLYDE NO. 1 (Lsd. 9, Sec. 29, Tp. 59, R. 24, W.4 Mer.) Prairie Evaporite Salt interval, 5598 to 5640 feet												
5598-5606	.056	.210	-	.008	.447	2.128	0.491	.093	.021	0.512	.070	0.978
ANGELUS ASHMONT NO. 1† (Lsd. 13, Sec. 3, Tp. 60, R. 11, W.4 Mer.) Prairie Evaporite Salt interval, 3462 to 3927 feet												
3467-3475	.086	.175	.046	.026	.358	0.564	0.281	.100	.031	0.436	.003	0.213
IMPERIAL DARLING NO. 1 (Lsd. 16, Sec. 19, Tp. 62, R. 19, W.4 Mer.) Prairie Evaporite Salt interval, 4636 to 4989 feet												
4653-4663	.085	.247	.010	.020	.490	1.223	0.349	.096	.030	0.531	.032	0.535
CHRISTINA RIVER HARDY NO. 1 (Lsd. 2, Sec. 25, Tp. 77, R. 9, W.4 Mer.) Prairie Evaporite Salt interval, 1897 to 2460 feet												
1905-1975	.175	.539	.017	.025	1.134	0.897	0.721	.045	.034	1.521	.016	0.229
2152-2156	.120	.295	.015	.017	.635	0.340	0.325	.037	.017	0.694	.010	0.149
2415-2416	.063	.473	.010	.012	1.034	1.907	0.930	.040	.014	1.980	.015	0.241
BEAR VAMPIRE NO. 1 (Lsd. 7, Sec. 28, Tp. 87, R. 12, W.4 Mer.) Prairie Evaporite Salt interval, 1293 to 1881 feet												
1369-1371	.076	.441	.016	.022	.949	0.812	0.561	.080	.034	1.259	.009	0.335
1421-1424	.084	.636	.012	.017	1.424	2.782	1.102	.143	.027	2.297	.046	0.748
1489-1496	.070	.162	.004	.020	.338	0.321	0.180	.050	.023	0.374	.005	0.197
1574-1575	.113	.145	.035	.029	.220	0.199	0.210	.041	.028	0.303	.001	0.092
1646-1647	.164	.277	.033	.020	.538	0.450	0.313	.050	.020	0.616	.011	0.204
1703 (light band)	.079	.096	.012	.016	.167	0.215	0.120	.017	.018	0.237	.006	0.106
1703 (dark band)	.145	.301	.023	.018	.602	0.979	0.329	.096	.023	0.687	.039	0.805
1774-1775	.094	.411	.008	.016	.889	0.858	0.481	.042	.020	0.968	.023	0.409
1821-1822	.238	.762	.006	.017	1.714	4.568	1.857	.077	.020	4.069	.027	0.612
1877-1880	.333	.686	.004	.016	1.533	3.686	1.700	.056	.017	3.831	.003	0.086
BEAR BILTMORE NO. 1 (Lsd. 7, Sec. 11, Tp. 87, R. 17, W.4 Mer.) Prairie Evaporite Salt interval, 1788 to 2442 feet												
1817-1825	.097	.371	.022	.021	.767	1.197	0.643	.056	.023	1.256	.012	0.186
BEAR RODEO NO. 1 (Lsd. 8, Sec. 20, Tp. 89, R. 9, W.4 Mer.) Prairie Evaporite Salt interval, 625 to 834 feet												
632-653	.038	.514	.005	.007	1.087	5.797	2.049	.063	.012	4.538	.011	0.120
761-833	.066	.206	.016	.011	.433	1.992	0.850	.038	.012	1.408	.004	0.065

* Includes "acid insolubles" plus acid soluble Fe_2O_3.

† presence confirmed by X-ray diffraction analyses of "water insolubles".

Calculated Mineral Composition (moisture-free basis)													
NaCl	$CaCl_2$	$MgCl_2$	KCl	$MgSO_4$	Na_2SO_4	†$CaSO_4$	†$CaMg(CO_3)_2$	†$CaCO_3$	†$MgCO_3$	Excess Mg	Excess K	Others*	Total
97.133	.141	.023	.021	-	-	1.013	0.364	.677	-	-	.007	0.492	99.871
97.156	.066	-	.015	-	-	0.725	0.705	.252	-	-	.013	1.049	99.981
98.625	.072	.180	.050	-	-	0.619	0.335	-	.035	-	.005	0.216	100.137
97.885	.119	.039	.038	-	-	0.753	0.392	-	-	.034	.010	0.567	99.837
97.194	.183	.067	.047	-	-	2.159	0.097	-	-	.015	.009	0.245	100.016
98.584	.083	.059	.032	-	-	0.985	0.023	-	-	.019	-	0.159	99.944
96.448	.116	.039	.023	-	-	2.807	0.227	.032	-	-	.002	0.256	99.950
97.611	.125	.063	.042	-	-	1.785	-	-	-	.064	.012	0.344	100.046
95.001	.116	.047	.032	-	-	3.258	0.469	-	-	.069	.010	0.795	99.797
99.087	.058	.016	.038	-	-	0.530	0.014	-	-	.044	.003	0.202	99.992
99.149	.147	.137	.055	-	-	0.430	0.046	.050	-	-	-	0.093	100.107
98.471	.147	.129	.038	-	-	0.871	0.014	-	-	.015	-	0.215	99.903
99.397	.072	.047	.031	-	-	0.336	-	-	-	.005	.002	0.112	100.002
97.903	.138	.090	.034	-	-	0.974	-	-	-	.073	.005	0.845	100.062
97.707	.111	.031	.031	-	-	1.373	0.169	-	-	.012	.004	0.432	99.870
92.800	.130	.023	.032	-	-	5.781	0.517	-	-	.003	.003	0.640	99.929
93.947	.127	.016	.031	-	-	5.448	0.254	-	-	.019	.001	0.089	99.932
97.446	.141	.086	.040	-	-	1.782	0.258	.030	-	-	.002	0.198	99.983
92.458	.169	.020	.013	-	-	6.433	0.437	-	-	-	.005	0.131	99.666
97.238	.069	.063	.021	-	-	1.997	0.167	.502	-	-	.001	0.069	100.027



To accompany Research Council of Alberta Bulletin 29, by W. N. Hamilton

FIGURE 4. STRATIGRAPHIC CROSS SECTION X - X'

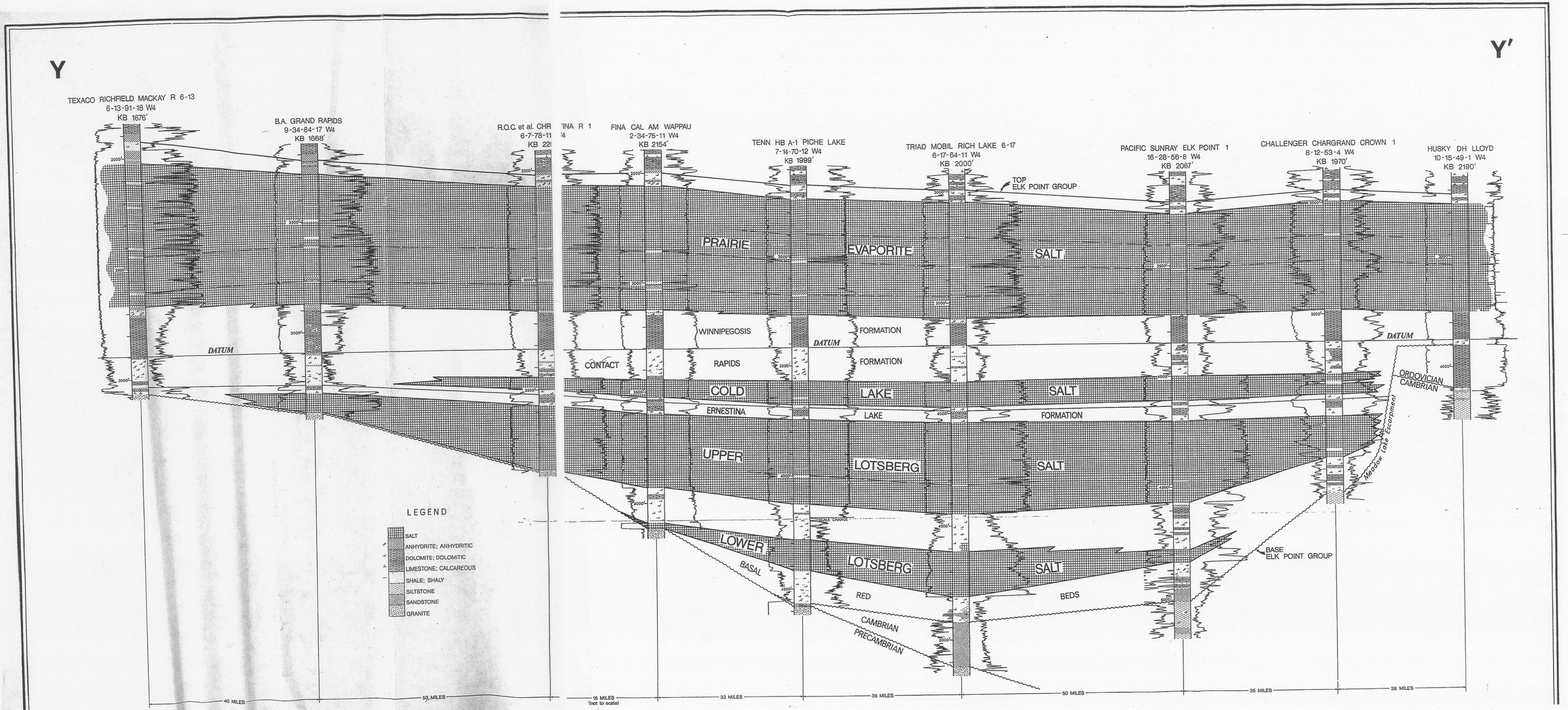
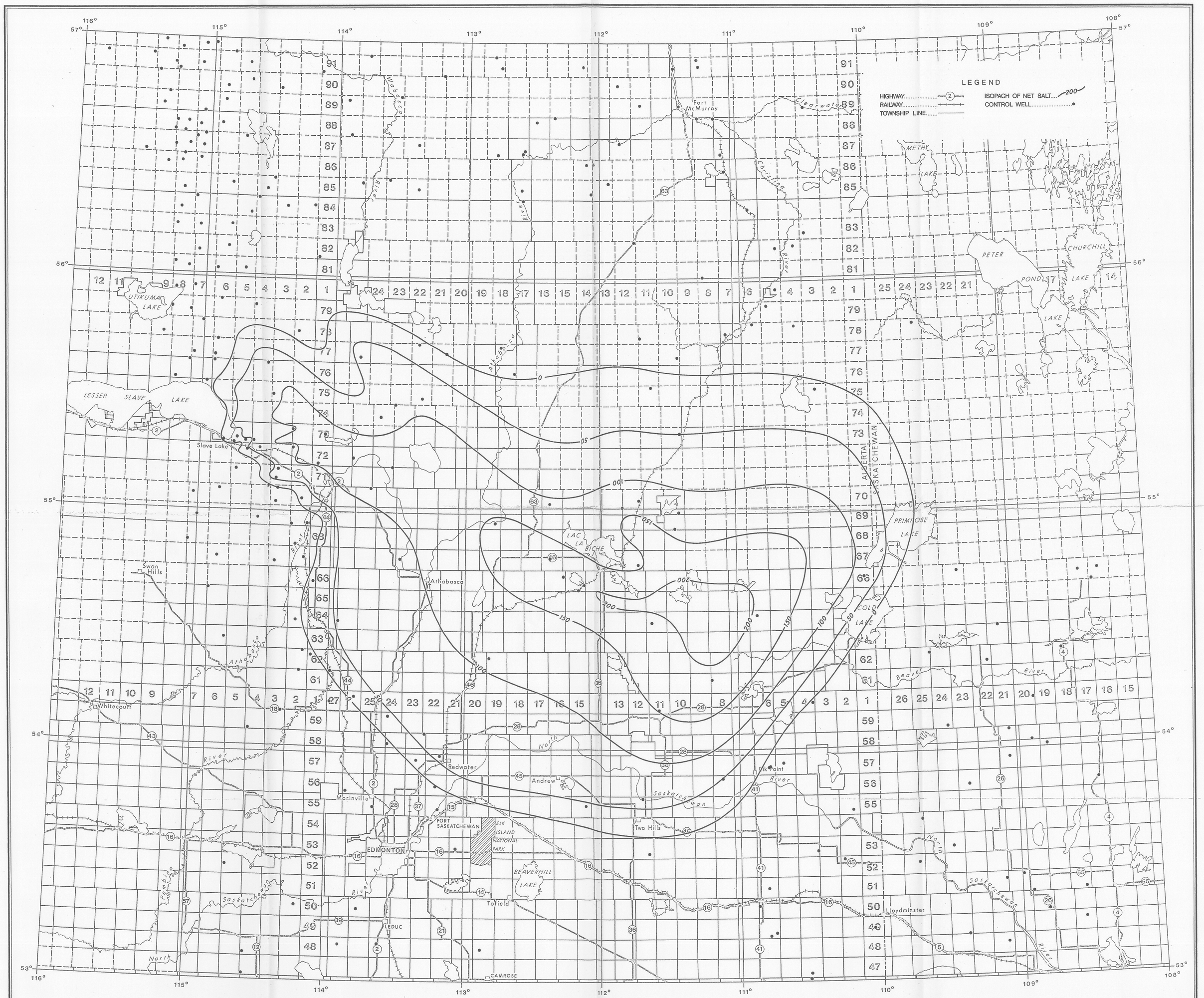


FIGURE 5. STRATIGRAPHIC CROSS SECTION Y - Y'



SCALE 1:1,000,000

1 Inch to 16 Miles Approximately

Miles 20 0 20 40 60 80

Kilometres 20 0 20 40 60 80 100 120

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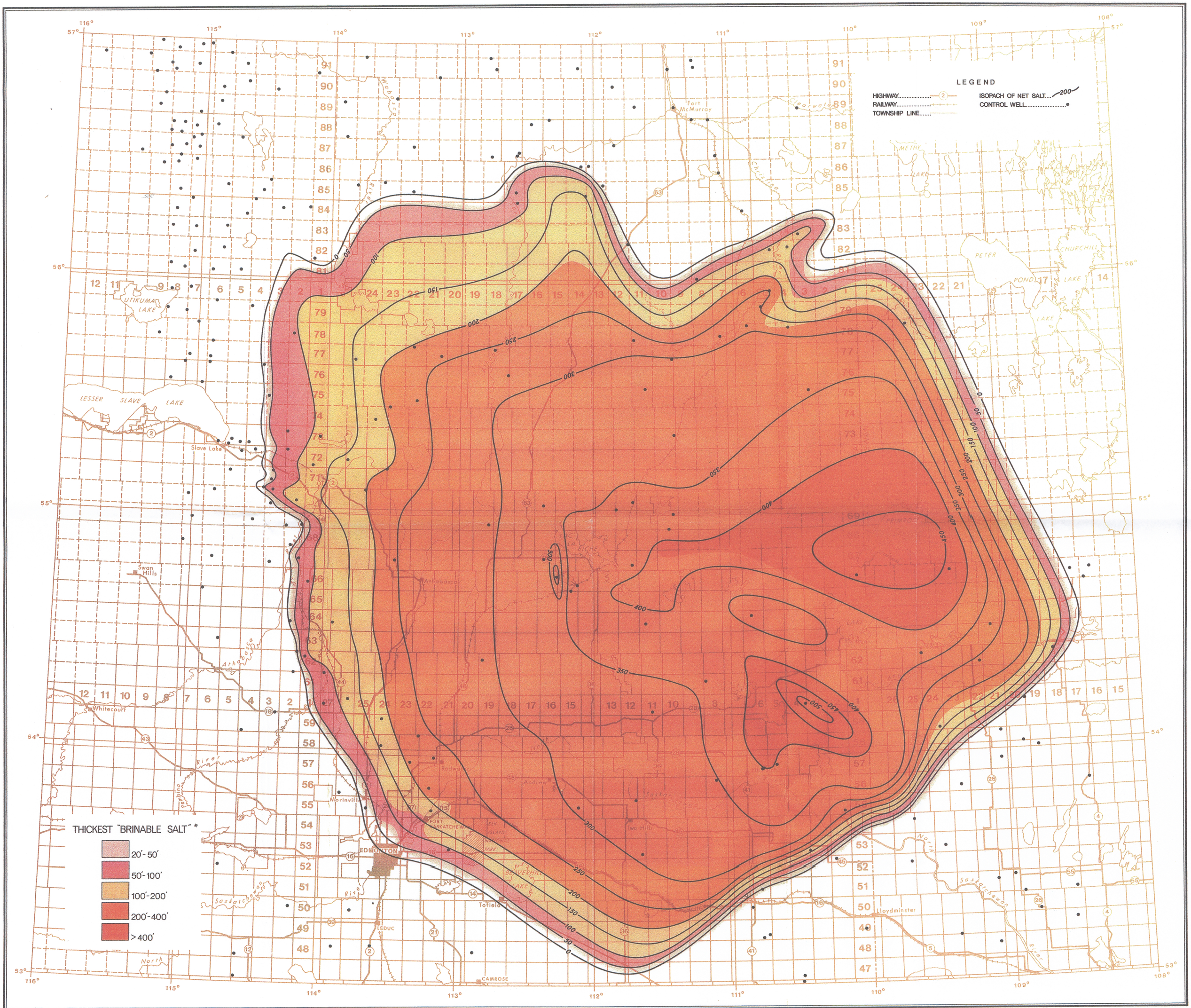
FIGURE 6. NET SALT IN LOWER LOTSBERG SALT



*"Brinable Salt" is defined as the net thickness of salt beds of an interval in the evaporite succession that can be solution mined as a unit.

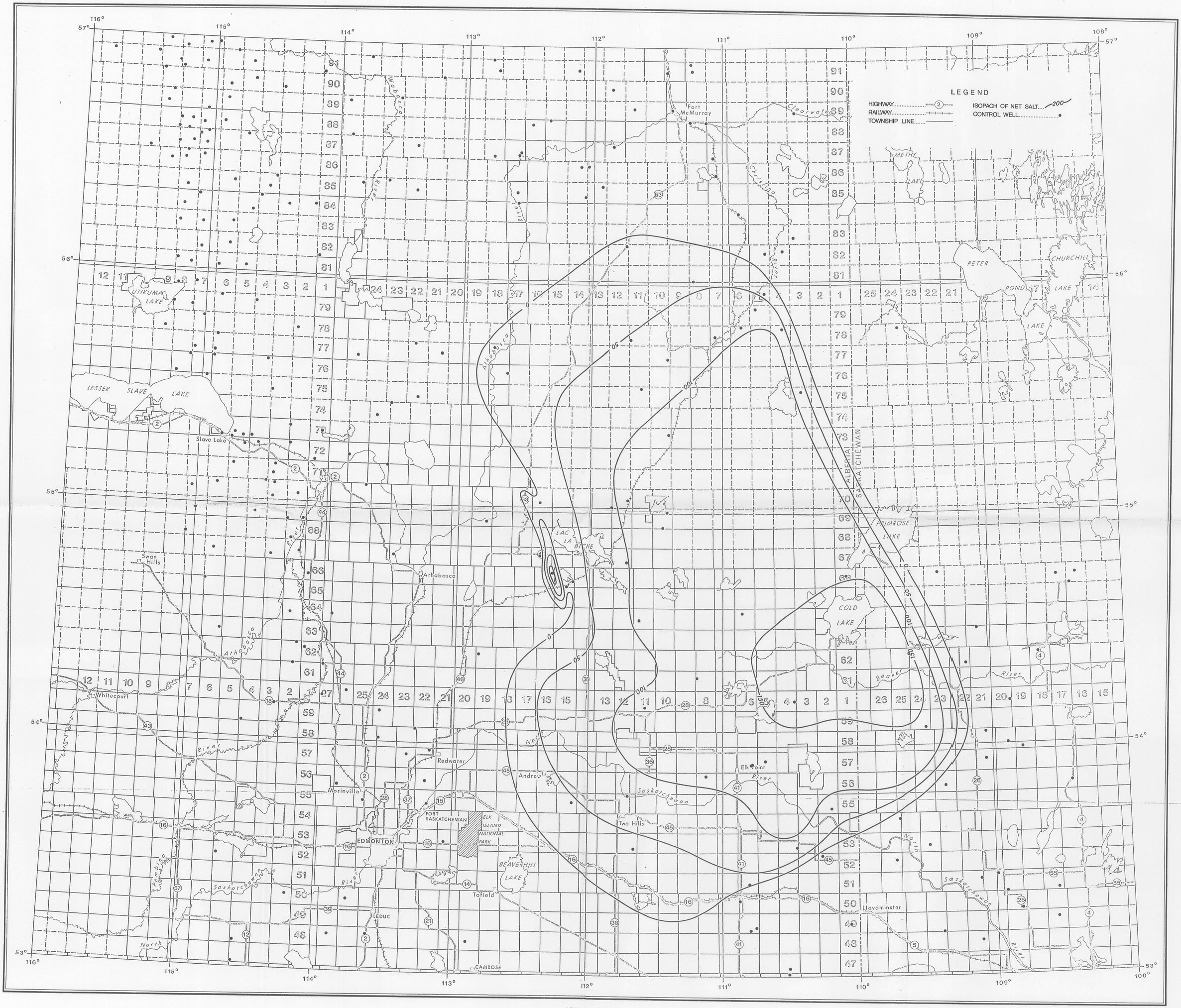
SCALE 1:1,000,000
1 Inch to 16 Miles Approximately

Miles 20 0 20 40 60 80

Kilometres 20 0 20 40 60 80 100 120

To accompany Research Council of Alberta Bulletin 29, by W. N. Hamilton

FIGURE 7. NET SALT IN UPPER LOTSBERG SALT, WITH THICKEST "BRINABLE SALT"



SCALE 1: 1,000,000
1 Inch to 16 Miles Approximately

Miles 20 0 20 40 60 80

Kilometres 20 0 20 40 60 80 100 120

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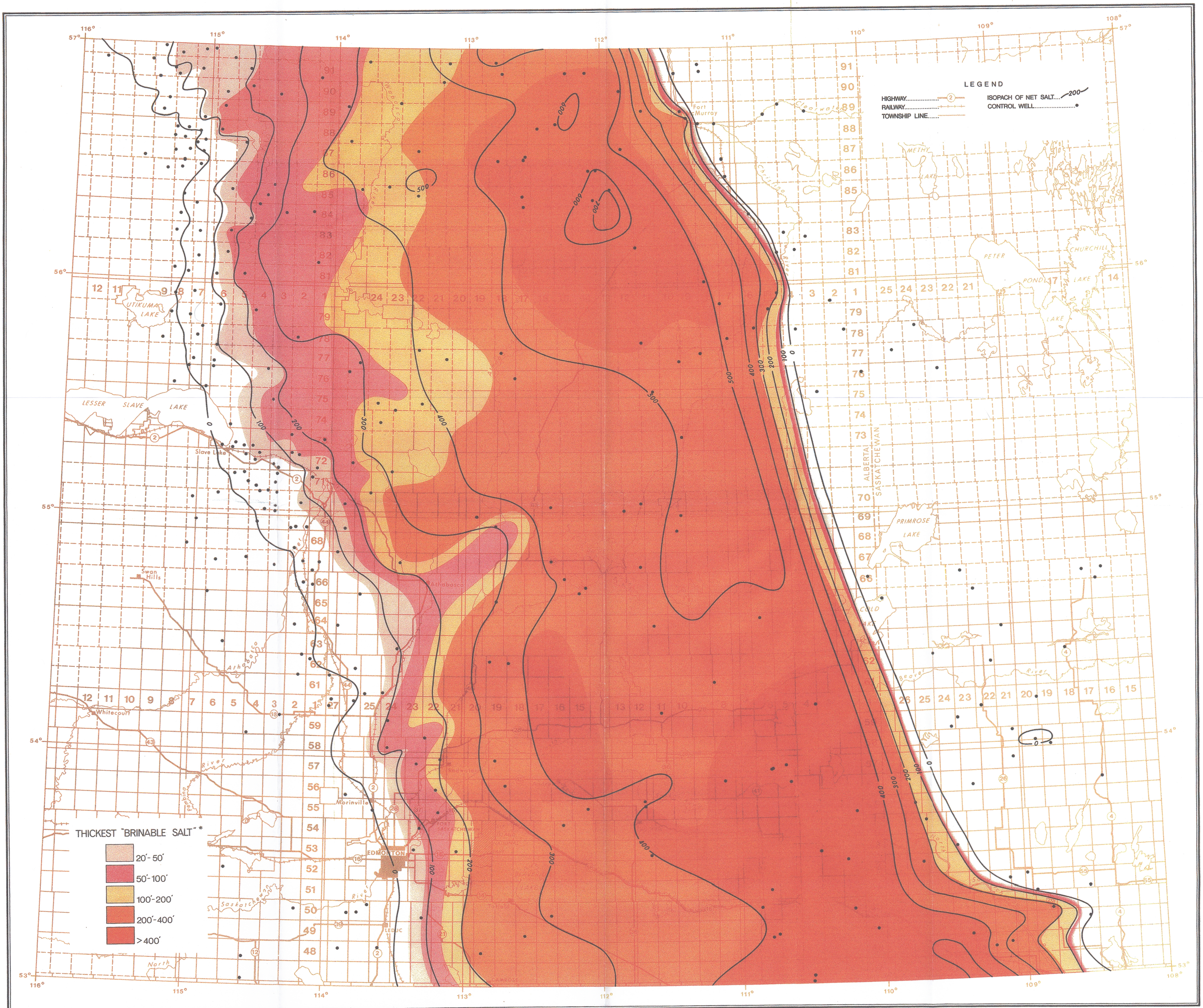
FIGURE 8. NET SALT IN COLD LAKE SALT



*"Brinable Salt" is defined as the net thickness of salt beds of an interval in the evaporite succession that can be solution mined as a unit.

SCALE 1:1,000,000
1 inch to 16 Miles Approximately

Miles 20 0 20 40 60 80
Kilometres 20 0 20 40 60 80 100 120

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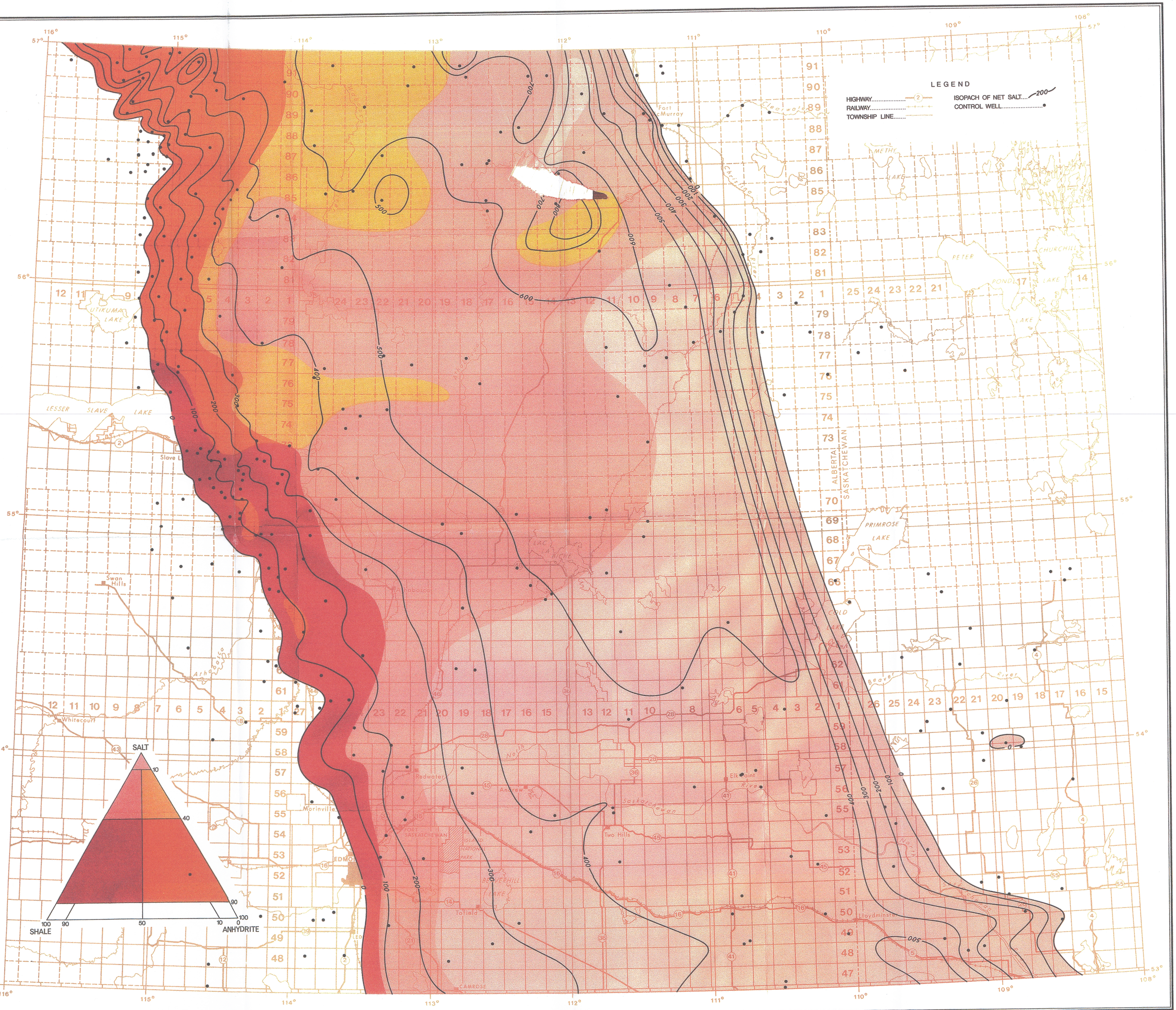
FIGURE 9. NET SALT IN PRAIRIE EVAPORITE SALT, WITH THICKEST "BRINABLE SALT"



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SCALE 1:1,000,000
1 Inch to 16 Miles Approximately

FIGURE 10. ISOPACHS AND LITHOFACIES OF THE GROSS SALT INTERVAL, PRAIRIE EVAPORITE SALT

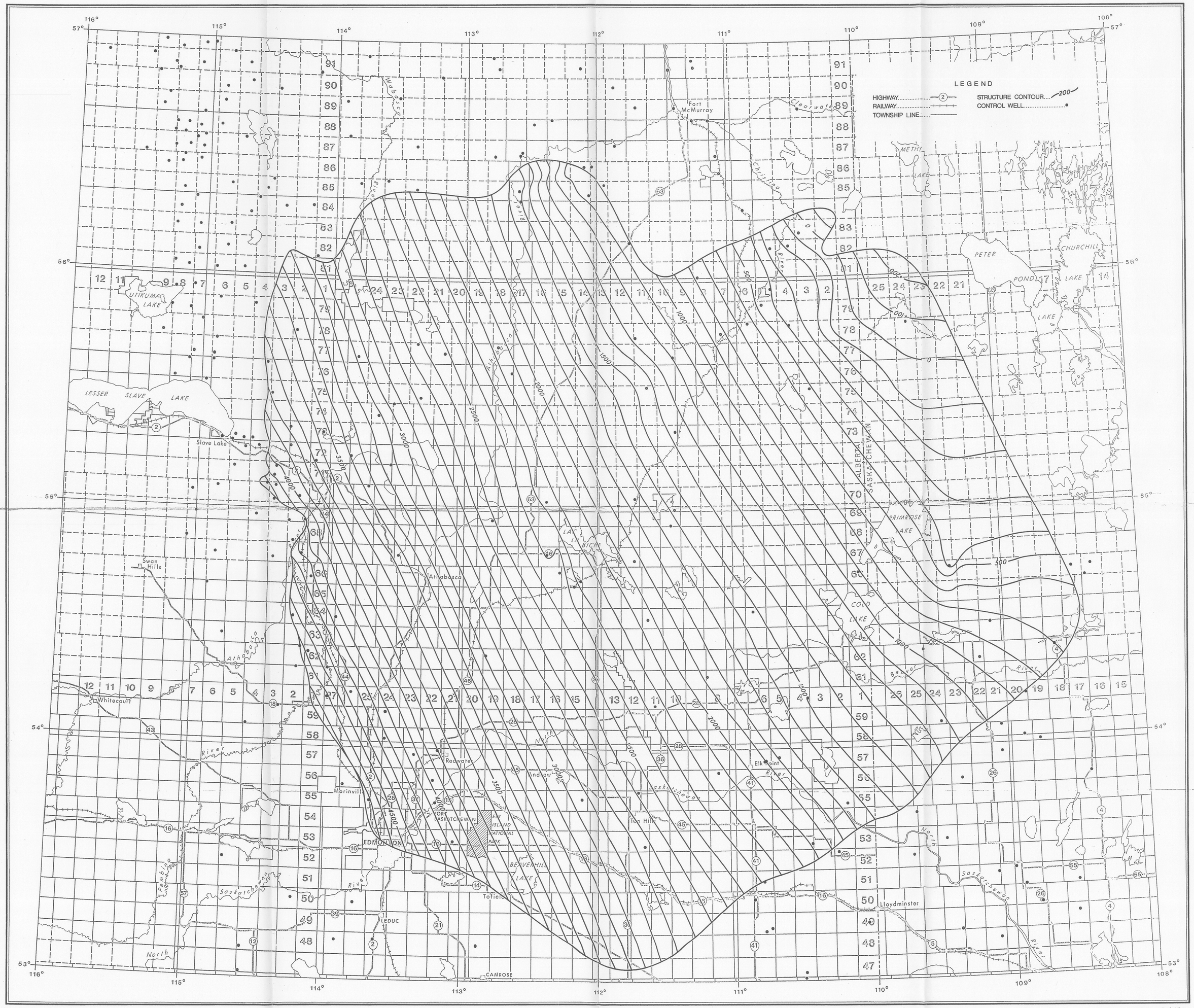

FIGURE 11. STRUCTURE ON THE UPPER SURFACE OF UPPER LOTSBERG SALT

SCALE 1:1,000,000
1 Inch to 16 Miles Approximately
Miles 20 0 20 40 60 80
Kilometres 20 0 20 40 60 80 100 120

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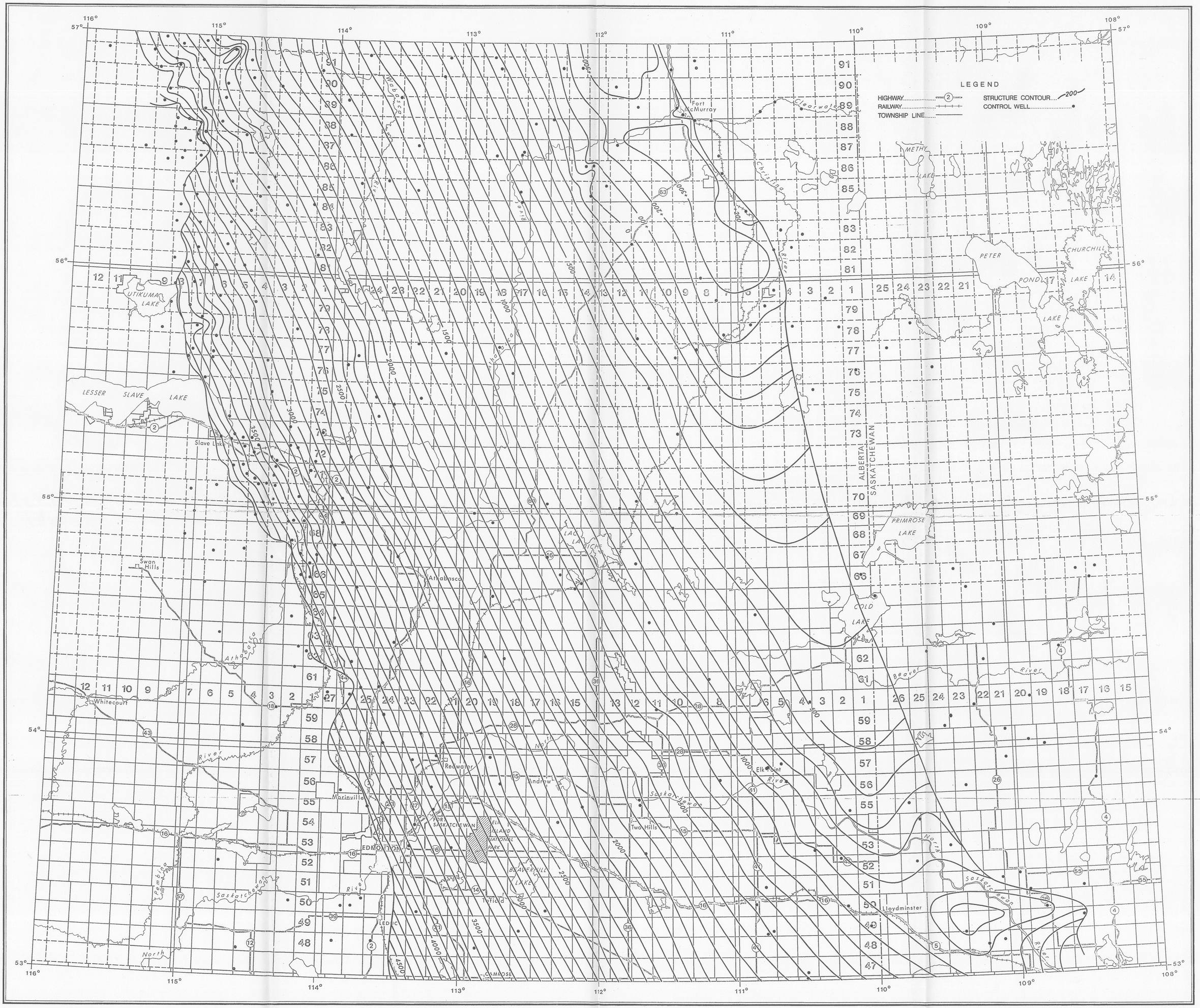

SCALE 1:1,000,000

1 Inch to 16 Miles Approximately

Miles 20 0 20 40 60 80

Kilometres 20 0 20 40 60 80 100 120

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FIGURE 12. STRUCTURE ON THE UPPER SURFACE OF PRAIRIE EVAPORITE SALT