Calcium and Magnesium in Alberta Brines

ABSTRACT

Approximately 850 subsurface brines from Alberta containing more than 20,000 mg/l calcium and more than 3,000 mg/l magnesium were studied to determine their commercial potential. The brines are from Devonian, Granite Wash, and Lower Paleozoic strata. Knowledge of the regional compositional gradients, hydraulic-head distribution, and origin of the brines in nine stratigraphic units has been used to indicate regions in the Alberta Plains which contain proven and probable brine fields.

Brines with more than 60,000 mg/l calcium and more than 9,000 mg/l magnesium are similar in composition to commercial brines in the United States which presently are being exploited for calcium chloride. These same brines also may be a potential source of magnesium. Potentially commercial brine fields are present only in the Upper Devonian Beaverhill Lake Formation of southern Alberta, and in the Middle Devonian Upper Elk Point Subgroup, Keg River Formation, and Lower Elk Point Subgroup of north-central Alberta.

by

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CALCIUM AND MAGNESIUM IN ALBERTA BRINES

INTRODUCTION

In 1969 the estimated value of the production of the mineral industry in Alberta was $1,190,000,000. This represented about 37 per cent of the gross provincial product. The value of crude oil, condensate, natural gas, and sulphur from sour natural gas was slightly more than $1,130,000,000, or about 95 per cent of the total value of the production of the mineral industry. During the production of crude oil, condensate and, to a lesser extent, natural gas, formation waters are brought to the surface. In 1969 the volume of formation waters coproduced with crude oil, condensate, and natural gas amounted to 54,000,000 barrels. Essentially all of these formation waters are returned to the ground either in waste disposal wells or are used in repressuring and water flooding schemes. No attempt is made to extract specific components, such as calcium and magnesium, from these formation waters.

Proration of crude oil production in Alberta means that the amount of coproduced formation water is dependent on the production of crude oil. The contingencies of optimum reservoir production economics, together with the proration plan in operation in Alberta, decrease the likelihood of the use of coproduced formation waters as a source of industrial minerals. This is quite apart from the fact that many of the coproduced formation waters are chemically unsuitable. However, study of the distribution and composition of formation waters in Alberta (Hitchon, 1964) indicates that enormous volumes of potentially valuable formation waters are present outside the limits of known oil and gas fields. It is the intention of this report to describe the distribution of these latent brine fields with particular reference to calcium and magnesium.

Acknowledgments

COMPOSITION OF COMMERCIAL BRINES

Sea water, brines from saline lakes, and subsurface brines are exploited commercially for a variety of components, including calcium and magnesium, at several places throughout the world. Analyses of sea water and some of these brines are shown in table 1.

Calcium chloride is produced as a byproduct of the Solvay process but also is extracted directly from subsurface brines. In the early 1960's, between 50 and 60 per cent of the calcium chloride sold in the United States originated from natural brines (Allen, 1964). The leader among the producers of calcium chloride from natural brines is The Dow Chemical Company which extracts calcium chloride, together with magnesium, potassium, bromide, iodide, and other components, from formation brines in the Lower Devonian Sylvania Sandstone at Midland, Michigan. The origin of this brine is evaluated by Egleson and Querio (1969).

Magnesium metal is produced commercially using three principal processes. One is the thermal reduction of calcined dolomite with ferrosilicon; this procedure will not be discussed further. The two other processes are electrolytic and involve (1) the decomposition of hydrous magnesium chloride derived from sea water (Dow process), and (2) the decomposition of anhydrous magnesium chloride (I. G. Farben process). In 1968, over 90 per cent of the United States output of primary magnesium was produced by The Dow Chemical Company at Freeport, Texas, by the electrolytic processing of sea water. Magnesium also is recovered from sea water by two other companies in the United States, but it is extracted in the form of magnesium compounds other than the chloride and used mainly for chemicals and refractories (Chemical and Engineering News, 1964). Detailed discussion of the processing of sea water for magnesium and other components is provided by Tallmadge, Butt, and Solomon (1964).

Considerable expansion of the magnesium market over the past decade, together with significant technological advances and price increases, have resulted in extensive plans by several companies to extract magnesium from the waters of Great Salt Lake and to process it by a modified I. G. Farben method. No analysis is available for the feedstock brine to be used, but the analysis from Great Salt Lake in table 1 is typical of brines from the south side of the railroad causeway there. The construction of the causeway

Table 1. Analyses of Sea Water and Commercial Brines

Sample Details	Chemical Constituents (mg/l)								Total Dissolved Solids	Reference
	Na	Ca	Mg	Cl	Br	I	SO$_4$	HCO$_3$		
Sea water (standard salinity of 35 ‰)	10,760	413	1,294	19,353	67	0.06	2,712	142	35,000	Culkin, 1965 (Table 1).
Great Salt Lake	91,000	<200	12,400	166,000	-	-	23,400	-	298,550[1]	George, Riley, and Crocker, 1967 (Table 1).
Dead Sea (Average)	34,940	15,800	41,960	208,020	5,920	-	540	240	315,040[2]	Livingstone, 1963 (Table 51, No. 1).
Lower Devonian[3] (Sylvania Sandstone, Midland, Michigan – The Dow Chemical Company)	22,500	74,800	9,960	208,000	2,910	40	40	-	331,000[4]	White, Hem, and Waring, 1963 (Table 13, No. 8).

[1]Includes K 5,500; Li 50.
[2]Includes K 7,560; Rb 60.
[3]Measured in ppm, which is essentially identical to mg/l.
  For waters with high contents of dissolved salts a density
  correction must be utilized in computing mg/l from ppm.
[4]Includes K 9,120; Sr 2,650; NH$_4$ 506; B 380.

resulted in cessation of natural mixing and stratification of the lake water (Hahl and Handy, 1969). The natural brines of the lake are to be concentrated by solar evaporation, but no analysis of the concentrated product is available. In addition, lithium is to be extracted from the solar-concentrated brine, making this operation particularly attractive. This very large round of expansion based mainly on extraction of magnesium from Great Salt Lake already has resulted in the closure (in December, 1969) of the only plant in the United States using the thermal reduction process, and in plans for the extraction by American Magnesium Company of magnesium (also by a modified I. G. Farben method) from subsurface brines at Snyder, Texas. The Texas brines are reported to contain 11 per cent magnesium chloride, equivalent to 25,500 mg/l magnesium (Jackson, 1968). The analysis of the water of the Dead Sea in table 1 is included because of persistent reports of plans to extract several components from Dead Sea brine, including magnesium.

If all the plans reported in trade journals materialize, by the middle 1970's only about one-half of the production of primary magnesium in the United States will be produced by the Dow process. The remainder will be produced by a modified I. G. Farben process from surface or subsurface brines, assuming continued brine production at Freeport, Texas, at the current rate.

The use of Alberta brines for the commercial production of calcium chloride and magnesium will depend on several factors. For the development of an industry based on calcium chloride, the presence of adequate reserves of brines of comparable composition to those of the Lower Devonian Sylvania Sandstone at Midland, Michigan, (Table 1) is essential. The development of plant capacity for the production of primary magnesium from subsurface brines will depend (1) on the presence of brines with contents of magnesium at least as high as those at Midland, Michigan, and (2) adequate cheap energy sources which can be used in lieu of solar energy to upgrade the original brines.

ORIGIN OF THE BRINES

The salinities of Alberta brines range from 200,000 to nearly 420,000 mg/l. They are composed principally of chlorides of sodium and calcium, with lesser amounts of magnesium, bicarbonate, and sulphate. The proportion of Na:(Ca + Mg)[1] is variable but generally greater than unity, although most of the potentially commercial brines have

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1 Note that the atom ratios are expressed in terms of chemical equivalents and can be read directly from the ternary diagrams. Atom ratios also are used in appendix B.
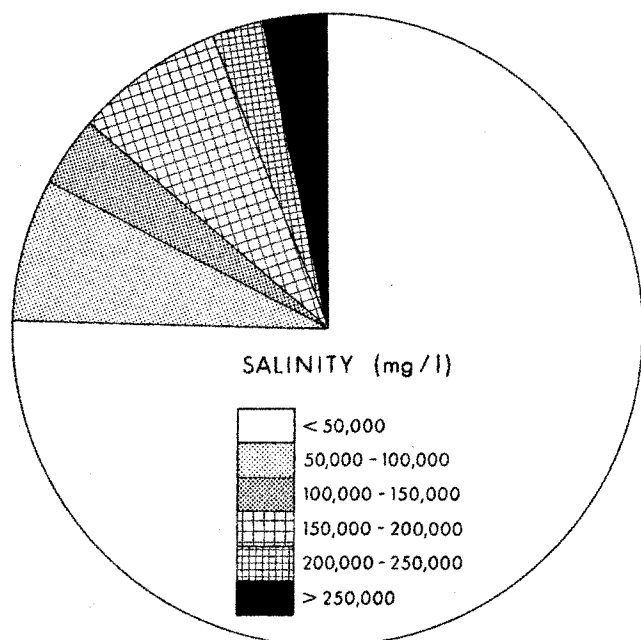
SALINITY (mg / l)

☐	< 50,000
▦	50,000 - 100,000
▨	100,000 - 150,000
▦	150,000 - 200,000
▦	200,000 - 250,000
■	> 250,000

FIGURE 1. *Relative amounts of formation waters of different salinities in the Plains region of Alberta. Total porosity of this region is 33,130 cubic miles.*

Na:(Ca + Mg) ratios less than unity. None of the formation waters has a Ca:Mg ratio less than unity. The contents of bicarbonate and sulphate are both generally less than 2,000 mg/l compared with chloride contents of up to 250,000 mg/l. Figure 1 shows the relative amounts of formation waters of different salinities in the Plains region of Alberta. These relative amounts were determined from knowledge of rock volumes (Table 2), assigned porosities (Hitchon, 1968, Table 4), and salinity distributions (Hitchon, 1964) in a complete succession of stratigraphic units. The rock volume data form part of the basic data of an earlier study on rock volumes and pore volumes in Western Canada (Hitchon, 1968); they are made available here in table 2 without further comment. A detailed breakdown of the salinity distribution in selected stratigraphic units is given in table 3.

The pie diagram (Fig. 1) and salinity distribution data (Table 3) indicate that only Devonian and Lower Paleozoic rocks contain significant quantities of brines with salinities greater than 200,000 mg/l. They are generally believed to have originated by ionically selective membrane filtration through charged-net shale micropore ultra filters. The process developed under a freshwater hydraulic head which resulted in the redistribution of the dissolved solids in the original sea water to form brines with the present compositions. In addition to membrane filtration, other

processes have been operative, including cation exchange on clays and solution of halite and anhydrite. The combined effect of all these processes has been to produce in Devonian and Lower Paleozoic rocks significant quantities of brines with salinities greater than 200,000 mg/l, which also contain potentially economic amounts of calcium and magnesium. More details of the membrane filtration process will be found in Graf, Friedman, and Meents (1965); White (1965); Anderson, Graf, and Jones (1966); Graf, *et al.*, (1966); van Everdingen (1968b); and Berry (1969). Papers discussing formation waters in Western Canada include Hitchon (1964); van Everdingen (1968a), Billings, Hitchon, and Shaw (1969); Hitchon and Friedman (1969); and Hitchon, Billings, and Klovan (1971). The fluid flow pattern has been discussed recently (Hitchon, 1969a,b), and selected aspects of the solution of halite and gypsum have been noted (Hitchon, Levinson, and Reeder, 1969). Detailed knowledge of the origin of the brines has been of considerable assistance in evaluating the regional variations in composition and particularly in delineating areas where brines might be present but which have not yet been drilled.

At the beginning of this study it was arbitrarily decided to examine all formation waters from Alberta with more than 20,000 mg/l calcium and more than 3,000 mg/l magnesium. No analyses were found that had more than the minimum content of magnesium but did not also contain the minimum amount of calcium. However, some analyses with up to 30,000 mg/l calcium had less than 3,000 mg/l magnesium. These two lower limits are approximately one third of the respective values reported for the commercial operation of The Dow Chemical Company at Midland, Michigan (Table 1). It was felt that by determining the distribution of brines within these limits there would be little chance of missing potential commercial trends because of uncertainties in the regional compositional gradients. Approximately 850 analyses from the files of the Oil and Gas Conservation Board were examined during the course of this study, of which about five per cent are quoted in this report. Each stratigraphic unit is considered in turn, and the regional distribution of brines with more than 20,000 mg/l calcium and more than 3,000 mg/l magnesium are illustrated in maps in appendix A. Typical analyses are tabulated in appendix B.

UPPER DEVONIAN–WABAMUN GROUP

Brines relevant to this study are found in deep strata in two regions adjacent to the disturbed belt (Figs. 2, 3). In both regions the hydraulic head distribution indicates good

Table 2. Estimated Volumes of Sandstone, Shale, Dolomite, Limestone and Evaporite in Plains Region of Alberta

Map Reference McCrossan and Glaister (1964)	Stratigraphic Unit	Sandstone		Shale		Dolomite		Limestone		Evaporite		Total
		Cubic miles	%	Cubic miles	%	Cubic miles	%	Cubic miles	%	Cubic miles	%	Cubic miles
13- 1	Tertiary	1,725.0	25.0	5,175.0	75.0	-	-	-	-	-	-	6,900.0
12-12 12-11 12-10	Upper Cretaceous: Post-Colorado Supergroup	3,555.0	8.2	39,600.0	91.8	-	-	-	-	-	-	43,155.0
12- 9	Upper Cretaceous: Upper Colorado Group, Second Specks-First Specks	1,086.4	5.2	19,982.8	94.8	-	-	-	-	-	-	21,069.2
12- 8	Upper Cretaceous: Upper Colorado Group, Fish Scales-Second Specks	2,180.4	12.2	15,765.2	87.8	-	-	-	-	-	-	17,945.6
11- 4	Lower Cretaceous: Lower Colorado Group	1,340.2	10.7	11,179.9	89.3	-	-	-	-	-	-	12,520.1
11- 3	Lower Cretaceous: Upper Mannville Formation	7,075.7	34.0	13,715.9	66.0	-	-	-	-	-	-	20,791.6
11- 2	Lower Cretaceous: Lower Mannville Formation	3,034.2	57.6	2,232.6	42.4	-	-	-	-	-	-	5,266.8
10- 7	Upper Jurassic	763.1	46.8	868.3	53.2	-	-	-	-	-	-	1,631.4
10- 6	Middle Jurassic	212.1	39.5	283.5	52.7	2.1	0.4	39.5	7.4	-	-	537.2
10- 5 10- 4	Lower Jurassic	322.8	36.7	557.7	63.3	-	-	-	-	-	-	880.5
9-13	Upper Triassic	73.2	11.2	343.9	52.6	19.7	3.0	177.7	27.2	39.1	6.0	653.6
9-11	Middle Triassic	111.8	25.1	333.6	74.8	0.4	0.1	-	-	-	-	445.8
9- 8	Lower Triassic	378.0	14.7	2,192.7	85.2	2.7	0.1	-	-	-	-	2,573.4
8- 1	Permian	472.3	53.2	170.8	19.2	232.7	26.2	12.2	1.4	-	-	888.0
7-12	Carboniferous: Chesteran	99.9	10.0	399.5	40.0	474.4	47.5	25.0	2.5	-	-	998.8
7- 8	Carboniferous: Osagean and Meramecian	-	-	494.8	5.0	940.2	9.5	8,461.5	85.5	-	-	9,896.5
7- 4	Carboniferous: Kinderhookian	282.2	2.3	7,783.8	62.3	-	-	4,427.5	35.4	-	-	12,493.5
6-26	Upper Devonian: "Wabamun"	-	-	173.3	1.2	4,215.4	29.9	8,721.8	61.8	997.5	7.1	14,108.0
6-24	Upper Devonian: "Winterburn"	-	-	55.3	0.7	4,478.1	56.1	3,327.6	41.8	108.7	1.4	7,969.7
6-22 6-21 6-16	Upper Devonian: "Woodbend"	-	-	18,939.7	63.6	7,896.4	26.5	2,340.1	7.9	600.5	2.0	29,776.7
6- 2	Upper Devonian: Beaverhill Lake Formation	-	-	6,884.8	35.5	1,533.1	7.9	10,585.0	54.6	390.5	2.0	19,393.4
5- 5	Middle Devonian: Upper Elk Point Subgroup	881.5	4.9	2,164.9	12.0	3,926.2	21.8	206.6	1.1	10,798.3	60.2	17,977.5
5- 4	Middle Devonian: Lower Elk Point Subgroup	648.0	7.3	2,465.1	27.8	589.6	6.6	65.5	0.7	5,108.0	57.6	8,876.2
4- 9 4- 8	Silurian: Interlake Group	-	-	0.1	10.0	0.7	70.0	0.2	20.0	-	-	1.0
4- 7 4- 6	Ordovician: Big Horn Group	-	-	45.5	10.0	348.0	76.5	38.6	8.5	22.8	5.0	454.9
4- 5	Ordovician: Winnipeg Group	-	-	-	-	-	-	-	-	-	-	-
3- 3	Upper Cambrian and Tremadoc	4,575.0	50.0	4,575.0	50.0	-	-	-	-	-	-	9,150.0
3- 2	Middle Cambrian	2,488.3	15.8	10,025.9	63.8	-	-	3,205.8	20.4	-	-	15,720.0
	Total or Average	31,305.1	11.1	166,409.6	59.0	24,659.7	8.7	21,634.6	14.8	18,065.4	6.4	282,074.4

Table 3. Salinity Distribution in Selected Stratigraphic Units of the Alberta Plains

Stratigraphic Unit	Rock Volume (Cubic Miles)	Pore Volume (Cubic Miles)	Percentage Salinity Distribution (mg/l x 10^3)						
			<50	50-100	100-150	150-200	200-250	250-300	>300
Tertiary	6,900.0	1,811.3	100	-	-	-	-	-	-
Upper Cretaceous	82,169.8	14,519.4	100	-	-	-	-	-	-
Lower Cretaceous: Lower Colorado Group	12,520.1	1,878.0	100	-	-	-	-	-	-
Lower Cretaceous: Mannville Formation	26,058.4	4,414.3	83	16	1	-	-	-	-
Jurassic	3,049.1	455.3	83	17	-	-	-	-	-
Triassic	3,672.8	506.8	24	48	27	1	-	-	-
Permian	888.0	88.8	16	28	46	10	-	-	-
Carboniferous	23,388.8	2,338.9	48	20	25	6	1	-	-
Upper Devonian: "Wabamun"	14,108.0	1,311.0	31	33	13	23	-	-	-
Upper Devonian: "Winterburn"	7,969.7	395.8	38	17	10	24	7	4	-
Upper Devonian: "Woodbend"	29,776.7	1,663.6	46	18	4	7	20	5	-
Upper Devonian: Beaverhill Lake Formation	19,393.4	1,193.9	-	-	-	35	26	39	-
Middle Devonian	26,853.7	863.3	4	3	3	21	21	43	5
Silurian	1.0	-	-	-	-	-	-	-	-
Ordovician	454.9	29.4	-	25	10	65	-	-	-
Cambrian	24,870.0	1,660.7	9	4	6	79	2	-	-
Total or Average	282,074.4	33,130.5	75.8	7.3	3.6	7.8	2.7	2.8	<0.1

hydraulic connection to the deep strata beneath the disturbed belt, although in the area separating the two regions the hydraulic connection to the deep strata beneath the disturbed belt is relatively poor. The hydraulic head distribution in the southern region has been illustrated by Hitchon (1969b).

In the proven areas calcium contents range up to 26,000 mg/l, and magnesium contents up to 11,300 mg/l at Gold Creek in the northern region (Fig. 3, Loc. 2; Appendix B, No. 2) and to just less than 5,000 mg/l in the southern region. Representative analyses are shown in appendix B (Nos. 1-3), and the relative proportions of the cations can be seen in figure 4. From knowledge of the hydraulic head distribution and compositional gradients, it seems unlikely

that contents of calcium over 35,000 mg/l or magnesium much over 10,000 mg/l will be found in the probable brine areas. In summary, the Upper Devonian Wabamun Group is unlikely to contain brine fields comparable to the commercial brine fields in the United States.

UPPER DEVONIAN—WINTERBURN GROUP

The broad regional controls of hydraulic head distribution which govern fluid flow in the Wabamun Group are present also in the Winterburn Group. Thus, the regional distributions of brines rich in calcium and magnesium are similar in both stratigraphic units (Figs. 5, 6). Most brines recovered during drilling are from the Nisku Formation, although a
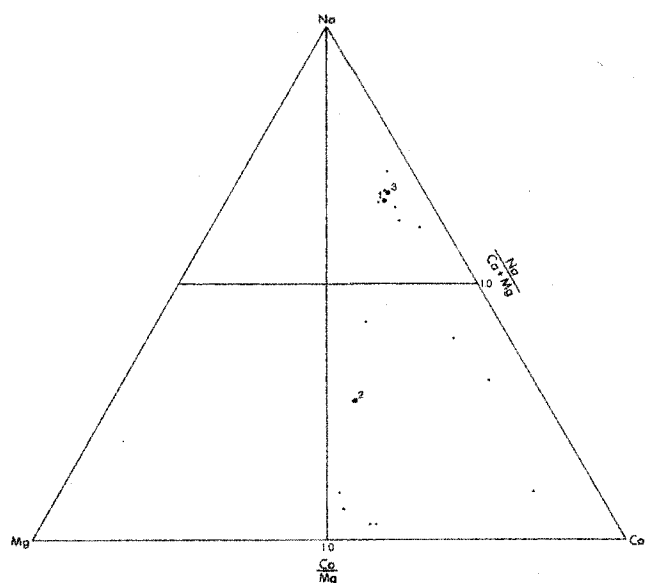
FIGURE 4. *Na-Ca-Mg (in m.e.l) in brines from Upper Devonian Wabamun Group, Alberta. Numbered points refer to analyses in appendix B.*

few are from the Graminia Formation or undifferentiated Winterburn Group strata. All analyses are similar, and only those from the Nisku Formation are given in appendix B (Nos. 4-9).

In the proven areas calcium contents range to nearly 30,000 mg/l, with magnesium contents generally less than 4,000 mg/l in the southern area and less than 6,400 mg/l in the northern area. The proportions of cations (Fig. 7) are quite similar in both areas. The hydraulic head distribution and known compositional gradients indicate that brines with more than 40,000 mg/l calcium or 10,000 mg/l magnesium are absent in the probable brine areas. Thus, the Winterburn Group is unlikely to contain brine fields comparable to the commercial brine fields in the United States.

UPPER DEVONIAN—WOODBEND GROUP

It is convenient to consider the Woodbend Group brines in two parts. These are (1) the brines in the carbonate reef complexes of the Leduc Formation, and (2) the brines in the carbonate reef platform of the Cooking Lake Formation, found only in central Alberta.

Leduc Formation

Most of the more deeply buried portions of the carbonate reef complexes of the Leduc Formation contain brines with more than 20,000 mg/l calcium (Fig. 8) and more than 3,000 mg/l magnesium (Fig. 9). Apart from the brines in a small region of the Rimbey-Meadowbrook reef complex, which contain from 30-40,000 mg/l calcium and more than 5,000 mg/l magnesium, all other brines in the proven brine region contain calcium in the range 20-30,000 mg/l and magnesium from 3,000 to about 5,000 mg/l. Some representative analyses are given in appendix B (Nos. 10-15). The relative proportions of the cations (Fig. 10) are similar for most of the brines, except for those in the Rimbey-Meadowbrook reef complex, which have more than 30,000 mg/l calcium and, consequently, Na:(Ca + Mg) ratios generally less than unity.

The hydraulic head distribution in the Woodbend Group (Hitchon, 1969b) together with the compositional gradients established in this study indicate that brines with more than 40,000 mg/l calcium or much more than 5,000 mg/l magnesium will not be found in the probable brine area. Calcium contents approaching 40,000 mg/l might be encountered in the basal part of the Leduc Formation, northeast of the Stettler reef complex along the northern
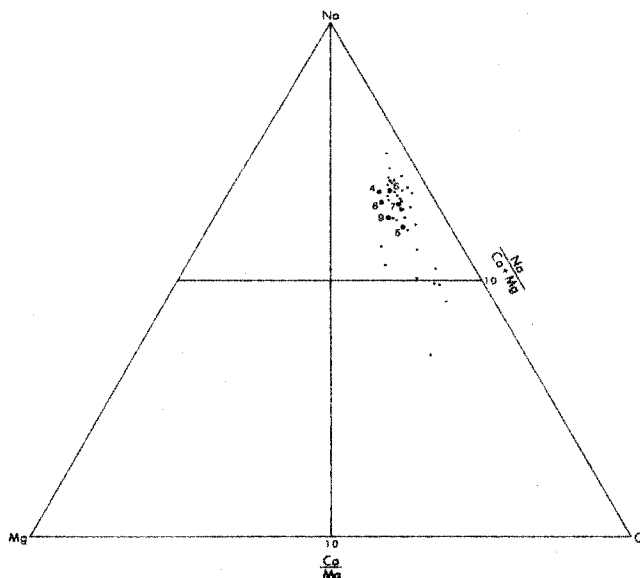
FIGURE 7. *Na-Ca-Mg (in m.e.l) in brines from Upper Devonian Winterburn Group, Alberta. Numbered points refer to analyses in appendix B.*

margin of the Southern Alberta Shelf. This situation is a reflection of the higher calcium contents in the formation waters of the underlying Cooking Lake Formation; thus the brines are better classified with that stratigraphic unit than with the Leduc Formation. Similarly, magnesium concentrations exceeding 5,000 mg/l, possibly up to 9,000 mg/l, might be found in the basal portion of the Leduc
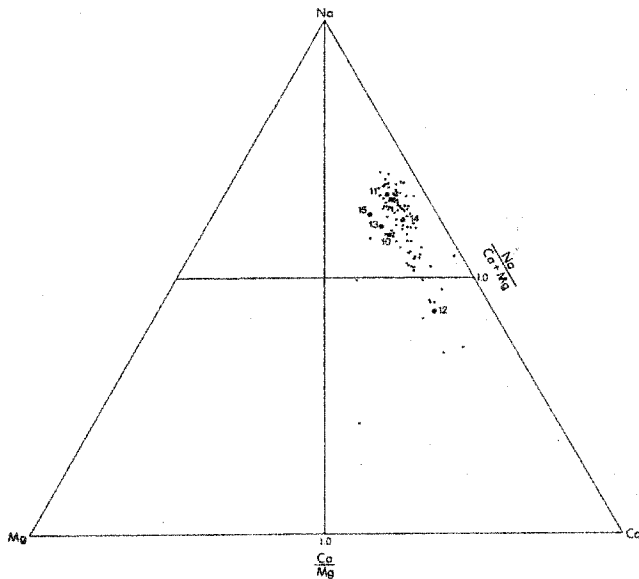
FIGURE 10. Na-Ca-Mg (in m.e.l.) in brines from Upper Devonian Woodbend Group, Leduc Formation, Alberta. Numbered points refer to analyses in appendix B.

Formation in the northern part of the Bashaw reef complex. It is unlikely, however, that the Leduc Formation contains brine fields comparable to the commercial brine fields in the United States.

Cooking Lake Formation

The carbonate reef platform of the Cooking Lake Formation is limited to the northeast by its subcrop beneath Cretaceous strata. At the northern margin of the Southern Alberta Shelf, it is difficult to distinguish carbonates equivalent to the Cooking Lake and Leduc Formations from the underlying carbonates of the Beaverhill Lake Formation. West of the Rimbey-Meadowbrook reef complex, the carbonates of the reef platform grade into calcareous shales.

Beneath the Rimbey-Meadowbrook reef complex the isoconcentration contours for both calcium (Fig. 11) and magnesium (Fig. 12) reflect the composition gradients of brines in the overlying Leduc Formation. Northeast of the Bashaw reef complex, brines in the Cooking Lake Formation range to approximately 63,000 mg/l calcium and slightly more than 9,000 mg/l magnesium. In this region the carbonate reef platform is just over 300 feet thick, and the regional variations in composition of the brines within the platform reflect the composition of the brines in the underlying Beaverhill Lake Formation. The relative proportion of cations in brines from the Cooking

Lake Formation are shown in figure 13, and selected analyses are given in appendix B (Nos. 16, 17). Brines with Na:(Ca + Mg) ratios less than unity are mainly from the region northeast of the Bashaw reef complex.

In the southwest portion of the map-area (Figs. 11, 12), the Cooking Lake Formation becomes difficult to distinguish from the overlying and underlying carbonates with the result that the composition of brines in this part of the map-area is uncertain. It is unlikely, however, that brines will be found which are of greater economic potential than those found in the region northeast of the Bashaw reef complex. Since the brines in this region are a reflection of those in the thicker, underlying Beaverhill Lake Formation, it is unlikely that any brines from the Cooking Lake Formation will be developed without simultaneous development of brines in the Beaverhill Lake Formation.

UPPER DEVONIAN—BEAVERHILL LAKE FORMATION

Approximately half the area occupied by the Beaverhill Lake Formation in Alberta contains brines with more than

FIGURE 13. Na-Ca-Mg (in m.e.l.) in brines from Upper Devonian Woodbend Group, Cooking Lake Formation, central Alberta. Numbered points refer to analyses in appendix B.

20,000 mg/l calcium, and a significant portion contains brines with more than 3,000 mg/l magnesium. About 8,820 square miles of the Beaverhill Lake Formation in southern Alberta contain brines with more than 60,000 mg/l calcium (Fig. 14) and more than 9,000 mg/l magnesium (Fig. 15). It is beyond the scope of this report to determine the reserves

The hydraulic head distribution in the Beaverhill Lake Formation (Hitchon, 1969b), together with the composition gradients established by this study, indicate several regions of probable brine occurrences. However, in these regions brines containing more than 60,000 mg/l calcium and more than 9,000 mg/l magnesium may be found only in the very deep strata southwest of Lethbridge. That is, the area outlined on the map within the proven brine region is probably the maximum extent of potentially commercial brine fields in the Beaverhill Lake Formation. The potential reserves of calcium- and magnesium-rich brines of southern Alberta (from which the commercial plant at Brooks produces brine) indicate that this region of the Beaverhill Lake Formation contains brines similar to those from commercial fields in the United States.

MIDDLE DEVONIAN—ELK POINT GROUP

It is convenient to discuss brines of the Elk Point Group in three sections: (1) the brines in the nearshore clastic rocks around the Peace River Arch, (2) the brines in the Keg River Formation, and (3) the brines in the Lower Elk Point Subgroup.

Gilwood Sandstone

The nearshore clastic rocks which rim the Peace River Arch comprise the Watt Mountain Formation, which includes the Gilwood Sandstone on the east and southeast side of the arch. The eastern limit of the clastic beds is marked by an increase in the amount of carbonate rocks until a complete thin carbonate succession is present overlying the Prairie Evaporite Formation, at about longitude 114° W.

Essentially all the brines reported from the Watt Mountain Formation are from the Gilwood Sandstone; figures 17, 18, and 19, and numbers 25 and 26 in appendix B are concerned with brines from this sandstone. There is complete fluid continuity between the brines in the Gilwood Sandstone and those in the carbonates of the overlying Beaverhill Lake Formation, which accounts for the similarity in distribution of calcium and magnesium. The maximum content of calcium within the proven brine area is 31,000 mg/l, and it is unlikely that contents greater than about 45,000 mg/l will be encountered in the probable brine areas. Contents of magnesium much above 5,000 mg/l have not been found in the proven brine areas, nor are they likely in the probable brine areas.

South of the map-area the Gilwood Sandstone becomes

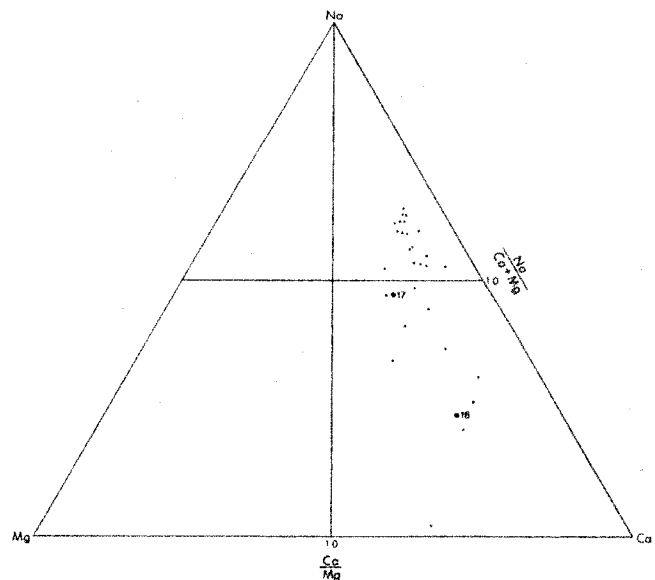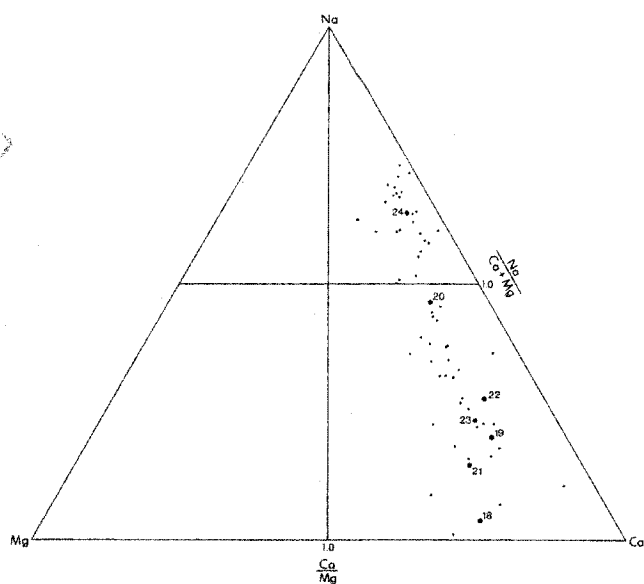*FIGURE 16. Na-Ca-Mg (in m.e.l.) in brines from Upper Devonian Beaverhill Lake Formation, Alberta. Numbered points refer to analyses in appendix B.*

of brines available for exploitation. Determination of the reserves requires knowledge of the lithology, thickness, porosity, and permeability within the potential brine field, much of which may be obtained from study of well logs, cores, and drillstem tests. McCrossan and Glaister (1964, Fig. 6-2) provide a regional isopach-lithofacies map of the Beaverhill Lake Formation. Within the potential brine field factors which should be considered are the presence of chalky lime-mud facies with very low porosity and permeability, the presence of anhydrite and calcite infillings of pores (especially towards the south) and the variable, lensing nature of the few high porosity and high permeability dolomite zones. Only detailed study of these factors will allow determination of the producible reserves.

Representative analyses of brines from the Beaverhill Lake Formation are given in appendix B (Nos. 18-24), and the relations among the cations in figure 16. The brines show a wide range in Na:(Ca + Mg) ratios with the lower values found in brines from southern Alberta. Reliable analyses from southern Alberta indicate that calcium contents ranging to approximately 90,000 mg/l and magnesium contents of more than 15,000 mg/l are present (Appendix B, No. 21), with pH values generally less than 6.5. Analyses from drillstem tests of doubtful reliability indicate that calcium contents at least to 100,000 mg/l and magnesium contents possibly exceeding 20,000 mg/l may be present.

shaly, and no reliable formation waters have been recovered there. North of the Peace River Arch, the Manning Sandstone — the correlative of the Gilwood Sandstone — contains formation waters of lower calcium and magnesium contents than those of interest to this study. Thus, it is unlikely that brines will be found in the Gilwood Sandstone which are similar to those from commercial brine fields in the United States.

Keg River Formation

The carbonates of the Keg River Formation essentially lie beneath the evaporites of the Prairie Evaporite Formation
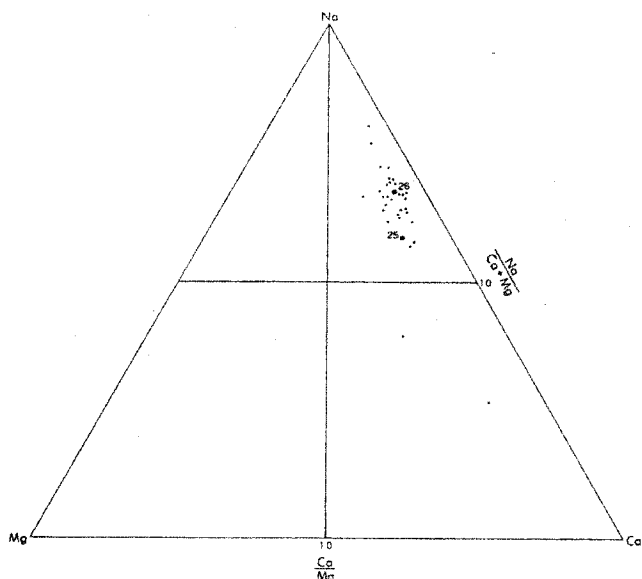

FIGURE 19. Na-Ca-Mg (in m.e.l.) in brines from Middle Devonian Upper Elk Point Group, Gilwood Sandstone, northern Alberta. Numbered points refer to analyses in appendix B.

and above the calcareous clastic beds of the Lower Elk Point Subgroup (Contact Rapids Formation). There is sufficient control in northwestern Alberta and in the area immediately east of the Peace River Arch to allow the compilation of reliable maps for calcium (Fig. 20) and magnesium (Fig. 21) in the brines from this stratigraphic unit. There is, however, a paucity of reliable data in northeastern Alberta and in the region immediately north, east, and southeast of Edmonton.

Three facts allow tentative regions to be designated as probable brine areas. First, although there is not the same marked decrease in salinity of formation waters in the Elk Point Group in the subcrop region beneath Cretaceous strata, as is common in most Paleozoic stratigraphic units (Hitchon, 1964), it is known that the saline waters at the

outcrop margin of the Elk Point Group originate by solution of halite and gypsum, and in fact contain relatively low calcium contents (Hitchon, Levinson, and Reeder, 1969). Second, the known distribution of calcium and magnesium in Lower Elk Point Subgroup strata (Figs. 23, 24) strongly suggests that the fluids of the Keg River Formation and the Lower Elk Point Subgroup are in good hydraulic continuity because of the similar regional variations in the calcium and magnesium contents of the brines from both stratigraphic units. Third, the limitation of the high calcium and high magnesium regions to portions of the Keg River Formation which are both underlain by halite beds of the Lower Elk Point Subgroup (particularly the Lotsberg Formation) and overlain by the halite of the Prairie Evaporite Formation suggests a possible causal relationship.

Within the proven brine area, calcium contents exceed 100,000 mg/l, with magnesium contents of more than 13,000 mg/l (Appendix B, No. 27). The areal limit of brines with more than 60,000 mg/l calcium and more than 9,000 mg/l magnesium is quite small (1,962 square miles) and the Keg River Formation in this area has an average thickness of 150 feet (Grayston, Sherwin, and Allan, 1964). Regional variations of porosity and permeability may be obtained by examination of well logs, cores, and drillstem tests from the numerous wells drilled in this area. The area of probable brine fields is at least the same as that in the proven area and may be up to five times that in the proven area once the full extent of the probable brine area is known. The relative proportions of cations in brines from the Keg River Formation are shown in figure 22, from which it is observed that the range of the ratio Na:(Ca + Mg) is similar to that for brines from the Beaverhill Lake Formation, with the lowest values from the calcium- and magnesium-rich brines. From these data it can be concluded that the Keg River Formation contains brine fields similar in composition to the commerical brine fields in the United States. These may be economically attractive, although the remote location of parts of the region will prevent development in the near future.

Lower Elk Point Subgroup

Analyses of brines from the Lower Elk Point Subgroup are available only from the area immediately north of Edmonton and north of the Peace River Arch. The regional distributions of calcium (Fig. 23) and magnesium (Fig. 24) suggest concentration gradients for these ions that are similar to those in the overlying Keg River Formation. This fact has been used to assist the delineation of the probable
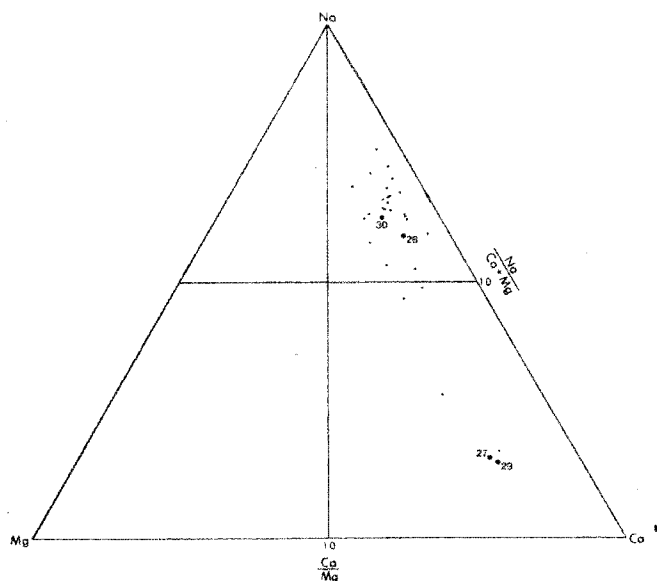
FIGURE 22. Na-Ca-Mg (in m.e.l.) in brines from Middle
Devonian Upper Elk Point Subgroup, Keg
River Formation, Alberta. Numbered points
refer to analyses in appendix B.

brine areas and also of the probable regions with more than
60,000 mg/l calcium and more than 9,000 mg/l magnesium.
The proven area underlain by these high-calcium and
high-magnesium brines is 666 square miles with an
estimated thickness of 50 feet for the porous strata of the
Contact Rapids and Ernestina Lake Formations. These
comprise the most important stratigraphic units from which
these brines can be extracted. Regional average porosity of
the sandstones may be expected to be higher than that of
the carbonates of the overlying Keg River Formation, but
only a detailed investigation of well logs, cores, and
drillstem tests will allow evaluation of producible reserves.

It is difficult to present a reasonable estimate of the area of
the probable brine fields with the data presently available.
If a region with the same area as that occupied by the
proven and probable brine fields of the overlying Keg River
Formation is considered, then probable brine fields in the
Lower Elk Point Subgroup will be at least 20 times that of
the proven area for this stratigraphic unit. The ternary
diagram (Fig. 25) indicates that the relative proportions of
the cations in brines from the Lower Elk Point Subgroup
are similar to those of brines from the overlying Keg River
Formation. Selected analyses are shown in appendix B
(Nos. 31, 32). It may be concluded that the brines of the
Lower Elk Point Subgroup are similar to brines from
commercial brine fields in the United States and are
therefore economically attractive. In view of the similar

regional compositional gradients to the overlying Keg River
Formation, parallel commerical development of both
stratigraphic units probably should be considered.

GRANITE WASH

The Granite Wash is an arkosic regolith which lies between
Devonian and Precambrian rocks over much of northern
Alberta. Because of its irregular distribution it is not
possible to indicate probable brine areas in the maps in
figures 26 and 27, which show the distribution of calcium
and magnesium, respectively, in brines from the Granite
Wash. Formation waters from the Granite Wash have been
recovered essentially only from wells drilled within the area
shown in figures 26 and 27. The isoconcentration contours
and the distribution of the proven brine areas indicate
clearly that brines with more than about 60,000 mg/l
calcium or much above 7,000 mg/l magnesium are unlikely
to be present within that area. Some representative analyses
of brines from the Granite Wash are given in appendix B
(Nos. 33-35), and the proportions of the cations are shown
in figure 28. The similarity of composition of these brines,
together with knowledge of the distribution of the proven
brine areas, indicates that brines from the Granite Wash are
unlikely to contain contents of calcium or magnesium
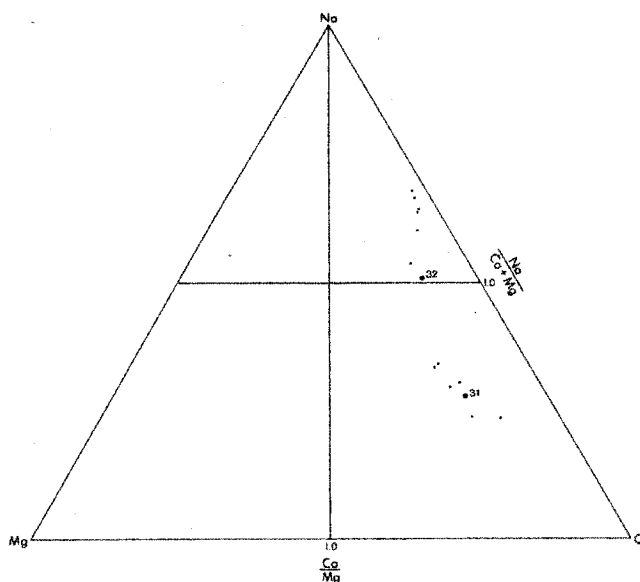similar to those of commercial brine fields in the United
States.

FIGURE 25. Na-Ca-Mg (in m.e.l.) in brines from Middle
Devonian Lower Elk Point Subgroup,
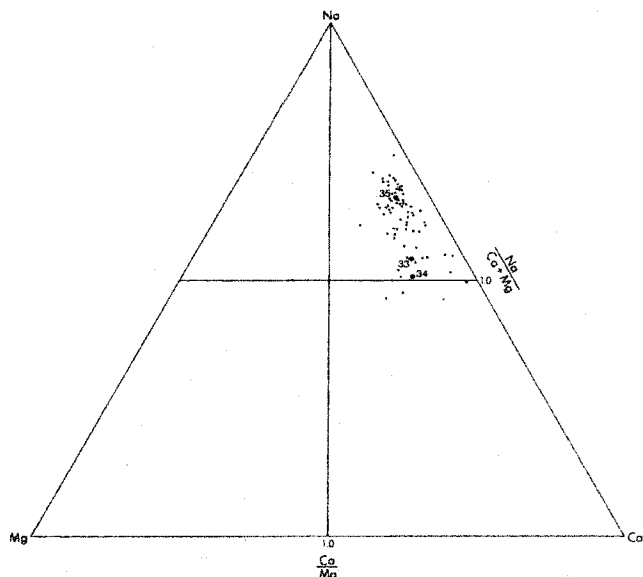Alberta. Numbered points refer to analyses
in appendix B.

FIGURE 28. Na-Ca-Mg (in m.e.l.) in brines from Granite Wash, northern Alberta. Numbered points refer to analyses in appendix B.

LOWER PALEOZOIC

Paucity of reliable analyses of brines from Lower Paleozoic strata precludes presentation of maps illustrating regional variations in the contents of calcium and magnesium. The few analyses of brines that are available from the Swan Hills region suggest that concentration gradients of brines in Cambrian rocks may be similar to those in the overlying Middle Devonian clastic rocks and Upper Devonian Beaverhill Lake Formation carbonates. If this suggestion proves correct when more data become available, then brines with compositions similar to those of commercial brine fields in the United States will not be present in the Cambrian strata of the Swan Hills area. Elsewhere, data are insufficient to draw any reliable conclusions concerning the presence of brine fields. The Ca:Mg ratios are all less than unity, and the Na:(Ca + Mg) ratios showed a wide range.

DISCUSSION

This report should be regarded as a preliminary study. The data essentially imply that potentially economic brine fields for the production of calcium chloride and magnesium are present in selected stratigraphic units in Alberta. The composition of the brines in these units are similar to, or better than, those presently being produced in the United States. The authors believe that those undertaking an economic analysis to determine the commercial viability of the brine fields may wish to take into consideration the following discussion.

The section of this report concerning the origin of the brines was intentionally brief and did not elaborate on some of the uncertainties regarding the origin of the very saline brines with high calcium contents. Several authors (Case, 1945; Valyashko and Vlasova, 1965; Pinneker, 1968; Pinneker and Lomonosov, 1968) have reported brines with nearly 650,000 mg/l total dissolved solids, calcium contents of more than 205,000 mg/l, and magnesium contents of 119,000 mg/l. Although the validity of certain of the data cited by these authors may be questioned by some geochemists, there is little doubt that brines more saline and with higher contents of calcium and magnesium than those tabulated in this report have been found in several sedimentary basins; also, such brines may exist in some portions of the Beaverhill Lake Formation, Keg River Formation, and Lower Elk Point Subgroup (Fig. 29). A critical feature of a commercially viable brine processing industry is the selection of a brine with the maximum content of calcium or magnesium, and therefore a more detailed study of the origin of these brines should be carried out owing to the possibility of locating brines more suitable than those tabulated in this report.

The basic geological and geochemical data for such a study are probably now available but should be supplemented by a program of data acquisition and interpretation. The broad regions of interest have been delineated in figure 29. Many wells are drilled for oil and gas in these regions each year and subsequently abandoned. Few wells penetrate the deeper stratigraphic units containing potential brine fields. When a well is drilled close to a stratigraphic unit of interest, it may be of value to those seeking brine fields to make arrangements, prior to abandonment, with those drilling for oil and gas to deepen the well to test the potential brine field. When sufficient supplementary data have been obtained in this manner, the brine fields can be outlined more reliably.

It is not the intention here to provide an economic analysis of the calcium chloride and magnesium industries. A market analysis report is available (Economic Research Branch, Alberta Department of Industry and Tourism, 1970) which is concerned specifically with calcium chloride from the Alberta point of view, and Jackson (1968) has discussed the economic aspects of the magnesium industry in relation to Canada as a whole. These references, together with those of Allen (1964); Chemical and Engineering News (1964); and Tallmadge, Butt, and Solomon (1964) supply

useful background reading on the economics of these industries. However, only a thorough economic analysis will determine the commercial viability of potential brine fields in Alberta.

CONCLUSIONS

(1) Potential reserves of brines with more than 60,000 mg/l calcium and more than 9,000 mg/l magnesium are present in the Upper Devonian Beaverhill Lake Formation of southern Alberta, and in the Middle Devonian Upper Elk Point Subgroup, Keg River Formation, and Lower Elk Point Subgroup of north-central Alberta.

(2) These brines are similar in composition to commercial brines in the United States which presently are being exploited for calcium chloride and magnesium.

(3) Further research should be carried out on (1) the origin of these brines, (2) the regional compositional gradients to determine the maximum contents of calcium and magnesium that are present within Alberta, (3) the additional potentially economic elements such as bromine and iodine, and (4) factors such as porosity and permeability in order to determine producible reserves.

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APPENDIX A.
MAPS SHOWING CALCIUM AND
MAGNESIUM CONCENTRATIONS
IN ALBERTA BRINES

LITHOLOGIC SYMBOLS, APPENDIX A
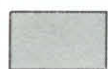
Outcrop area, equivalent strata

Subcrop area
(underlying Cretaceous strata)

Area of nondeposition

Margin reef complex

Limit salt basin,
Lower Elk Point Subgroup

Limit salt basin,
Upper Elk Point Subgroup

Eastern limit Middle
Devonian clastic rocks
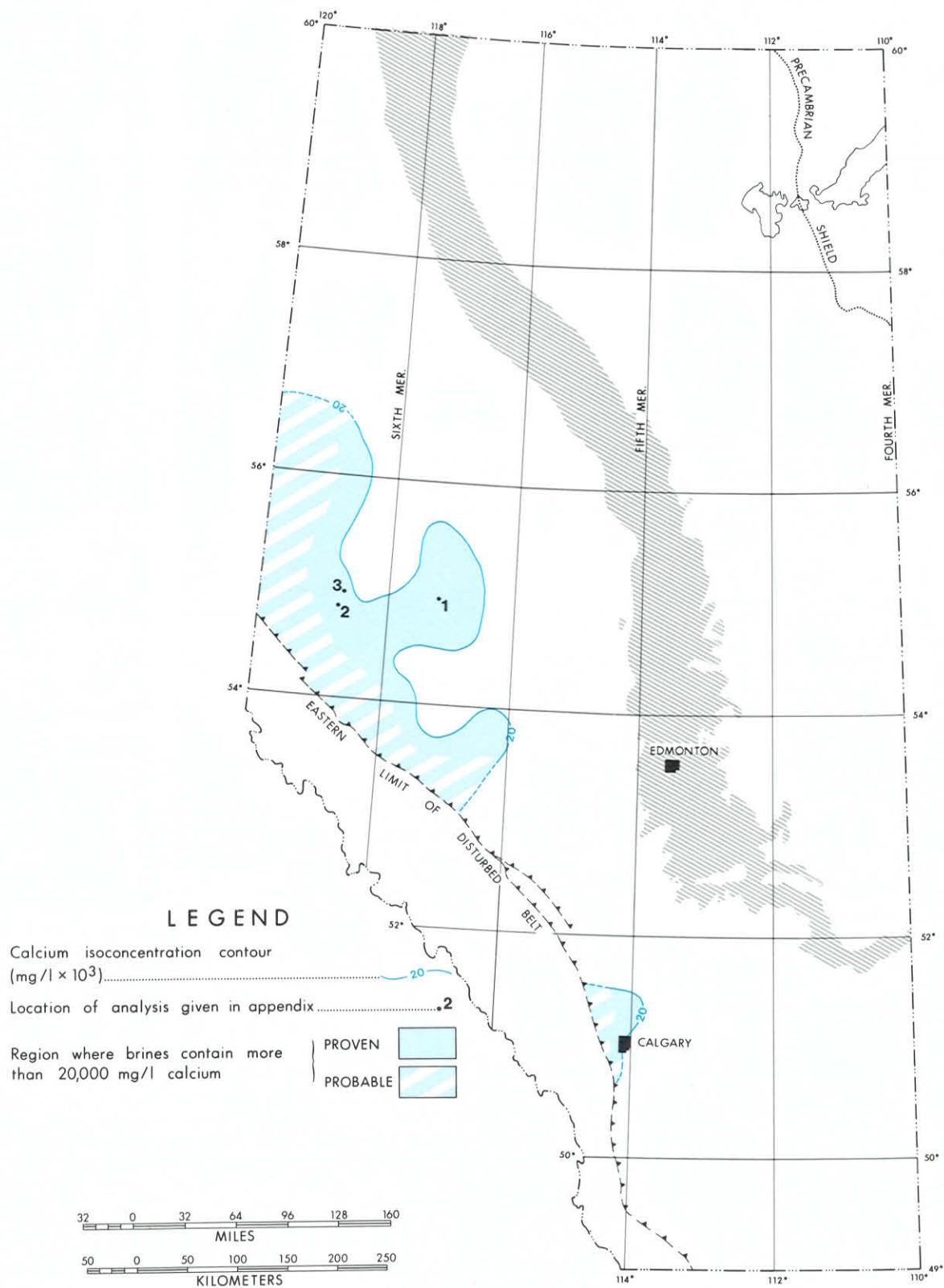
FIGURE 2.   Distribution of brines with more than 20,000 mg/l calcium,
             Upper Devonian Wabamun Group, Alberta.

FIGURE 3. Distribution of brines with more than 3,000 mg/l magnesium,
Upper Devonian Wabamun Group, Alberta.
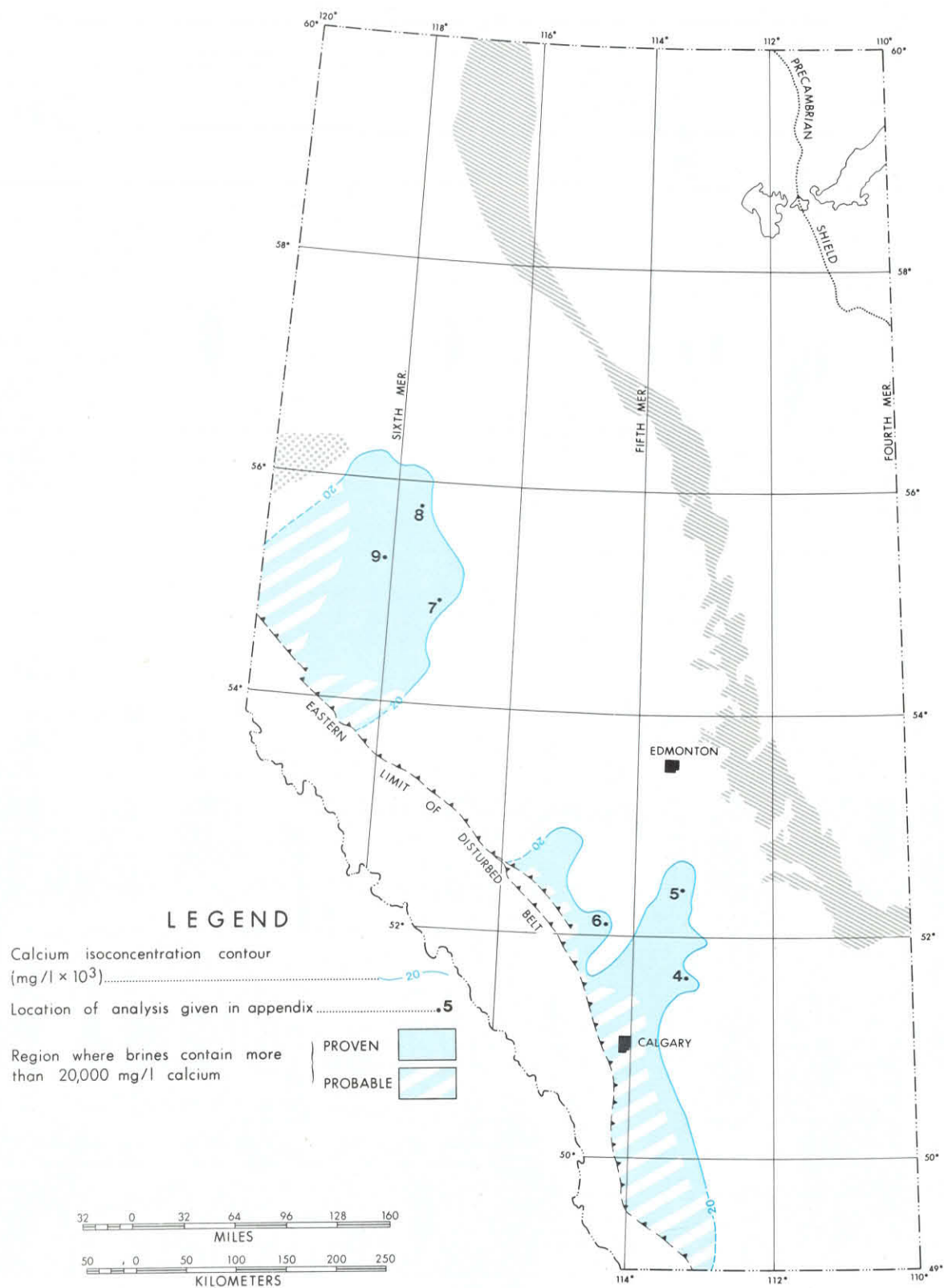
FIGURE 5.   *Distribution of brines with more than 20,000 mg/l calcium,*
Upper Devonian Winterburn Group, Alberta.

FIGURE 6. Distribution of brines with more than 3,000 mg/l magnesium,
Upper Devonian Winterburn Group, Alberta.
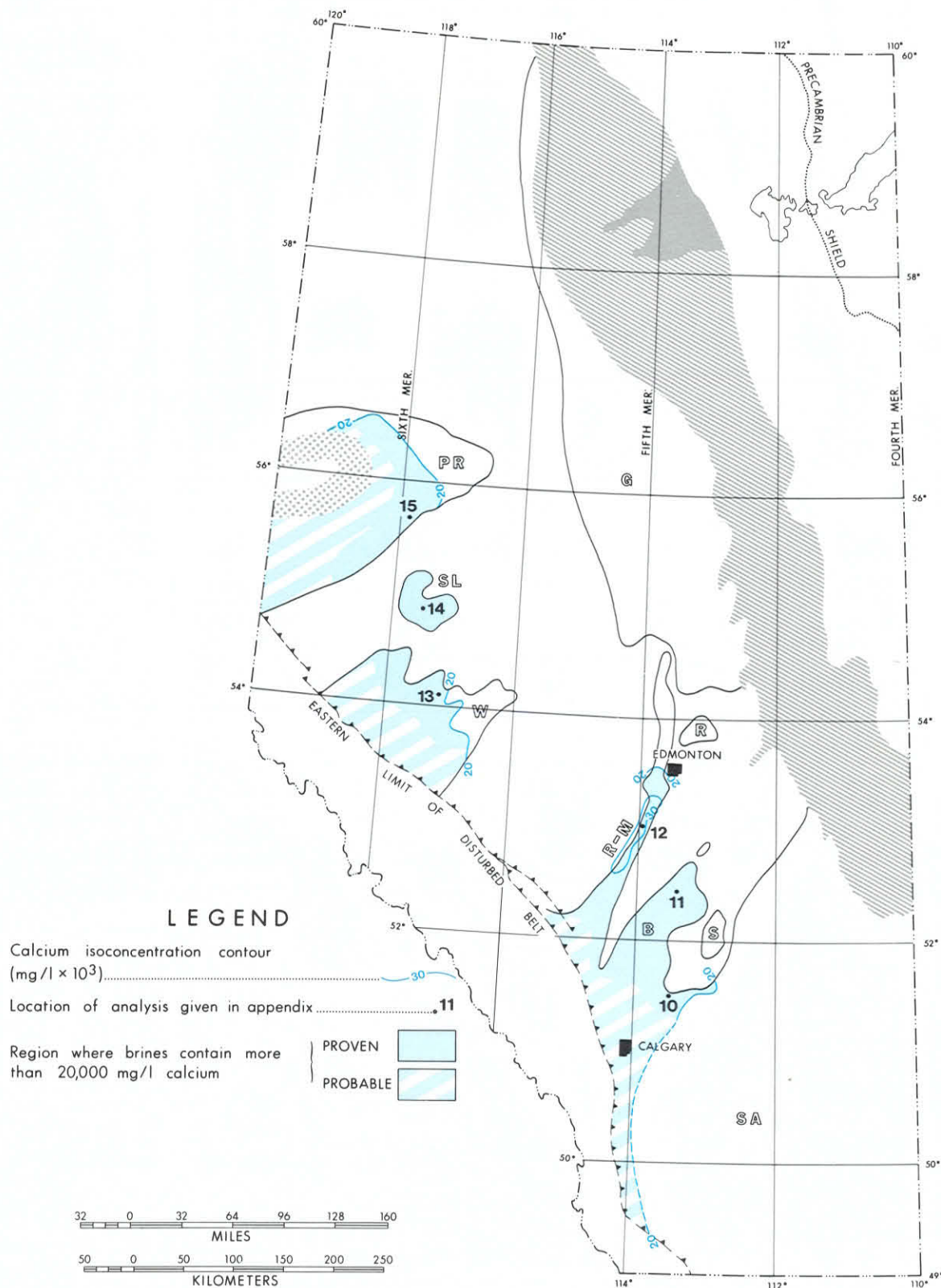
FIGURE 8.   Distribution of brines with more than 20,000 mg/l calcium,
            Upper Devonian Woodbend Group, Leduc Formation, Alberta.
            The reef complexes are identified as follows: B = Bashaw;
            G = Grosmont; PR = Peace River; R = Redwater;
            R-M = Rimbey-Meadowbrook; S = Stettler; SA = Southern
            Alberta Shelf; SL = Sturgeon Lake; W = Windfall.
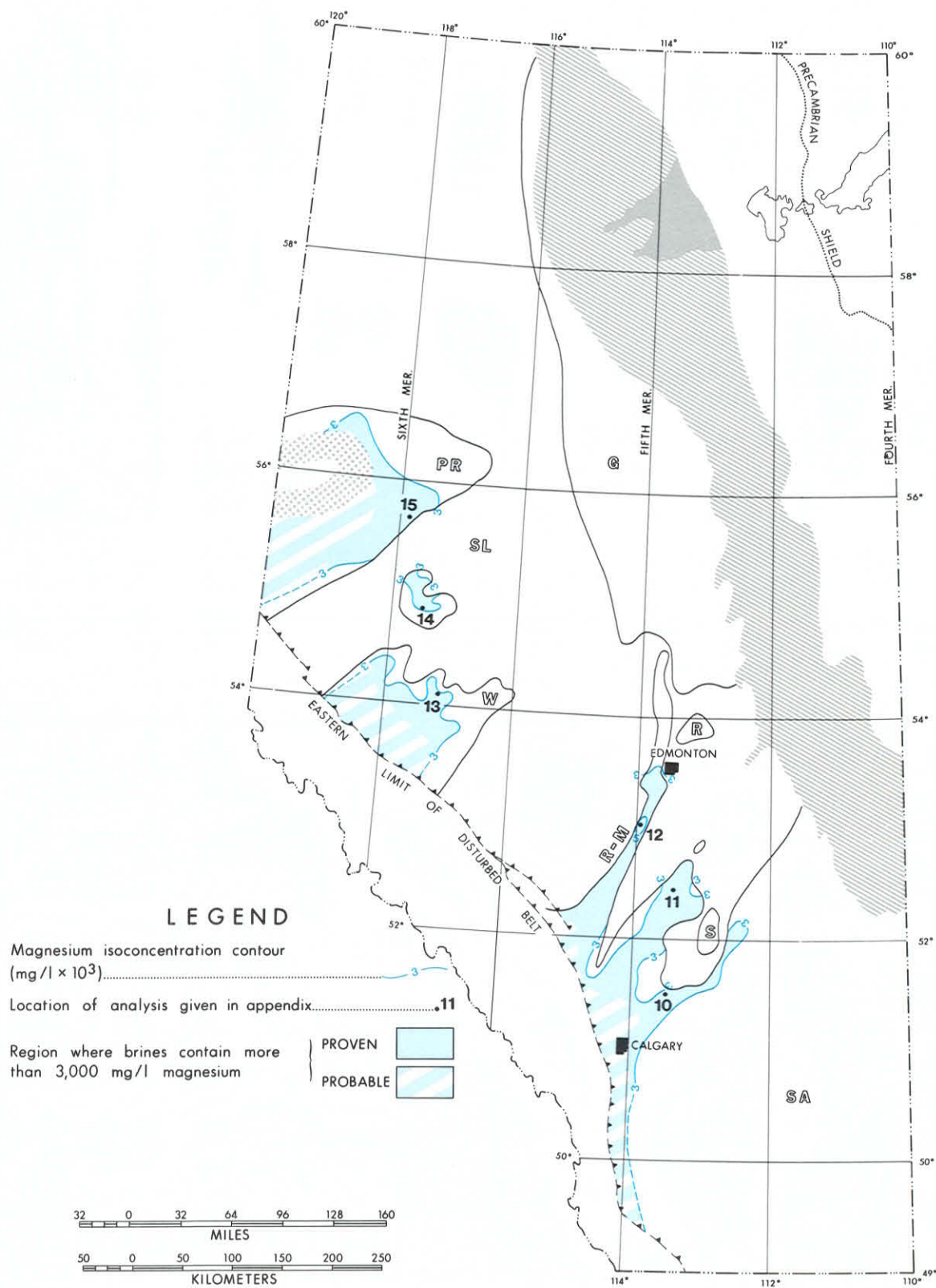
FIGURE 9.   Distribution of brines with more than 3,000 mg/l magnesium,
            Upper Devonian Woodbend Group, Leduc Formation, Alberta.
            For the identification of the reef complexes see figure 8.
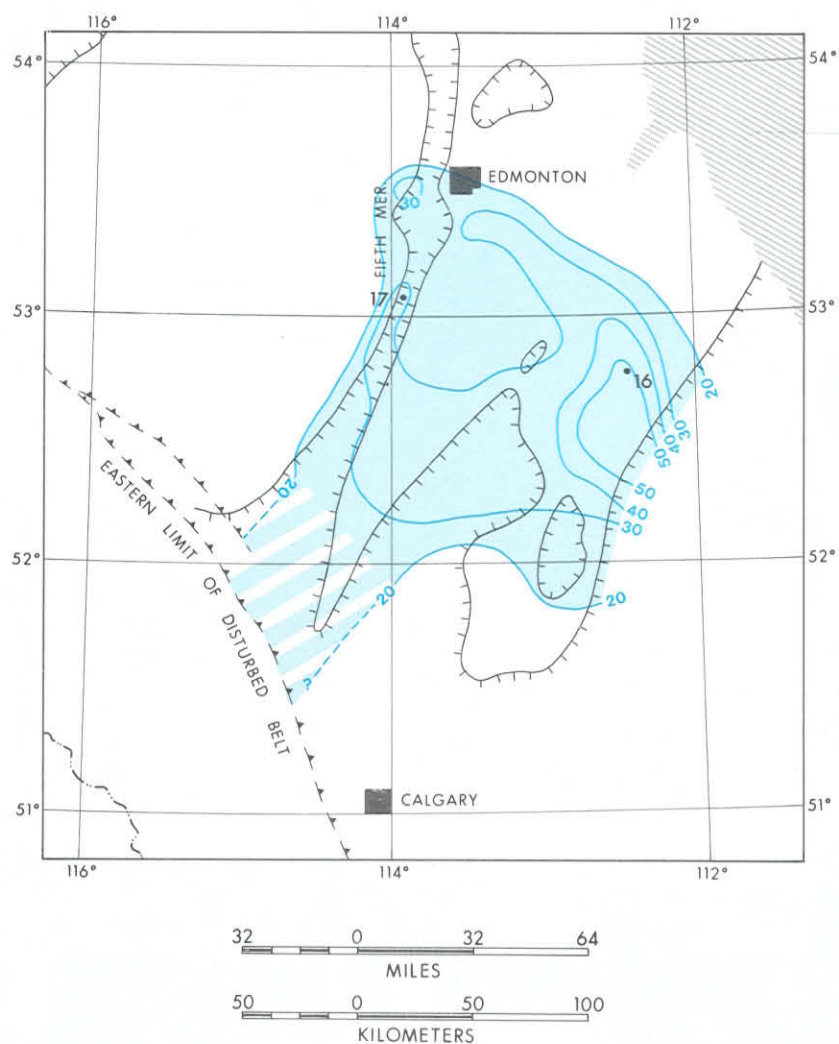
LEGEND

Calcium isoconcentration contour
(mg/l × 10³) .... — 30 —

Location of analysis given in appendix .... •16

Region where brines contain more
than 20,000 mg/l calcium

PROVEN

PROBABLE

KEY MAP

FIGURE 11. Distribution of brines with more than 20,000 mg/l calcium, Upper Devonian Woodbend Group, Cooking Lake Formation, central Alberta.
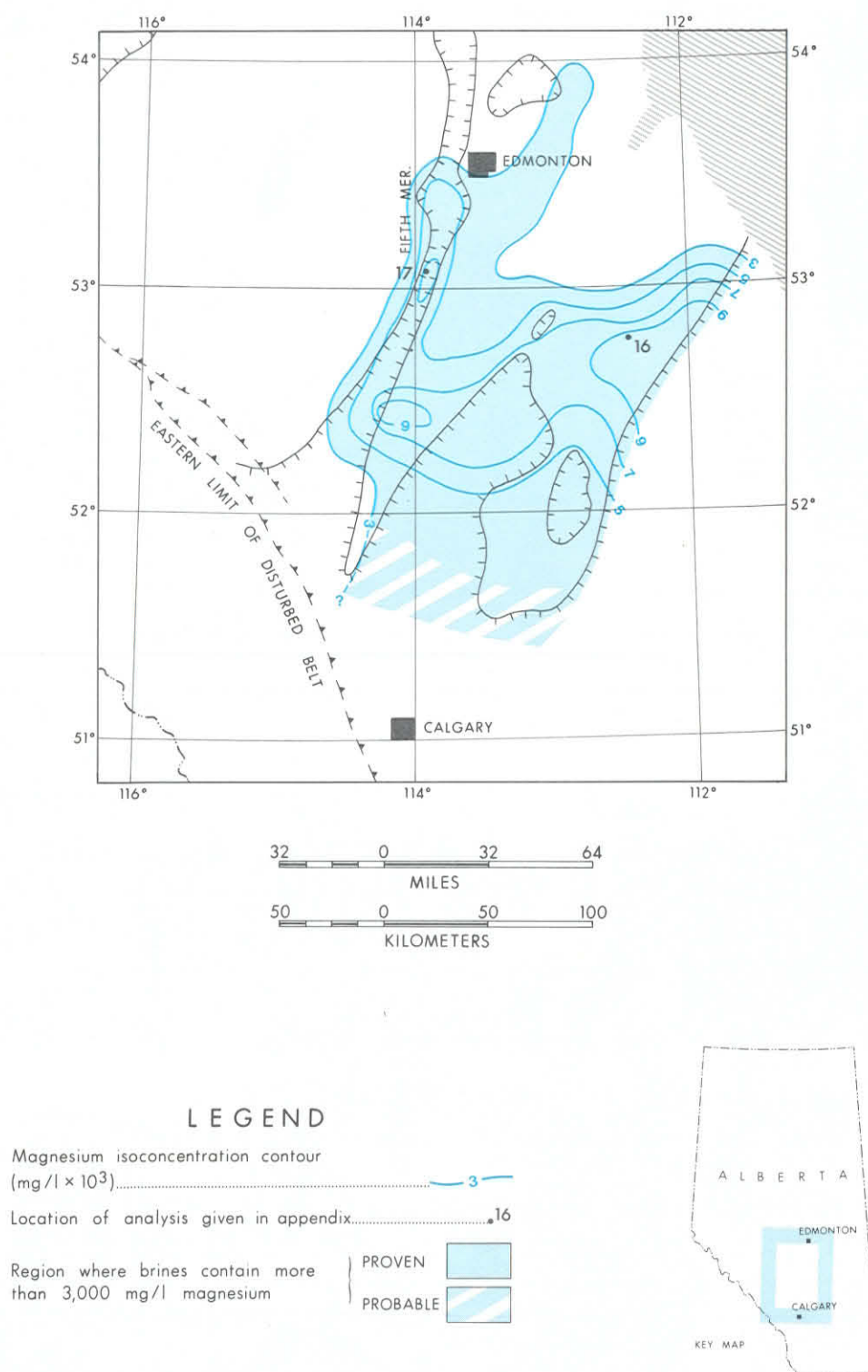
FIGURE 12. Distribution of brines with more than 3,000 mg/l magnesium, Upper Devonian Woodbend Group, Cooking Lake Formation, central Alberta.
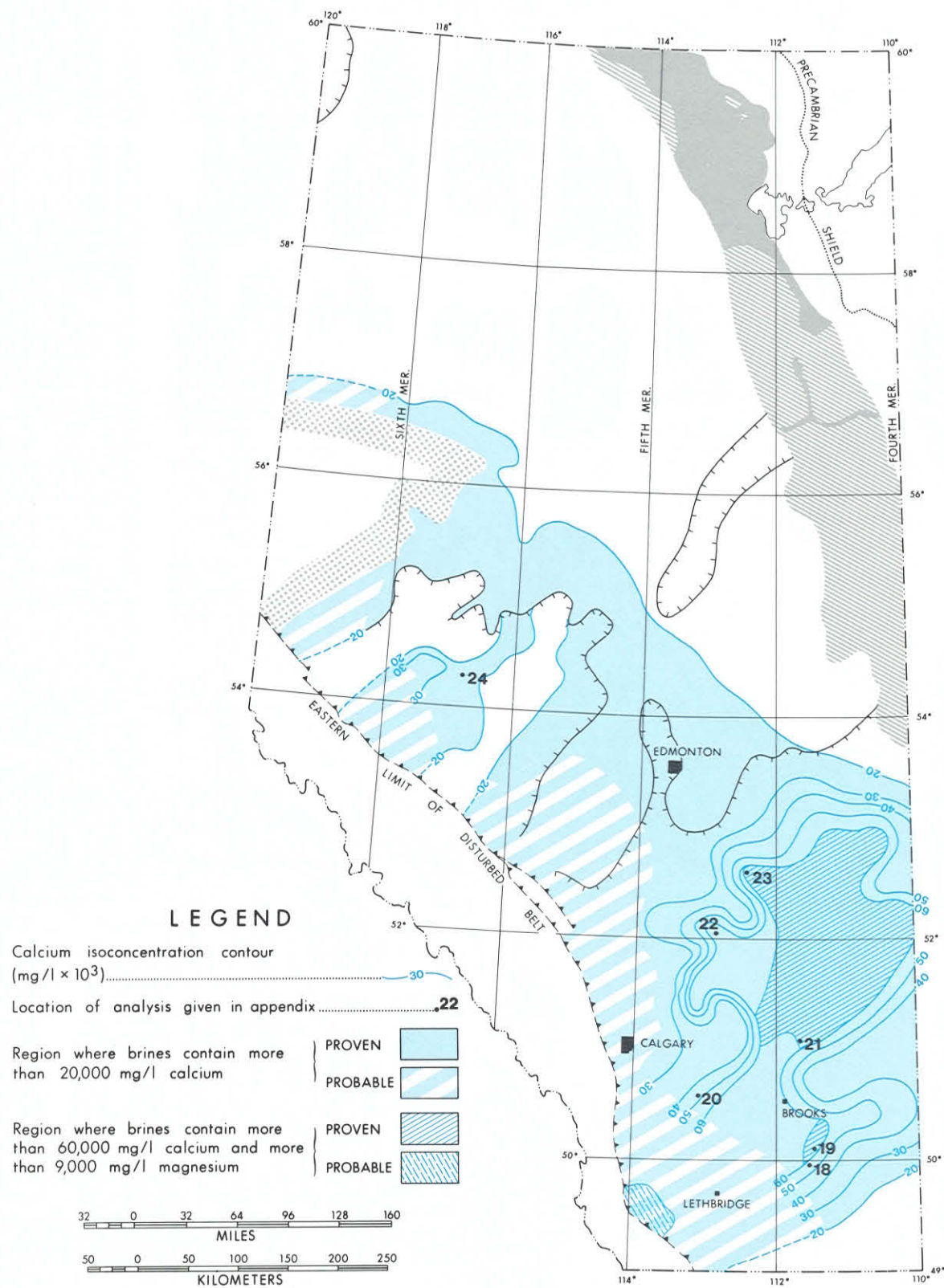
FIGURE 14. *Distribution of brines with more than 20,000 mg/l calcium,*
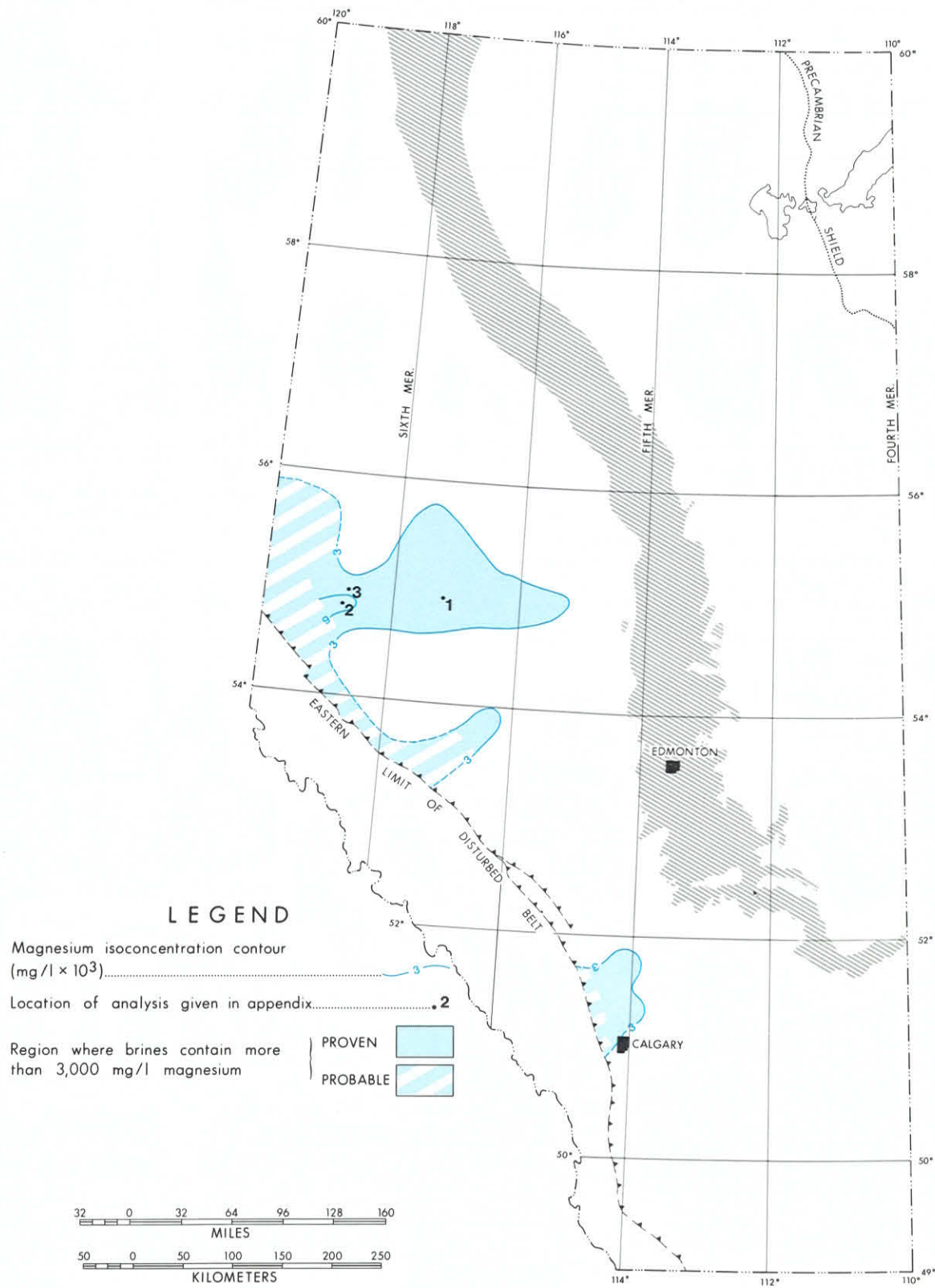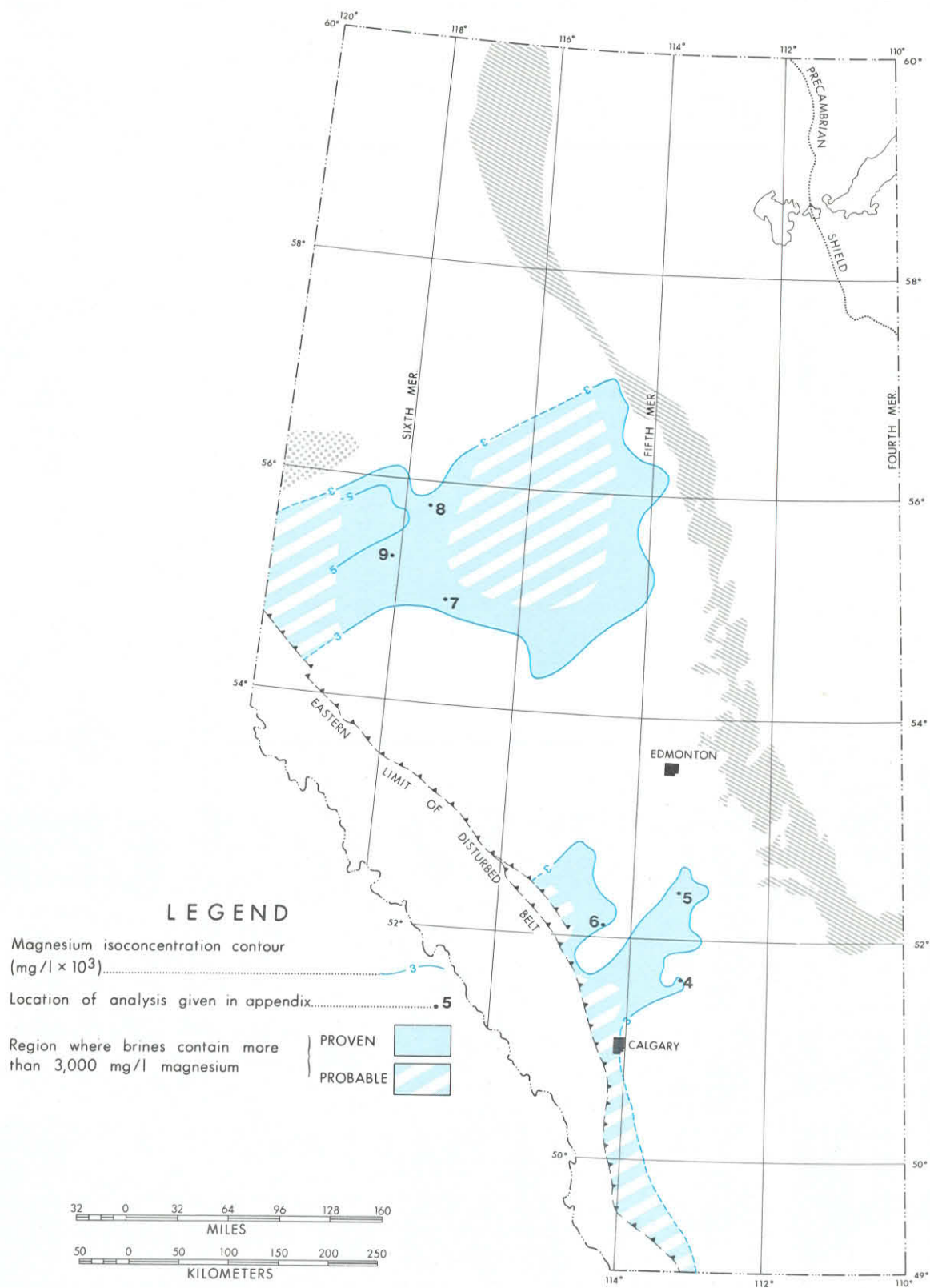*Upper Devonian Beaverhill Lake Formation, Alberta.*
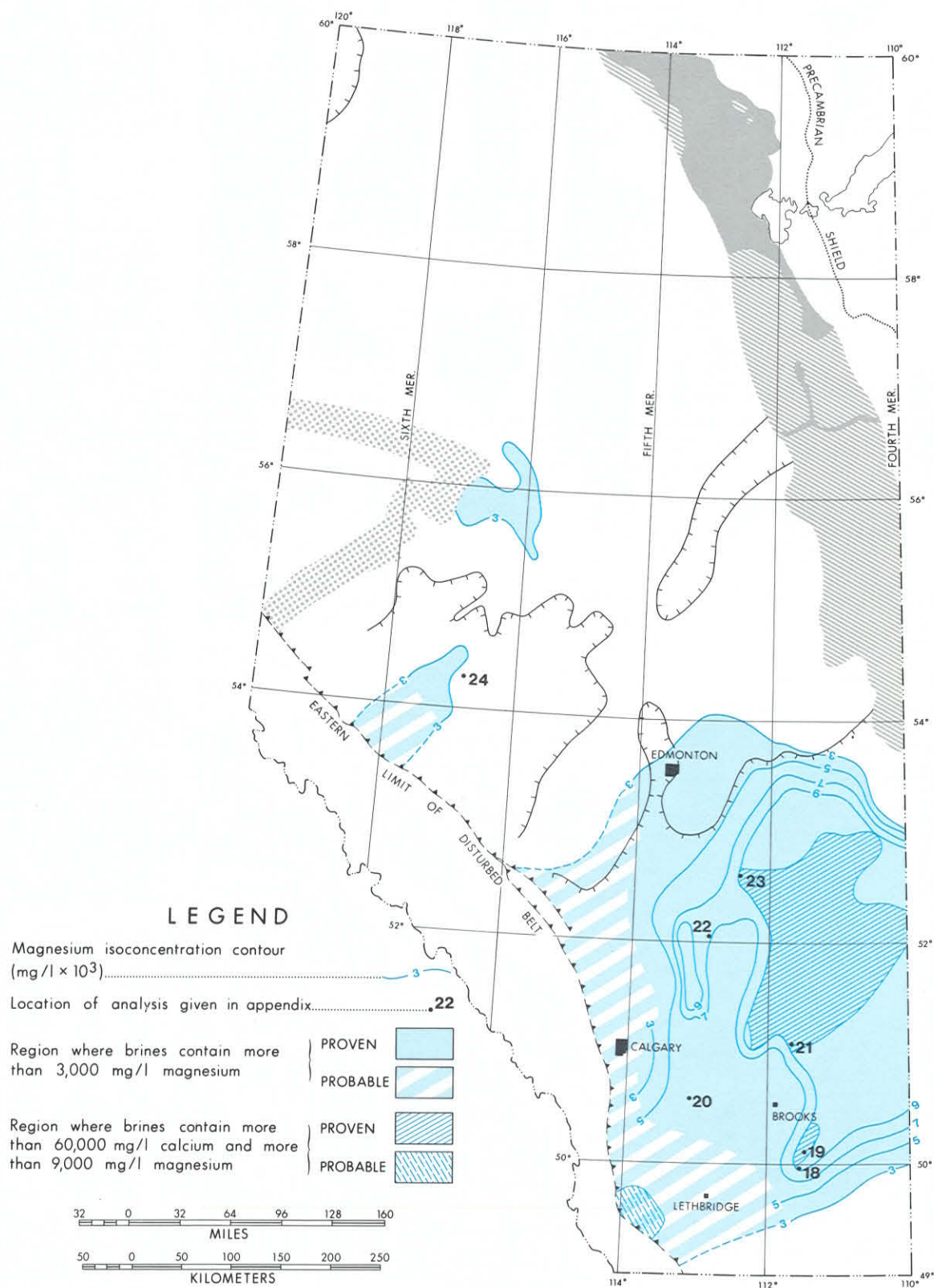
FIGURE 15. Distribution of brines with more than 3,000 mg/l magnesium,
Upper Devonian Beaverhill Lake Formation, Alberta.

FIGURE 17. Distribution of brines with more than 20,000 mg/l calcium,
Middle Devonian Upper Elk Point Subgroup, Gilwood
Sandstone, northern Alberta.
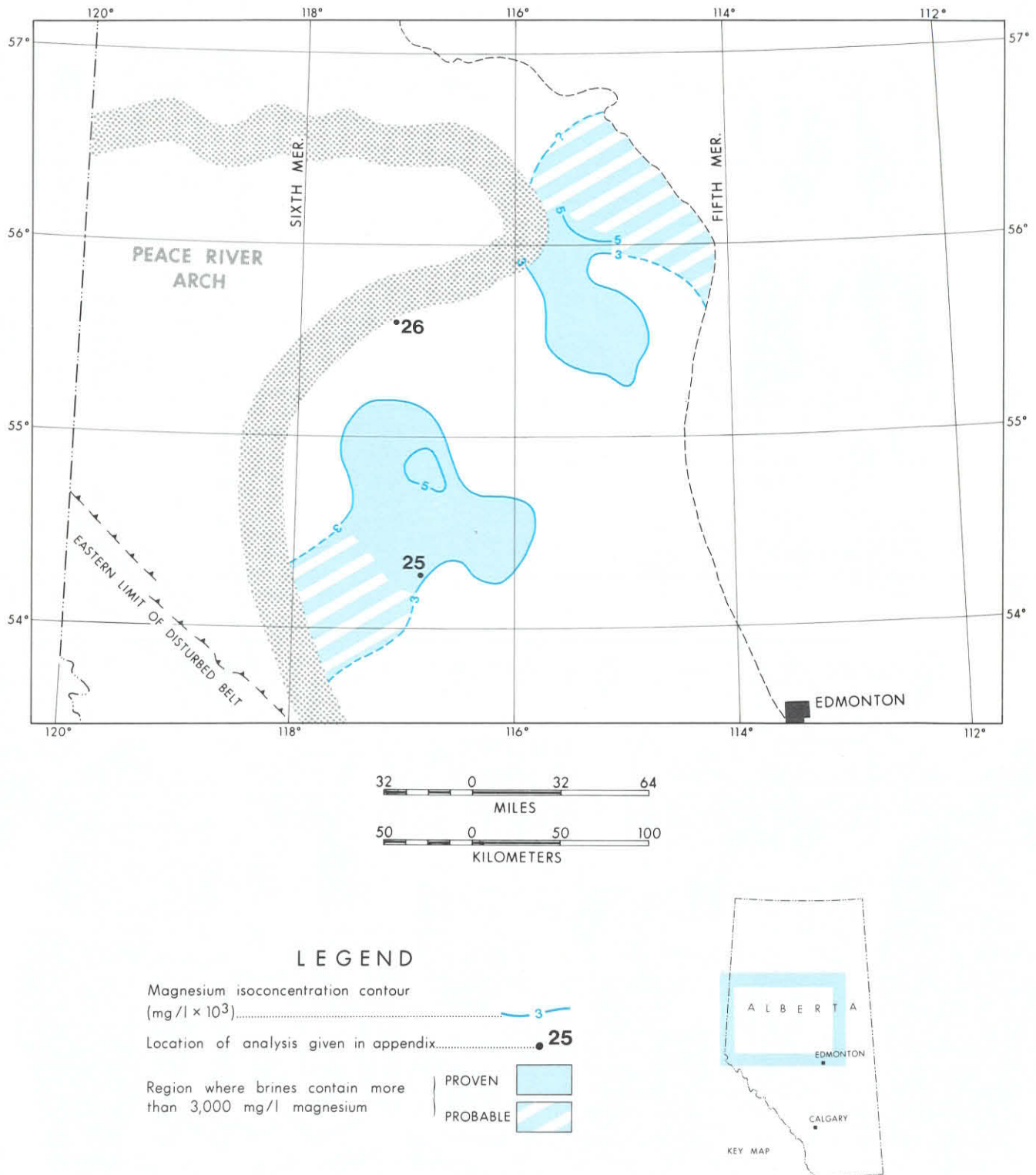
FIGURE 18. Distribution of brines with more than 3,000 mg/l magnesium, Middle Devonian Upper Elk Point Subgroup, Gilwood Sandstone, northern Alberta.

LEGEND

Calcium isoconcentration contour
(mg/l × 10³).. —30—

Location of analysis given in appendix................... •27

Region where brines contain more   PROVEN
than 20,000 mg/l calcium   PROBABLE

Region where brines contain more   PROVEN
than 60,000 mg/l calcium and more
than 9,000 mg/l magnesium   PROBABLE

32   0   32   64   96   128   160
MILES

50   0   50   100   150   200   250
KILOMETERS
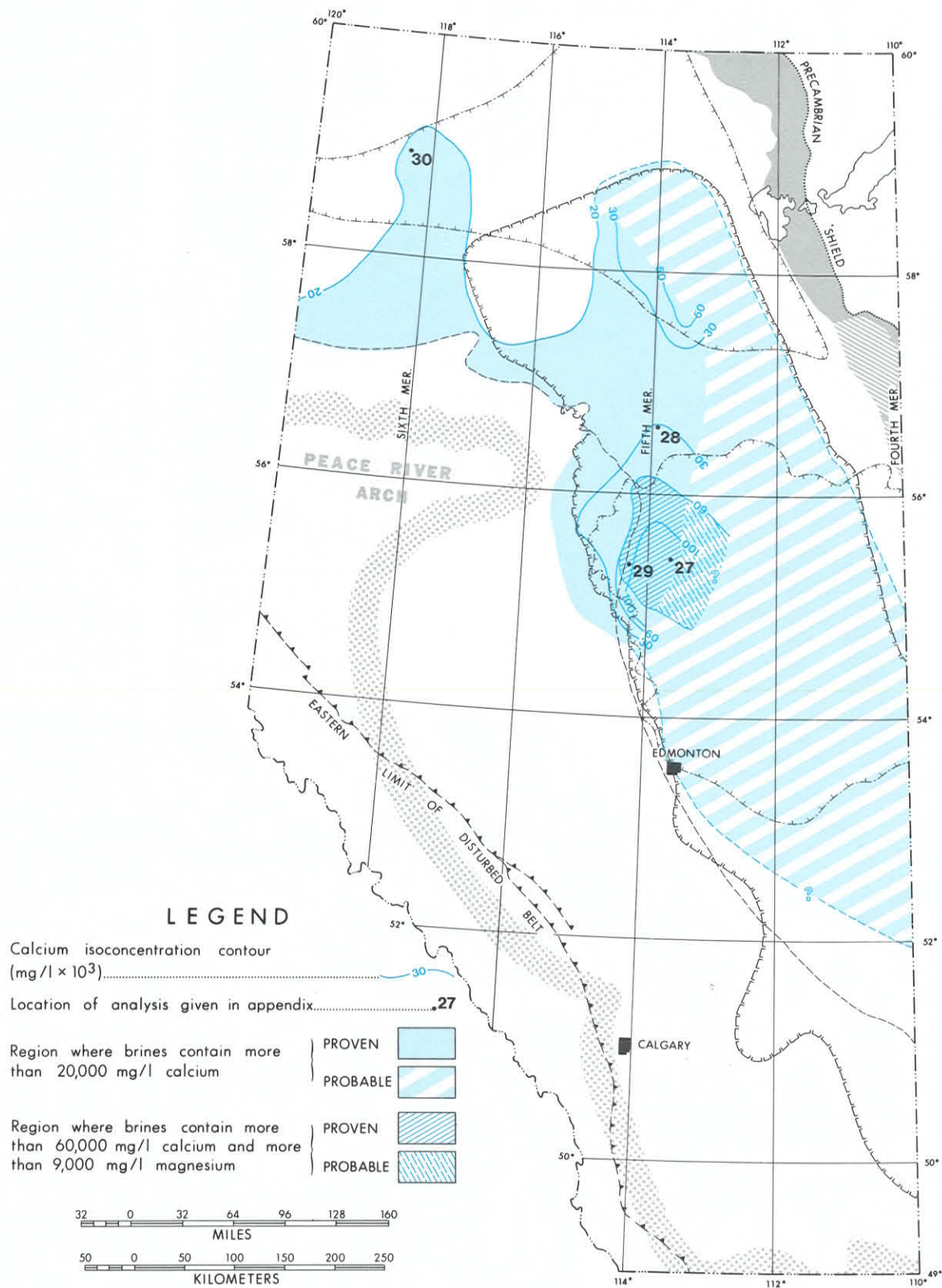
FIGURE 20. Distribution of brines with more than 20,000 mg/l calcium,
Middle Devonian Upper Elk Point Subgroup, Keg River
Formation, Alberta. Limits of Middle Devonian halite beds
from Hamilton (1970).
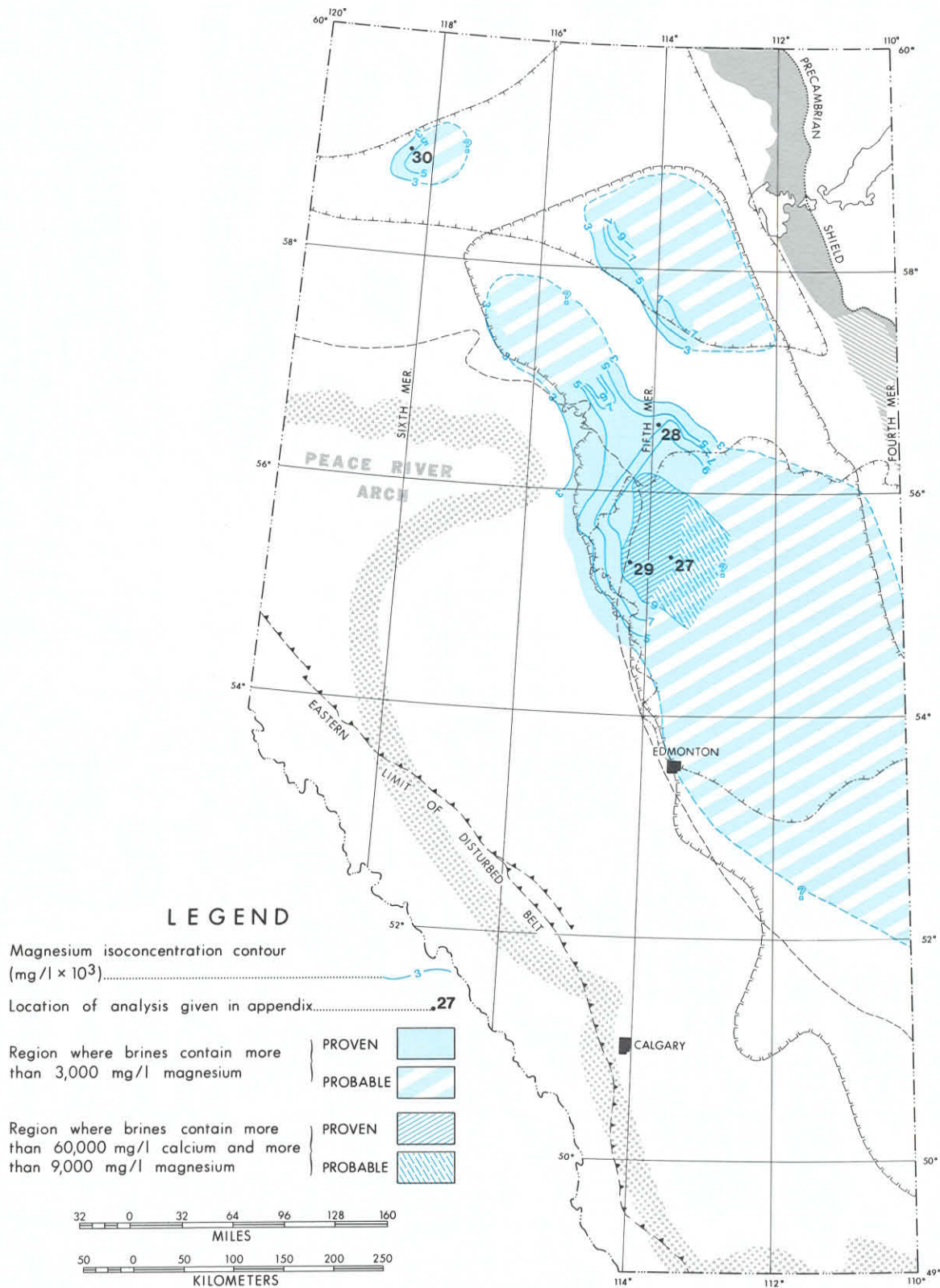
FIGURE 21. Distribution of brines with more than 3,000 mg/l magnesium, Middle Devonian Upper Elk Point Subgroup, Keg River Formation, Alberta. Limits of Middle Devonian halite beds from Hamilton (1970).

LEGEND

Calcium isoconcentration contour
(mg/l × 10³) .... —30

Location of analysis given in appendix .... •31

Region where brines contain more
than 20,000 mg/l calcium

PROVEN

PROBABLE

Region where brines contain more
than 60,000 mg/l calcium and more
than 9,000 mg/l magnesium

PROVEN

PROBABLE
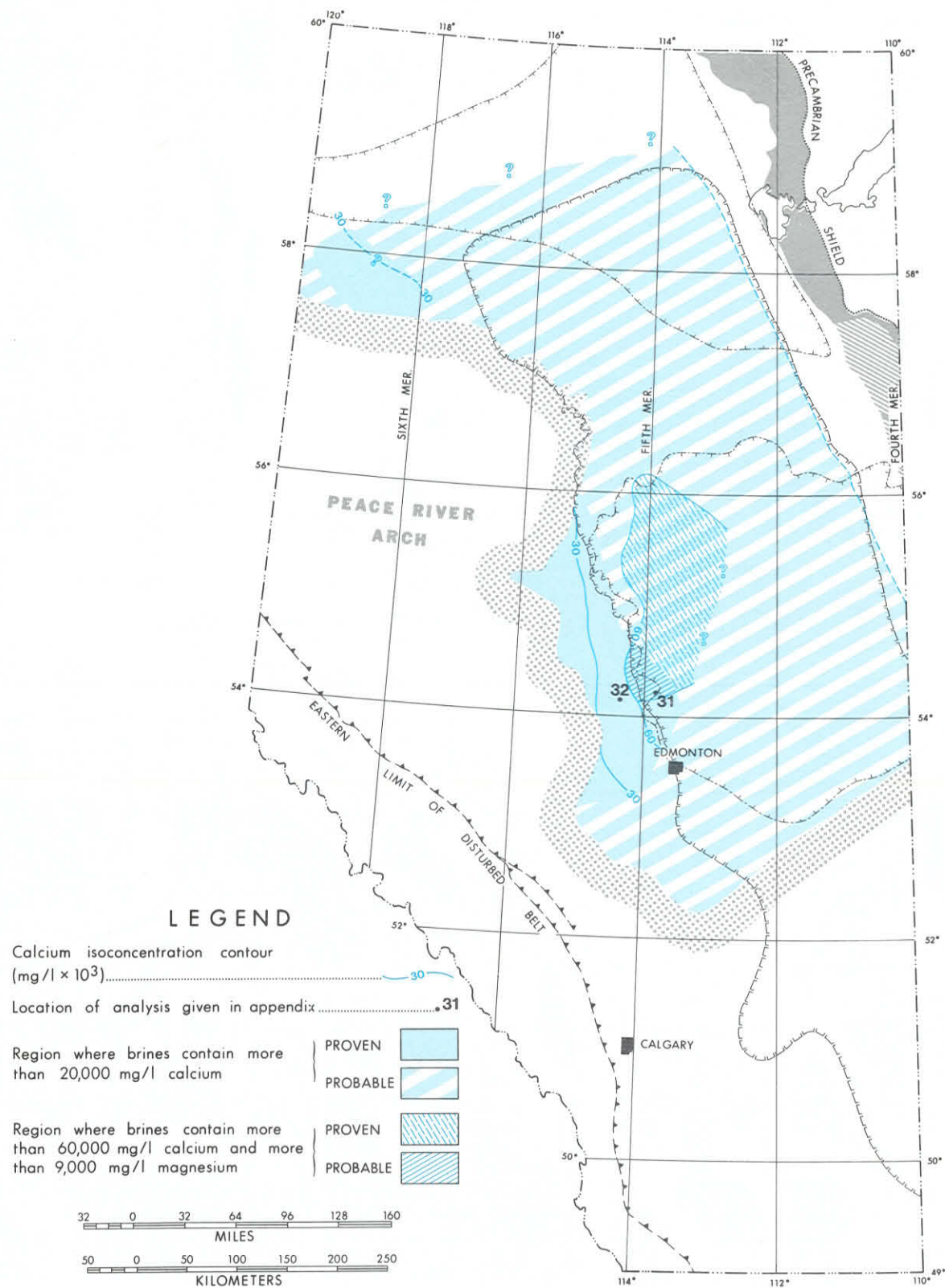
FIGURE 23. Distribution of brines with more than 20,000 mg/l calcium,
Middle Devonian Lower Elk Point Subgroup, Alberta.
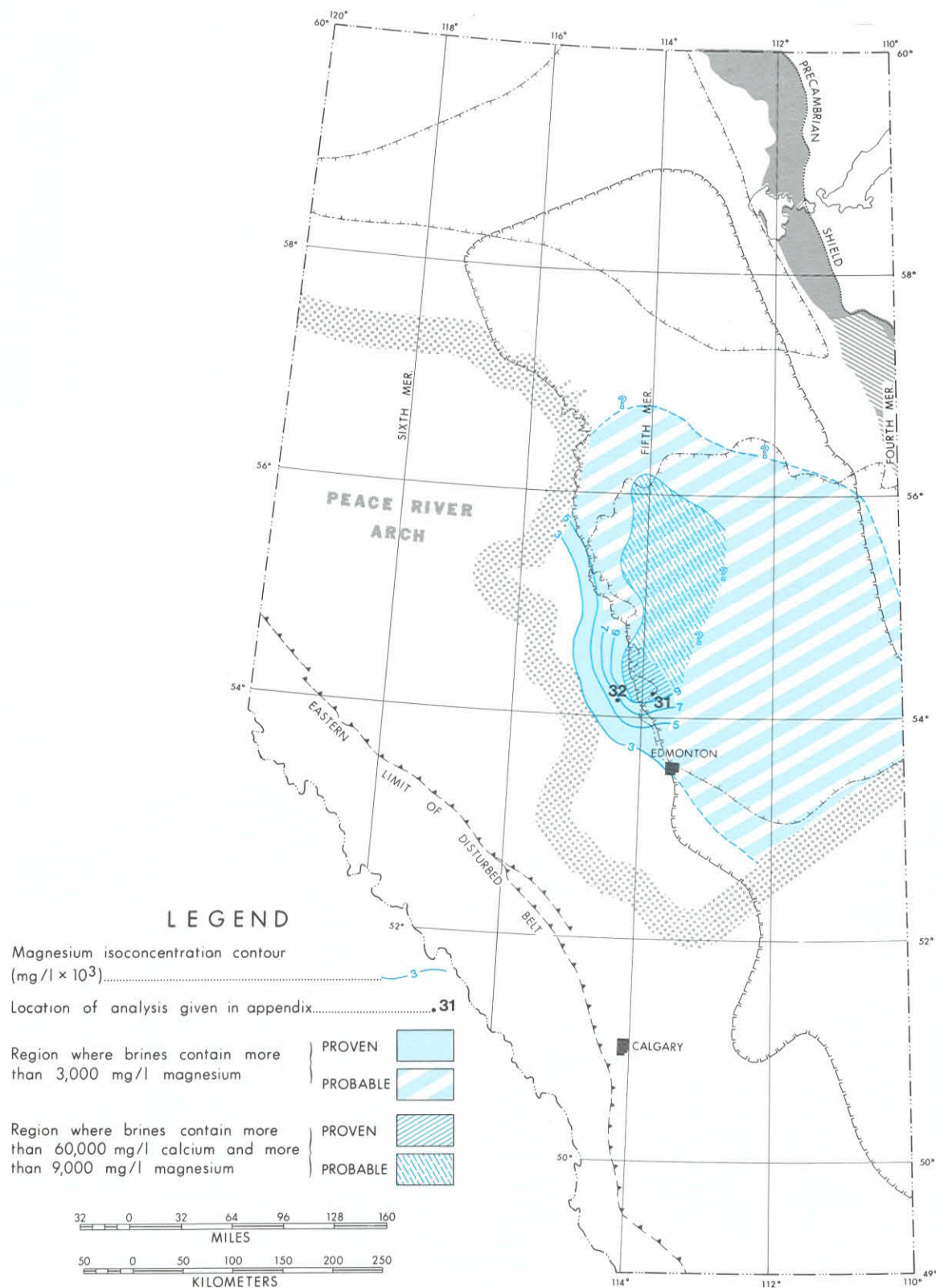
FIGURE 24. Distribution of brines with more than 3,000 mg/l magnesium,
Middle Devonian Lower Elk Point Subgroup, Alberta.
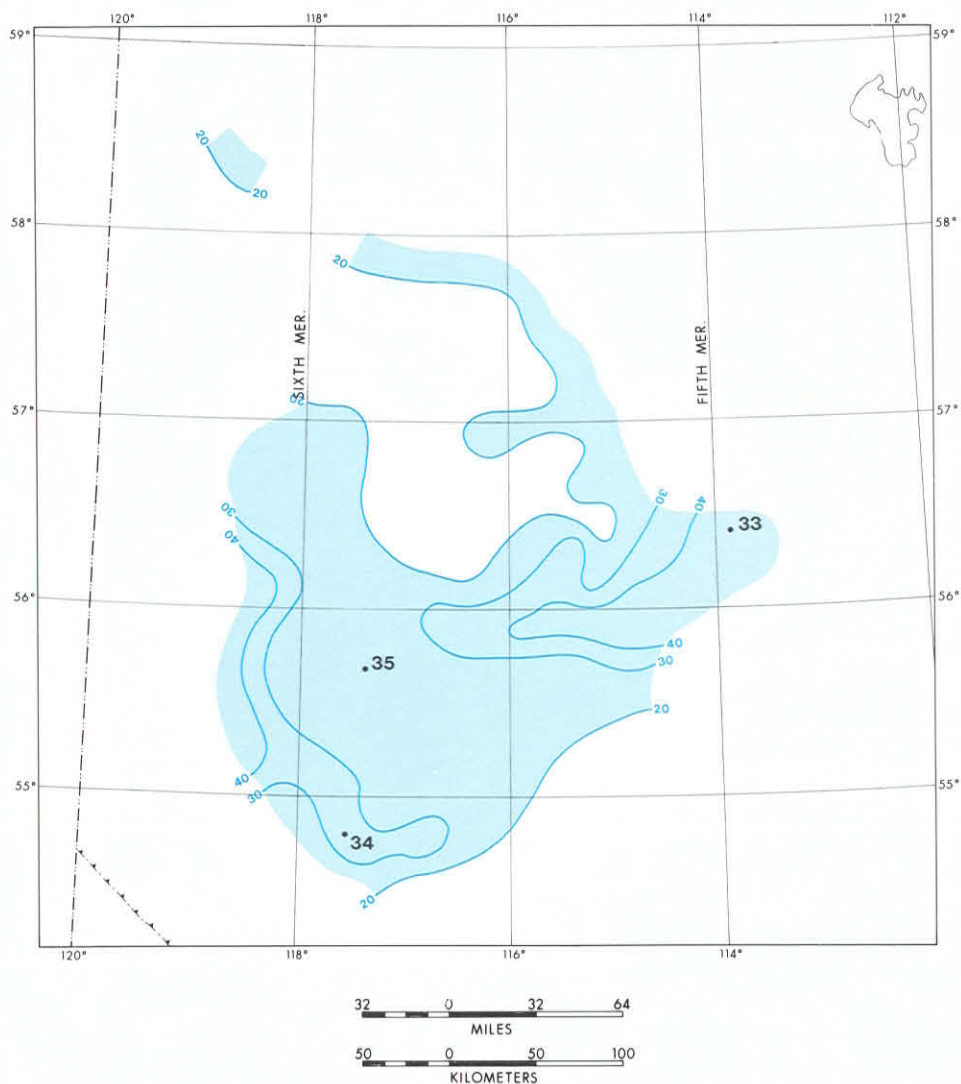
LEGEND

Calcium isoconcentration contour
(mg/l × 10³).. ⎯ 30 ⎯

Location of analysis given in appendix...................... •34

Region where brines contain more   } PROVEN
than 20,000 mg/l calcium   } PROBABLE

FIGURE 26. Distribution of brines with more than 20,000 mg/l calcium,
Granite Wash, northern Alberta.

FIGURE 27. Distribution of brines with more than 3,000 mg/l magnesium,
Granite Wash, northern Alberta.

FIGURE 29. Distribution of brines in Alberta with more than 60,000 mg/l
calcium and more than 9,000 mg/l magnesium.

APPENDIX B.
LOCATION, CHEMICAL COMPOSITION, AND PHYSICAL
PROPERTIES OF SELECTED BRINES
FROM THE ALBERTA PLAINS

Well Name	Location					Field	Pool	Sampling Conditions
	Lsd.	Sec.	Tp.	R.	W. of			
UPPER DEVONIAN, WABAMUN GROUP								
1. HB et al Sturls 10-5W-69-21 depth: 7,492-7,505 feet (perfs.)	10	5	69	21	5	Sturgeon Lake South	D-1A	Separator-flowing
2. Shell Smoky River 10-20-67-5 depth: 11,325-11,605 feet (perfs.)	10	20	67	5	6	Gold Creek	Wabamun B	Separator-flowing
3. Pan Am Scurry F-1 Goldck 7-1-69-5 depth: 11,010-11,120 feet	7	1	69	5	6	Wildcat		DST 7,300 ft sw, 700 ft wc
UPPER DEVONIAN, WINTERBURN GROUP, NISKU FORMATION								
4. Grt Plns Choqua Thr Eh 9-9-31-23 depth: 6,630-6,745 feet	9	9	31	23	4	Wildcat		DST 4,730 ft sw
5. Ambass BA Alix 7-7-40-23 depth: 5,974-5,980 feet (perfs.)	7	7	40	23	4	Alix	D-2	Treater Inlet-pump
6. Imp HB Dickson 1-28-36-3 depth: 9,185-9,301 feet	1	28	36	3	5	Wildcat		DST 3,430 ft sw, 465 ft sulf sw, 1,845 ft wc
7. HB Union Liberal No 5-5-69-21 depth: 7,685-7,720 feet	5	5	69	21	5	Sturgeon Lake South	D-2A	DST 275 ft sw, 785 ft oil cut mud, 90 ft mud, gas TSTM
8. Caroline Hunt Sands Culp 4-31-78-23 depth: 6,540-6,607 feet	4	31	78	23	5	Wildcat		DST 3,745 ft clean sulf sw
9. Amerada Crown AQ 2-2 depth: 8,938-9,021 feet	2	2	73	1	6	Wildcat		DST 3,780 ft sulf sw
UPPER DEVONIAN, WOODBEND GROUP, LEDUC FORMATION								
10. TGT A1 Acme 10-32-29-25 depth: 7,440-7,494 feet	10	32	29	25	4	Wildcat		DST 1,400 ft black sulf sw
11. Pohl No. 3-21 depth: 6,294-6,297 feet (perfs.)	3	21	40	24	4	Clive	D-3A	Wellhead-pump
12. Texaco Bonnie Glen CPR No. K1 depth: 7,070-7,072 feet (perfs.)	3	19	47	27	4	Bonnie Glen	D-3A	Treater-flowing
13. Mobil et al Jackfish 10-17-59-20 depth: 11,559-11,568 feet	10	17	59	20	5	Wildcat		DST 3,900 ft sw
14. Amerada Crown AJ 1-8 depth: 9,194-9,216 feet	1	8	68	23	5	Wildcat		DST 2,700 ft sw
15. HB Union Eaglesham 6-14-77-25 depth: 7,594-7,610 feet	6	14	77	25	5	Eaglesham	D-3A	DST 5,100 ft sulf sw
UPPER DEVONIAN, WOODBEND GROUP, COOKING LAKE FORMATION								
16. Imperial Rosalind 9-9-44-17 depth: 4,829-4,835 feet	9	9	44	17	4	Wildcat		DST 360 ft sw, 100 ft mud
17. Kissinger South Wizard 10-32-47-27 depth: 6,975-6,985 feet	10	32	47	27	4	Wildcat		DST 2,360 ft oil cut sw, 90 ft condensate, gas 310 MCF/D
UPPER DEVONIAN, BEAVERHILL LAKE FORMATION								
18. BA Grand Forks 12-14-12-12 depth: 5,260-5,295 feet	12	14	12	12	4	Wildcat		DST 4,250 ft gassy sw
19. BA Grand Forks 10-21-13-11 depth: 5,205-5,225 feet	10	21	13	11	4	Wildcat		DST 350 ft sw
20. Amerada Crown DZ Milo 12-1-19-23 depth: 8,060-8,240 feet	12	1	19	23	4	Wildcat		DST 2,500 ft sw
21. HB Dehli Cess 10-5-25-12 depth: 5,470-5,545 feet	10	5	25	12	4	Wildcat		DST 830 ft sl gaseous sw with oil scum

[1]Calculated

Chemical Constituents (mg/l)						Total Dissolved Solids (mg/l)		Density (60°F)	pH	Resistivity (ohm meters)	$\frac{Na}{Ca+Mg}$	Ca:Mg
Na[1]	Ca	Mg	Cl	SO₄	HCO₃	calculated	ignition					
69,769	24,424	4,131	162,400	318	435	261,480	232,860	1.173	6.3	0.052 at 68°F	1.95	3.59
18,140	24,030	11,301	102,800	202	880	157,364	118,750	1.107	6.4	0.072 at 25°C	0.37	1.29
71,847	24,431	3,492	163,800	321	340	264,229	255,040	1.177	5.9	0.046 at 68°F	2.07	4.25
68,484	21,790	4,573	156,500	535	1,100	252,986	221,250	1.157	6.1	0.071 at 68°F	2.04	2.89
51,020	23,482	3,563	129,492	520	578	209,666	203,890	1.144	6.48	0.062 at 25°C	1.52	4.00
59,678	20,274	3,050	135,103	1,061	1,616	220,812	–	1.151	7.85	–	2.06	4.03
60,498	25,011	3,388	146,850	344	610	236,704	229,160	1.075	7.3	0.054 at 68°F	1.72	4.48
59,773	21,141	4,471	142,200	382	290	231,557	231,080	1.157	6.3	0.053 at 68°F	1.83	2.87
55,218	22,128	4,480	137,034	331	205	219,399	211,820	1.150	6.3	0.056 at 68°F	1.63	3.00
55,756	26,639	5,168	148,000	142	190	235,899	235,950	1.172	7.8	0.059 at 68°F	1.38	3.13
56,491	20,567	3,071	131,464	425	456	213,522	203,300	1.144	6.75	0.946 at 25°C	1.92	4.06
41,741	39,311	5,070	148,144	284	222	235,378	237,610	1.169	6.2	0.059 at 25°C	0.76	4.70
58,078	24,940	5,502	148,610	391	1,490	239,016	225,620	1.158	6.6	0.062 at 68°F	1.49	2.75
56,899	26,465	3,045	142,992	286	475	230,164	224,280	1.162	6.1	0.065 at 68°F	1.58	5.27
64,319	24,007	6,242	159,577	334	130	254,614	251,161	1.170	7.2	0.062 at 68°F	1.63	2.33
21,986	52,142	9,126	152,435	292	246	236,235	204,700	1.179	6.1	–	0.29	3.47
45,124	30,800	8,384	146,260	2,815	376	233,830	–	1.165	6.7	0.045 at 76°F	0.88	2.23
3,232	55,580	10,390	132,420	400	723	203,882	–	1.135	6.1	0.092 at 76°F	0.04	3.25
28,940	86,030	9,830	223,770	80	817	352,276	–	1.273	7.65	0.040 at 75°F	0.25	5.31
57,910	47,900	6,596	192,800	356	450	306,016	274,490	1.204	6.4	0.055 at 68°F	0.86	4.41
22,189	88,800	15,552	236,253	64	712	363,599	–	1.273	6.15	0.048 at 73°F	0.17	3.46

Well Name	Location					Field	Pool	Sampling Conditions
	Lsd.	Sec.	Tp.	R.	W. of			
UPPER DEVONIAN, BEAVERHILL LAKE FORMATION (continued)								
22. BA CPR Fenn West 5-7-36-20 depth: 6,870–6,890 feet	5	7	36	20	4	Wildcat		DST 1,425 ft gassy sw
23. BA Arnold Donalda A5-20-42-17 depth: 5,427–5,457 feet	5	20	42	17	4	Wildcat		DST 1,000 ft sw, 440 ft muddy sw
24. HB BL Gas Unit 1 KaybobS 3-28-61-19 depth: 10,802–10,827 feet	3	28	61	19	5	Wildcat		DST 2,530 ft sulf sw
MIDDLE DEVONIAN, UPPER ELK POINT SUBGROUP, GILWOOD SANDSTONE								
25. HB Union Kaybob 2-19-61-19 depth: 11,063–11,073 feet	2	19	61	19	5	Wildcat		DST 4,860 ft sw, 2,520 ft wc
26. Jeff Lake Imp Iroquois 10-32-76-20 depth: 7,988–8,010 feet	10	32	76	20	5	Wildcat		DST 5,200 ft sw
MIDDLE DEVONIAN, UPPER ELK POINT SUBGROUP, KEG RIVER FORMATION								
27. Home Marten Hills 4-16-74-24 depth: 5,060–5,108 feet	4	16	74	24	4	Wildcat		DST 4,500 ft sw, 180 ft mud
28. IOE Corn Lake 4-3-88-25 depth: 4,278–4,316 feet	4	3	88	25	4	Wildcat		DST 3,260 ft sw, 360 ft muddy sw
29. Shell IOE Driftwood 4-30-73-2 depth: 5,689–5,742 feet	4	30	73	2	5	Wildcat		DST 816 ft sw
30. Mobil Oil Nagus Creek 6-24-114-3 depth: 4,749–4,795 feet	6	24	114	3	6	Wildcat		DST 2,656 ft black sulf sw
MIDDLE DEVONIAN, LOWER ELK POINT SUBGROUP								
31. Imp Baysel Riverdale 1-27-60-26 depth: 6,140–6,195 feet	1	27	60	26	4	Wildcat		DST 3,955 ft sw
32. Home Barrhead 10-35-59-3 depth: 6,972–7,042 feet	10	35	59	3	5	Wildcat		DST 5,708 ft sw
GRANITE WASH								
33. Imp Wabasca 6-25-85-25 depth: 4,490–4,550 feet	6	25	85	25	4	Wildcat		DST 4,154 ft sw
34. Amerada Crown AE 9-8 depth: 10,744–10,775 feet	9	8	67	23	5	Wildcat		DST 5,500 ft sw
35. Colorado et al G'ville 16-17-77-22 depth: 8,001–8,030 feet	16	17	77	22	5	Wildcat		DST 4,300 ft sw, trace of oil scum

[1]Calculated

Bromide (mg/l) and iodide (mg/l) were determined only on the following samples:

5: Br – 961 I – 21	18: Br – 1,126 I – 0
11: Br – 996 I – 21	19: Br – 2,786 I – 0
12: Br – 550 I – 28	28: Br – 1,475 I – 18

Chemical Constituents (mg/l)						Total Dissolved Solids (mg/l)		Density (60°F)	pH	Resistivity (ohm meters)	$\frac{Na}{Ca+Mg}$	Ca:Mg
Na[1]	Ca	Mg	Cl	SO$_4$	HCO$_3$	calculated	ignition					
32,630	72,700	7,200	199,740	218	125	312,636	–	1.232	5.5	0.051 at 71°F	0.34	6.13
29,039	69,300	9,200	194,000	250	113	301,924	–	1.227	5.85	0.053 at 70°F	0.30	4.57
58,064	24,455	2,403	139,082	227	1,030	225,293	–	1.157	6.75	0.044 at 77°F	1.78	6.17
60,214	30,000	4,540	158,598	700	160	254,215	254,910	1.179	6.6	0.062 at 68°F	1.40	4.01
70,710	25,200	2,916	161,880	253	176	261,173	–	1.180	6.2	0.048 at 74°F	2.05	5.24
25,797	101,472	13,333	258,070	48	216	398,948	392,060	1.291	5.9	0.058 at 68°F	0.18	4.62
77,664	38,611	5,493	203,211	253	148	326,873	319,660	1.225	5.66	0.039 at 25°C	1.42	4.26
23,077	99,324	11,865	245,740	159	165	380,344	–	1.281	5.5	0.063 at 60°F	0.17	5.08
59,300	23,250	4,994	146,000	1,419	225	235,280	203,640	1.104	7.2	0.070 at 68°F	1.64	2.82
40,719	75,485	10,663	227,300	179	80	354,436	355,150	1.258	5.8	–	0.38	4.30
69,901	48,609	6,853	213,600	202	130	339,300	310,160	1.225	6.1	0.053 at 68°F	1.02	4.30
70,869	42,572	6,347	202,902	188	207	323,120	–	1.224	6.0	–	1.16	4.07
53,663	36,480	6,072	164,838	211	75	261,360	268,300	1.184	6.5	0.065 at 68°F	1.01	3.65
68,163	25,840	3,234	160,000	321	110	257,671	257,200	1.174	6.0	0.060 at 68°F	1.91	4.85

Refractive index (25°C) was determined only on the following samples:

1:	1.3775	12:	1.3754
5:	1.3606	16:	1.3810
11:	1.3692	28:	1.3892