Report 74-4
HYDROGEOLOGY OF THE FOREMOST AREA, ALBERTA

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OF THE FOREMOST AREA,

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Abstract

In the western half of the map area, sandstone of the lower member of the Milk River Formation (hereafter referred to as the lower Milk River sandstone) is the main aquifer; in the eastern half permeable lenses in the drift are the main sources of groundwater. Yields range from 5 to 500 igpm (0.38 to 38 l/s) in the lower Milk River sandstone and from 5 to 100 igpm (0.38 to 7.6 l/s) in the drift. Higher yields are more common in the lower Milk River sandstone than in the drift.

Total dissolved solids are usually over 1 000 ppm in waters from both aquifers. The Milk River sandstone waters are mostly sodium bicarbonate type, with a northern area of sodium carbonate (corresponding to a change in lithology and depth) as well as sodium bicarbonate and chloride waters. Nitrates do not seem to be significant in either of these two areas. Fluorides are generally high in the Milk River sandstone waters.

INTRODUCTION

The map area, with the province of Saskatchewan as its eastern boundary and the state of Montana as its southern boundary, is located in the southeasternmost corner of the province of Alberta and covers an area of approximately 6 300 square miles (16 300 km^2). It is located between longitudes 110° and 112° west and latitudes 49° and 50° north, which, on the basis of the Alberta Land Survey system, coincides with townships 1 to 12, and ranges 1 to 15, west of the fourth meridian.

The main towns in the area are: Bow Island in the northwest (population, 1 105), Coutts in the southwest (population, 427), and Foremost in the west-central part of the map area (population, 604).

Prairie grasses are the dominant vegetation covering most of the area; the only wooded zones are found on the Cypress Hills, along major rivers and occasionally along coulees. The Cypress Hills are an anomaly in the flat prairie landscape. Forest covers the northern slopes, with lodgepole pine as the principal tree growth, and aspen, poplar and spruce becoming important locally (Westgate, 1965).

Wheat and barley are the main agricultural products, and are grown both in nonirrigated and irrigated areas in the northwestern corner of the map area.

Acknowledgments

Southern Alberta Drilling Co. of Foremost carried out the test drilling and pump testing.

Plotting of water well data on 1:50 000 scale maps prior to the start of field work was completed by Miss A. Badry and R. Steinhauer, both of the Groundwater Division. Field assistance was provided by R. Stein, M. Brulotte, and R. Bibby.

The help of many others is gratefully acknowledged, including the various health units for chemical analyses, the Provincial Analyst of Alberta Agriculture and the Geochemical Laboratory of Alberta Research Council[1] for chemical analysis of water samples, and also the Energy Resources Conservation Board in Edmonton for the formation water analyses they provided. The Energy Resources Conservation Board in Calgary provided structure testholes, electrical logs, litho-logs, and geological reports.

The author would like also to thank the residents of the area for their cooperation on this project, and the water well drillers who submitted reports for water wells drilled.

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TOPOGRAPHY AND DRAINAGE

Topography

The Foremost map area can be divided into three topographic units:

(1) The plains, rising gradually from 2 500 feet (760 m) in the north to 2 900 feet (880 m) in the south, occupy the western half of the map area. Their surface is deeply cut by east-west and northwest-southeast oriented coulees such as Chin, Etzikom, and Verdigris Coulees and, in the northwestern corner, by the 200 to 300 foot (60-106 m) deep valleys of the Oldman, Bow, and South Saskatchewan Rivers.

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[1] **Formerly Research Council of Alberta.**

(2) The Cypress Hills overlook the plains to the west and reach an altitude of 4 800 feet (1 460 m). Their flanks have been deeply eroded by numerous radiating streams and creeks.

(3) The flanks of the Sweetgrass Hills, along the southern edge of the map area, reach an altitude of 4 200 feet (1 280 m). Just north of these heights the Milk River has carved a canyon into the Cretaceous bedrock to a depth locally exceeding 400 feet (120 m).

Drainage

The map area is divisible into three drainage systems (Table 1) as follows:

(1) The South Saskatchewan River system, part of the Nelson drainage to Hudson Bay, drains the northern half of the map area (about 2 500 sq mi), including the northern slopes of the Cypress Hills. This system has large tributaries, the South Saskatchewan River having a maximum mean discharge of 7 430 cfs (210 m^3/s) at Medicine Hat.

(2) The Milk River drainage system to the south of the map area is part of the Missouri drainage system and eventually empties into the Gulf of Mexico. In the map area this system accounts for approximately 1 000 square miles and includes the southern slopes of the Cypress Hills. The Milk River has a mean discharge of 314 cfs (9 m^3/s).

(3) The Pakowki Lake drainage system (about 1 500 square miles in the map area) is a closed system situated between the South Saskatchewan River and the Milk River drainage systems. Streams and creeks converge on Pakowki Lake (Fig. 1). Streams are rather small in this system, the most important being Manyberries Creek which has an average discharge of 14.3 cfs (0.4 m^3/s).

CLIMATE

The map area can be divided into two different units according to Koeppen's system of climate classification (Atlas of Canada, 1957).

With the exception of the Cypress Hills, the map area is characterized by a semiarid, cold climate with a mean annual temperature less than 64.4°F, a mean temperature for the warmest month over 64.4°F, and annual precipitation between 13 and 14 inches (330 and 350 mm).

The Cypress Hills are characterized by a humid microthermal climate, having a hot summer, a mean temperature for the warmest month over 71.6°F, and precipitation in excess of 16 inches (406 mm) annually (Longley, 1968).

Table 1. Characteristic Features of Rivers and Creeks

SOUTH SASKATCHEWAN DRAINAGE SYSTEM

Location	Gauging Station	Drainage Area sq mi (sq km)	Mean Discharge cfs	Mean Discharge m³/s	Period of Record
NW 33-12-12-W4	Bow River near mouth	-	4180	118.3	5 years
SW 9-11-4-W4	Gros Ventre Creek near Dunmore	82 (212)	10.6	0.3	1921-1970
NW 1-9-22-W4	Oldman River near Lethbridge	6630 (17170)	3260	92.3	1911-1970
NW 19-7-7-W4	Peigan Creek near Pakowki Road	163 (422)	17.2	0.5	1960-1970
NW 34-11-3-W4	Ross Creek near Irvine	234 (600)	19.9	0.6	1910-1970
NW 31-12-5-W4	South Saskatchewan River at Medicine Hat	22500 (58270)	7430	210	1911-1970

MILK RIVER DRAINAGE SYSTEM

Location	Gauging Station	Drainage Area sq mi (sq km)	Mean Discharge cfs	Mean Discharge m³/s	Period of Record
SE 34-5-1-W4	Middle Creek near Alberta boundary	116 (300)	16.1	0.5	5 years
NE 6-37-09-EPM	Milk River at eastern crossing of International boundary (in USA)	2590 (6700)	314	8.9	1909-1970
SW 10-01-11-W4	Miners Coulee near International boundary	43.4 (112)	4.5	0.1	1966-1970
SE 3-1-2-W4	Sage Creek near International boundary	220 (570)	2.7	0.1	1946-1970
NE 9-1-2-W4	Sage Creek at Q Ranch near Wild Horse	175 (450)	18.4	0.5	1935-1970
SW 13-4-1-W4	Walburger Coulee below diversions	-	2.82	0.1	5 years

PAKOWKI LAKE DRAINAGE SYSTEM

Location	Gauging Station	Drainage Area sq mi (sq km)	Mean Discharge cfs	Mean Discharge m³/s	Period of Record
NE 3-5-6-W4	Manyberries Creek at Brodin's farm	137 (354)	14.3	0.4	1911-1970

Table 2. Average Annual Climatological Characteristics

	Rainfall		Temperature		Potential Evapotranspiration	
	(ins)	(mm)	(°F)	(°C)	(ins)	(mm)
Bow Island	12.73	323.30	41.60	5.32	22.87	581.06
Foremost	13.48	342.60	40.95	4.97	22.43	569.97
Manyberries	13.02	330.70	39.40	4.11	22.16	563.08
Average	13.07	332.20	40.65	4.80	22.48	571.37

The average annual potential evapotranspiration is 22.5 inches (571.37 mm). Values of mean annual rainfall, temperature, and total annual potential evapotranspiration for three stations in the map area are listed in table 2. Calculations were made using the Thornthwaite method (Thornthwaite and Mather, 1957).

GEOLOGY

Previous work in this area was done by Dowling (1917); Dowling *et al.* (1919); Howells (1936); Russell and Landes (1940); Russell (1948); Glaister (1957); Meyboom (1960); Stalker (1961); Irish (1968); Westgate (1968); and by the Coal Division of Alberta Research Council in 1963.

Bedrock Geology

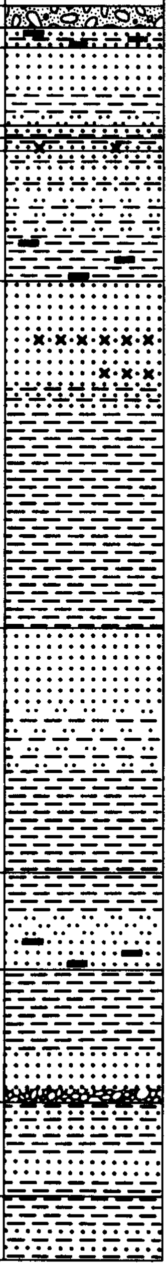
The map area is underlain by sediments of late Upper Cretaceous and Tertiary age (Table 3). The following is a description of the formations modified from Irish (1968).

Cretaceous

The oldest strata are those of the Alberta Group, exposed at only one locality within the map area and consisting of grey sandy shales and sandstones. Beds in the upper part of this group, though not the upper contact, are exposed in the valley of Deer Creek at the southern boundary of the study area.

The lower member of the Milk River Formation is exposed along the Milk River and for some distance upstream along Red Creek and Police Creek. This massive, light grey to white weathering, grey, soft to hard sandstone outcrops within Writing-on-Stone Provincial Park; grey and light grey shale and sandy shale are also present in the lower Milk River Formation. This formation is the main aquifer in the western half of the map area.

Table 3. General Stratigraphy of the Foremost Area

Period	Formation	Lithology
TERTIARY	CYPRESS HILLS (50ft, 15m)	
	RAVENSCRAG (40ft, 12m)	
CRETACEOUS	FRENCHMAN (200ft, 61m)	
	BATTLE (30ft, 9m)	
	WHITEMUD (25ft, 7.6m)	
	EASTEND (330 ft, 101 m)	
	BEARPAW (850 ft, 259 m)	
	OLDMAN (600 ft, 183m)	
	FOREMOST (260 ft, 79m)	
	PAKOWKI (300 ft, 91m)	
	MILK RIVER (220 ft, 67m)	
	ALBERTA GROUP (1500 ft, 457m)	

The nonmarine, upper member of the Milk River Formation underlies large areas north and south of the Milk River valley. This member is softer than the lower member and consists essentially of argillaceous sandstones and sandy shales.

Dark grey shale and sandy shale with some interbedded thin grey sandstone, comprising the marine Pakowki Formation, overlie Milk River strata. The base of the formation is marked in many places by a thin, chert-pebble conglomerate or by a layer of small chert pebbles within the shale. The presence of these pebbles may indicate that the Milk River-Pakowki contact is a disconformity.

The marine Pakowki shales are gradational upward into the Foremost Formation. Foremost strata, a succession of interbedded green and grey shales, grey siltstone, and pale brown sandstones, underlie most of the western half of the map area north of the Milk River.

The Oldman Formation underlies a semicircular area north, west, and south of the Cypress Hills. Oldman strata are comprised of green, grey, and light grey shales interbedded with grey and light grey sandstones; thick, crossbedded, light grey weathering, lenticular sandstone units are typical of the upper part of the formation. The Oldman Formation is an aquifer in a few locations along the northern edge of the map area.

The marine Bearpaw Formation rests conformably upon the Oldman beds and underlies an extensive region in the eastern part of the map area flanking the Cypress Hills. The formation consists essentially of dark grey and brownish grey shale and contains thick sandstone units in its upper part.

Sandstone strata of the Eastend Formation conformably overlie the Bearpaw shale. Eastend strata are confined to the Cypress Hills area and occupy a belt at the foot of the main escarpment.

The Whitemud Formation occurs on the north and south slopes of the Cypress Hills and consists of nonmarine, argillaceous sandstone, clay, and silty clay.

The uniform dark clays and bentonitic shales of the Battle Formation conformably overlie the Whitemud Formation. Its upper contact is an erosional surface resulting in a variable thickness up to a maximum of 30 feet (9.1 m).

Strata of the Frenchman Formation are also confined to the slopes of the Cypress Hills. They are composed of massive sandstones intercalated with siltstone and shale.

Tertiary

The Ravenscrag Formation, confined to a narrow rim around the highest parts of the Cypress Hills, consists of sandstones, clays, coal seams, and bentonitic layers.

The Cypress Hills Formation is the youngest within the map area. It caps the Cypress Hills and consists of pebble and cobble conglomerate with some sandstone lenses. Most of the pebbles and cobbles are composed of chert and quartzite, with a matrix of calcareous sandstone.

Surficial Deposits

The surficial deposits of the map area have been investigated by Westgate (1965).

In general, surficial deposits are of little importance as sources of groundwater; however, east and south of the town of Foremost, and along the northern edge of the map area, bedrock channels infilled with surficial material are aquifers.

The thalwegs of major buried channels (Westgate, 1968) have been indicated on the accompanying hydrogeological map. These channels are seldom deeper than 200 feet (61 m) and have been named Lethbridge, Skiff, Foremost, Medicine Hat, Wildhorse, and Jaydot channels.

The only channel that proved to be water-bearing is in the south branch of the Medicine Hat channel, between Pakowki Lake and the Milk River valley, where several Alberta Research testholes and one previous well encountered a clean, water-bearing gravel resting on top of bedrock; other gravel and sand aquifers exist near the northern edge of the map area in the same Medicine Hat channel.

Gravels are exploited at several localities in the Etzikom Coulee and on the edge of the Medicine Hat channel south of Groton.

An Alberta Research testhole drilled two miles south of the hamlet of Skiff in the Skiff bedrock channel encountered a 204-foot (62 m) section of completely dry till overlying the bedrock.

Sand dunes are found north and northeast of Pakowki Lake. They are composed of medium-grained, beige lacustrine sand. Sand and sand dunes are also well developed in the northwestern corner of the map area north of the Oldman River.

Glaciofluvial sands and gravels occur north of the Oldman River and are saturated with water; a spring located on the southern edge of this area has a measured flow rate of 800 igpm (60.5 l/s).

HYDROGEOLOGY

The hydrogeological map has been divided into a western and an eastern area in which the Milk River sandstone and the drift are the main aquifers, respectively. The boundary appearing on the map has been delineated in the following manner: for four-fifths of its length from south to north, the boundary defines a depth of 1 000 feet (304 m) to the Milk River sandstone; the remainder divides the map according to which of the above aquifers is most often used.

Water levels from wells completed in the milk River sandstone aquifer are shown on the main map while the water levels from the drift in the Pakowki Lake region are shown in figure 1. The water levels from the Milk River sandstone aquifer appear only in the western part of the map area because to the east this aquifer is deeper than 1 000 feet (304 m) which is the depth of investigation. In some cases the water levels were measured at different times of the year and sometimes a few years apart. The reader should use the water levels in the Milk River sandstone aquifer with caution as large fluctuations have been observed over the years. It is believed, however, that a reasonably good picture of both water levels is shown.

The fact that numerous wells completed in the Milk River sandstone have been allowed to flow freely indicates a gross mismanagement of the water resources of the area. This situation is not recent; some wells tapping the sandstone have been flowing for over 60 years. A single well in the vicinity of Pakowki Lake was found to be flowing at 50 igpm; others, in the Milk River valley, have been washed out by the river and continue to flow into the river. The author encountered several farmers who expressed concern over sharply decreasing flow rates. Meyboom (1960) estimated the drop in piezometric level of the Milk River sandstone to be as great as 100 feet (30.4 m) locally. It is recommended that appropriate steps be taken to govern water use from this aquifer in order to remedy this unnecessary waste.

A special mention should be made of the drift water levels in the vicinity and north of Pakowki Lake (Fig. 1), as their configuration suggests that groundwater crosses the northern divide of this closed basin, and enters the Medicine Hat bedrock channel that passes under Pakowki Lake and trends toward the northern part of the map area.

This hypothesis seems to be confirmed by the following observations:

(1) The topography of this area is very flat.

(2) Creeks and streams converge on Pakowki Lake, but several creeks disappear before they reach the lake.

(3) The water levels in the drift show a gradient toward the lake and from the lake in a northerly direction following the bedrock channel path.

(4) Four Alberta Research testholes drilled along this channel to the southwest, one of them very close to Pakowki Lake, have shown the presence of very clean, medium-size gravel which is a good aquifer with a calculated transmissivity of 3 600 igpd/ft (6.2×10^{-4} $m^3/s/m$).

(5) There is no surface expression of discharge in the Pakowki Lake vicinity besides the flowing wells which tap the lower Milk River sandstone at a depth of about I 000 feet (330 m).

Thus, the gravel present in the bedrock channel, under Pakowki Lake and north of it, could act as a drain for groundwater, and could explain the absence of discharge features in the area.

This phenomenon could be studied further with the aid of piezometers installed along the bedrock channel; existing control points are neither numerous nor deep enough. Piezometers would help define the nature, thickness, and hydraulic properties of the channel's sediments. Also, a complete groundwater balance would indicate the different contributions to and from various parts of the basin.

Test Drilling

Test drilling was carried out during the summer of 1971 at six locations. Lithologs and locations of the testholes are given in appendix A.

The purpose of testhole No. 1 was to reach strata of fairly good permeability in the Foremost and Oldman Formations present in several structure testholes drilled previously in the same general area. Drift in this area is composed of fine-grained silty and clayey sand at the surface overlying gravel with a great proportion of clay and sand to a depth of 60 feet (18 m). Below this, bedrock consists of shales interbedded with very hard, fine-grained sandstones and siltstones. The testhole showed that neither the drift nor the bedrock contained sufficient water for development.

Testhole Nos. 2, 3, 4 and 5 were drilled in order to locate and test gravels known to exist in one location but which had previously been ignored because of drilling difficulties. Gravels resting on bedrock were found, tested and followed in testhole Nos. 2, 3 and 4 in the Medicine Hat bedrock channel. In testhole No. 5, no or very poor returns, with frequent circulation loss, suggested the presence of very permeable sediments (gravel?) to a depth of 150 feet (45 m). It was not possible to conduct a pump test because of the poor condition of the hole.

Testhole No. 6 encountered till from the surface to 204 feet (62 m) overlying sandstones and shales from 204 feet (62 m) to 222 feet (67 m).

The aquifer parameters obtained from pump test data are shown in table 4. In order to show the range of values obtained for the gravel aquifer present in the Medicine Hat channel, the results of testhole No. 4 have been included, despite the poor quality of the pump test.

Groundwater Yields

Yield values for the Milk River sandstone are 20-year estimates, based on apparent transmissivity (and available drawdown) values calculated by Meyboom (1960). In order to evaluate the Milk River flowing wells, Meyboom used recovery data obtained in the following manner: the flowing wells were shut in and fitted with a pressure gauge; the pressure build-up was then measured (in lbs/in^2) and converted to feet of water, thus giving the recovery. Recovery data were then plotted on semilogarithmic paper and interpreted.

The remaining 20-year yield values are also based on apparent transmissivity, apart from Alberta Research testhole No. 2 where an 84-hour test was conducted. Yield values shown on the main map are, therefore, approximate over most of the map area, except in one area (denoted by a darker shade of color) where sufficient and fairly accurate data exist.

The yield map has been drawn on the basis of apparent transmissivity, permeability values, geology, and lithology when available. The fairly high yield values of 5 to 500 igpm (0.38 to 38.2 l/s) shown for the Milk River sandstone are due to the fact that there is always a large available drawdown in wells which produce from this aquifer.

Yields in the drift area to the east are generally much lower and seldom reach the category 50 to 100 igpm (3.8 to 7.6 l/s). High yields in the drift are usually of small areal extent; the average yield value is about 15 igpm (1.1 l/s). The flanks of the Cypress Hills are somewhat different from the rest of the drift area. Small springs are numerous and several issue from gravels at rates of 50 to 75 igpm (3.8 to 5.7 l/s). Water supplies of most farms flanking the Cypress Hills are from permanent springs with good quality water.

Original aquifer conditions in the Milk River sandstone cannot be properly evaluated by pump testing due to the drastic change in piezometric level caused by prolonged exploitation over the period of use. Meaningful results can only be obtained if water levels are allowed to recover for a very long period of time prior to pumping. A trial pump test on the Foremost town wells was unsuccessful because sufficient time for complete recovery was not available. Pumping commenced after shutting down the three town wells for 20 hours. All three wells were

Table 4. Aquifer Parameters in Testholes

Location W 4th Mer.	Hole	Aquifer Interval ft (m)	Aquifer Material	Length of Pump Test, Pumping Rate and Comments	Transmissivity		Permeability		Q_{20}	
					Drawdown igpd/ft ($m^3/s/m$)	Recovery igpd/ft ($m^3/s/m$)	Drawdown igpd/ft^2 (cm/s)	Recovery igpd/ft^2 (cm/s)	Drawdown igpm (l/s)	Recovery igpm (l/s)
NE 18-3-9	2	175-184 (54-56)	Clean coarse gravel	2 hrs drawdown; 2 hrs recovery @ 24 igpm (1.8 l/s)	3334 (5.7×10^{-4})	3579 (6.2×10^{-4})	370 (2.9×10^{-6})	397 (3.1×10^{-6})	179 (13.6)	192.5 (14.6)
		same	same	24 hrs drawdown; 60 hrs recovery @ 20 igpm (1.5 l/s)	705 (1.2×10^{-4})	919 (1.6×10^{-4})	140 (6×10^{-5})	182 (7.9×10^{-5})	37 (2.8)	48 (3.6)
Lsd. 5-18-3-9	3	180-191 (55-58)	Sand and gravel	100 min drawdown; 120 min recovery @ 8 igpm (0.6 l/s); air test	none -	40 (0.7×10^{-5})	none -	40 (3.4×10^{-4})	none -	2 (0.15)
Lsd. 13-15-2-11	4	84-112 (25-34)	Gravel	2 hrs drawdown; 2 hrs recovery @ 12.4 igpm (0.9 l/s); pumping rate too low for capacity of hole Recovery complete one minute after pumping stopped	9500 (1.6×10^{-3})	- -	340 (8×10^{-2})	- -	99 (7.5)	- -

still recovering 10 hours after pumping started, and practical problems did not allow continuation of the recovery for a week. The town wells flowed at one time but at present the depth to water is approximately 300 feet (91 m).

HYDROCHEMISTRY

Milk River Sandstone Waters

Waters of the Milk River sandstone generally have a total dissolved solids content (TDS) of less than 1 500 ppm over most of the western part of the map area, but increasing rapidly from 1 500 to 4 000 ppm in the northern quarter of this part. The increase is accompanied by a pronounced rise in chloride concentrations to the point where chloride becomes the dominant anion in the area of highest total dissolved solids. Both increases are attributed to the lower hydraulic conductivity and subsequent sluggish movement of waters in the Milk River sandstone due to the higher shale content of this part of the aquifer. Sodium plus potassium, when computed on an epm basis, constitute over 60 percent of the cations in all water samples taken from the Milk River sandstone. None has over 60 percent calcium plus magnesium. The line of over 60 percent carbonate and bicarbonate follows approximately the 2 000 ppm TDS line. A few small areas show the presence of over 60 percent sulfates; these waters could well be from a different aquifer (probably the Verdigris sandstone).

In addition to the usual ions mentioned above, the Milk River waters have a high fluoride content. It reaches 8 ppm along the western edge of the map area and is probably related to both the hydraulic conductivity and the mineralogic composition of the sandstone. According to the Alberta Health Standards' upper limit of 1.5 ppm for fluoride content, not much of this water can be considered potable; it seems to be widely used, however, without showing any obvious adverse effects.

In the area underlain by the Milk River Formation a number of wells are completed in the drift. They are usually very shallow and produce waters high in total dissolved solids, some as high as 30 000 ppm. Most are quite old and have often been abandoned in favor of deeper Milk River Formation wells. For this reason, as well as their scattered occurrence in this portion of the map area, they were not used in drawing the chemistry maps. Appendix B shows formation water analyses which were used in outlining the vertical chemical changes along the cross section lines.

Drift Waters

The only discernible trend in the chemistry of drift waters is the increase in total dissolved solids downslope from the Cypress Hills. Total dissolved solids values range from 1 000 to 12 000 ppm, and have patchy distribution over the map area with no general patterns discernible.

Calcium plus magnesium constitutes more than 60 percent of the cation content in most of the area, but a few areas of sodium plus potassium waters do occur. Areas of high total dissolved solids are usually characterized by a high sulfate content while areas of low total dissolved solids often have carbonate and bicarbonate as the dominant anions.

In general, groundwaters from drift wells in the map area have a total dissolved solids content of over 1 000 ppm and are either calcium sulfate or calcium bicarbonate waters. No chlorides occur in this area of shallow drift wells, and the fluoride content is generally low, seldom reaching the upper accepted limit of 1.5 ppm. Iron content in drift waters is higher than in waters from the Milk River sandstone and in the northern part of this zone commonly exceeds the accepted 0.3 ppm upper limit.

The southern part of this area has no hydrochemical control other than saline soils; areas of extensive salt precipitates are shown on the main hydrogeological map. These are quite extensive and if shallow groundwater occurs its quality would reflect the chemical quality of the soils. In addition, the drift cover is thin in this zone and the Bearpaw Formation can be observed in extensive outcrops south of the Cypress Hills. Large selenite crystals ($Ca_2SO_4.2H_2O$) are common at or near the surface of many of these outcrops.

CONCLUSIONS

Meyboom (1960) stated that a great deal of water was being wasted in the map area due to the mismanagement of flowing wells penetrating the Milk River Formation: this situation still exists. For example, the well in the vicinity of Pakowki Lake, flowing freely for 25 years at 50 gallons per minute (3.8 l/s), would result in 660 000 000 gallons (2 545 000 m^3) of water being wasted. The gross mismanagement of the groundwater resources of this area should be halted.

In general, the Foremost area presents a fair groundwater situation. The Milk River sandstone provides yields ranging from 5 to 500 igpm (0.38 to 38 l/s) of generally fair quality water. The quality decreases with depth; wells over 900 feet (270 m) do not yield potable water. Sodium chloride content is very high and total dissolved solids range from 2 000 ppm to 8 000 ppm, especially in the lower Cretaceous formations (Appendix B).

North of the Cypress Hills drift waters are of poor quality and yields are low but sufficient for local use; however, in and around the Cypress Hills many springs yield a large amount of good quality water.

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APPENDIX A

LOGS OF ALBERTA RESEARCH COUNCIL TESTHOLES

ONEFOUR NO. 1

Location: Lsd. 3, Sec. 11, Tp. 2, R. 5, W 4th Mer.
Date drilled: July 28-30, 1971

Depth (feet)	Description
0-4.5	Sand, fine-grained with small black mica fragments; clay
4.5-60	Gravel; ironstone pebbles; clay; sand; shell fragments
60-79	Shale, carbonaceous, dark grey to black
79-84	Sandstone, very fine-grained, bentonitic, grey
84-210	Shale, carbonaceous; coal and sandstone layers
210-240	Sandstone, fine-grained, soft to hard
240-501	Shale, medium hard to hard; sandstone and siltstone ledges

FOREMOST NO. 2

Location: NE¼, Sec. 18, Tp. 3, R. 9, W 4th Mer.
Date drilled: August 3-5, 1971

Depth (feet)	Description
0-5	Sand, medium brown
5-30	Gravel and sand, gravel up to 0.5 in diameter
30-40	Gravel and clay; coal fragments; oil stains; shell fragments
40-45	Clay and gravel; coal fragments; oil stains
45-94	Till; coal fragments; some shell fragments
94	Boulder
94-150	Till; numerous coal fragments
150-173	Till, very clayey
173-181	Gravel
181-186	Sandstone, fine-grained, soft, grey
186-188	Sandstone, fine-grained, hard, grey
188-189	Sandstone, fine-grained, soft, grey
189-196	Sandstone, grey

FOREMOST NO. 3

Location: Lsd. 5, Sec. 18, Tp. 3, R. 9, W 4th Mer.
Date drilled: August 6-14, 1971

Depth (feet)	Description
0-5	Sand, fine-grained, brown; clay
5-25	Sand, fine-grained, brown; gravel, variable size up to 0.5 in diameter constituting 10 percent of sample; clay
25-92	Till, with rock fragments up to 1 in diameter, grey, distinct color change from above
92-142	Gravel, small, fairly uniform; abundant quartz; some fine sand
142-180	Clay, soft (laminated with sandy layers when dry)
180-191	Gravel
191-195	No sample
195-200	Sandstone, fine-grained, soft; sandstone, fine-grained, hard, grey
200-205	Sandstone, fine-grained; shale, medium hard; siltstone, grey
205-210	Sandstone and siltstone

FOREMOST NO. 4

Location: Lsd. 13, Sec. 15, Tp. 2, R. 11, W 4th Mer.
Date drilled: August 16-26, 1971

Depth (feet)	Description
0-5	Clay, dark brown; sand and gravel
5-35	Till, gravelly (5-10, 15-25, sandy; 25-30 coal), brown
35-40	Gravel, fine
40-84	Till, very clayey with coal fragments, grey
84-104	Gravel up to 1 in diameter, rounded pebbles
104-112	No sample
112-122	Clay, soft, black
122-130	Shale, hard and soft, black

FOREMOST NO. 5

Location: Lsd. 5, Sec. 27, Tp. 4, R. 8, W 4th Mer.
Date drilled: August 29-30, 1971

Depth (feet)	Description
0-10	Till, very sandy and gravelly, pebbles up to 2 in diameter, brown
10-20	Till, very sandy and gravelly, brown; some coal fragments
20-38	Till, sandy and gravelly, grey
38-43	Boulder
43-50	Sand, medium-grained, grey, well sorted
50-55	Sand and gravel
55-60	Gravel fragments up to 2-in diameter; coal; some sand
60-150	Very poor returns, drilling very difficult in what seems to have been gravel (the rock bit was completely worn during this length of drilling).

FOREMOST NO. 6

Location: Lsd. 10, Sec. 10, Tp. 6, R. 14, W 4th Mer.
Date drilled: August 31, 1971

Depth (feet)	Description
0-5	Soil, sandy, and gravelly, brown
5-62	Till sandy and gravelly (pebbles up to 1 in diameter), brown; some clay
62-84	Sand, medium to fine, pale brown
84-96	Till, brown, mixed with grey till
96-204	Till, sandy, gravelly, clayey, grey
204-206	Sandstone, fine-grained, soft, brown
206-208	Shale, soft, carbonaceous
208-211	Sandstone, fine-grained, hard
211-222	Alternating soft, carbonaceous, light grey shale and soft, fine-grained sandstone

APPENDIX B

FORMATION WATER ANALYSES

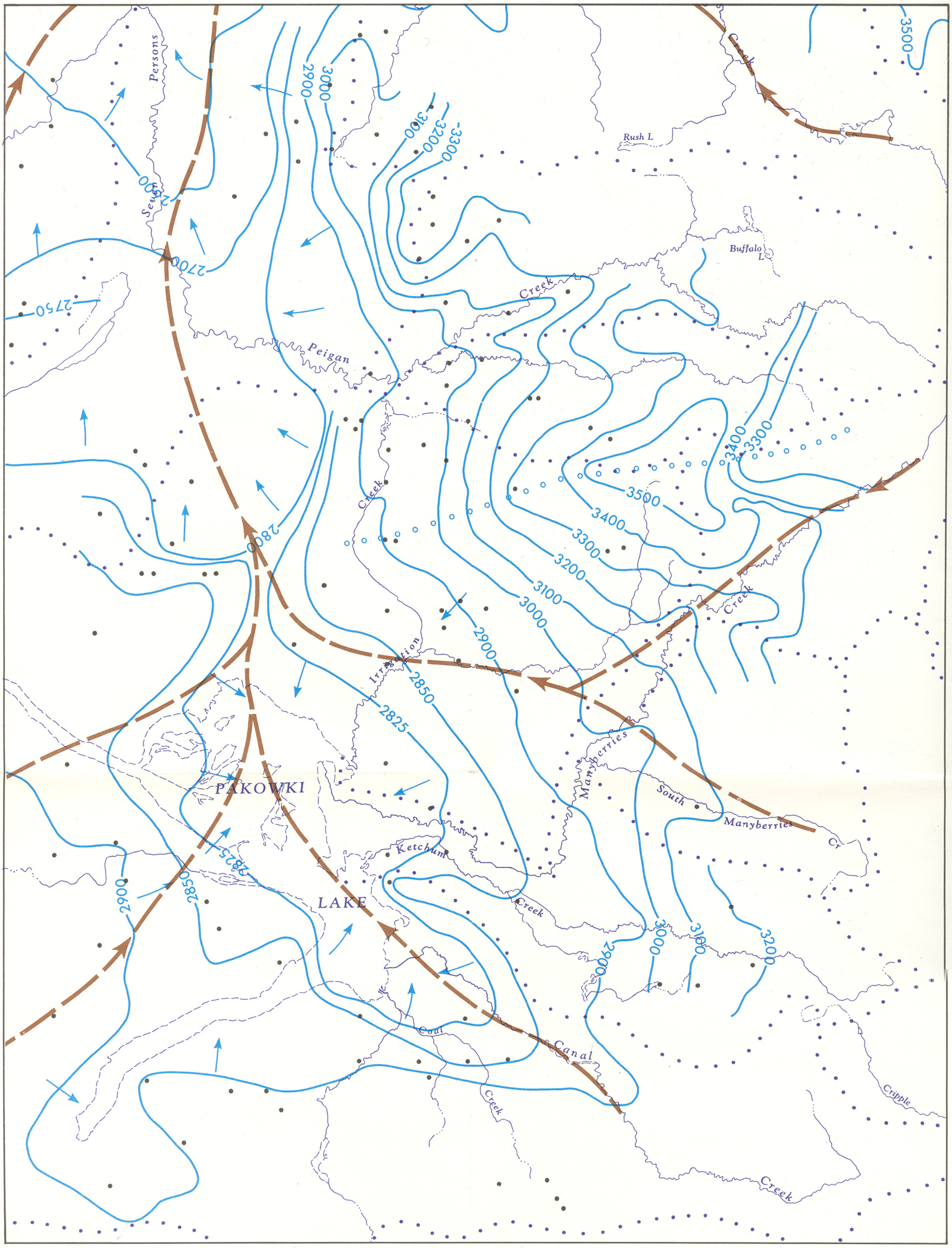
(from Energy Resources Conservation Board files)

Location West of 4th Mer. Lsd.	Sec.	Tp.	R.	Geologic Unit (interval sampled in feet)	Cross Section	TDS[1] (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	SO_4 (mg/l)	CO_3 $+HCO_3$ (mg/l)	Cl (mg/l)
11	4	1	9	Rundle Grp (2 815-2 905)	C-C'	1 770 (2 390)	85	84	612	3	873	729
11	4	1	9	Rundle A Grp (2 815-2 905)	C-C'	1 720 (2 287)	96	58	541	9	1 263	320
10	5	1	9	Colorado ss (2 306-2 340)	C-C'	- (291 ?)	tr	tr	97	48	76	70
1	6	1	9	Sunburst ss (3 008-3 029)	C-C'	5 230 (5 789)	41	0	1 918	576	1 872	1 369
1	6	1	9	Bow Island Fm (2 234-2 457)	C-C'	3 090 (3 538)	9	0	1 286	178	1 104	948
10	19	1	9	Sunburst ss (2 820-2 826) (2 832-2 836)	C-C'	1 460 (1 628)	11	5	518	33	604	457
6	22	1	9	Rundle Grp (3 314-3 341)	C-C'	3 110 -	Ca+Mg (as Ca) 213		-	30	2 671	973
11	7	2	3	Milk River Fm (1 156-1 178)	D-D'	1 650 (2 245)	37	2	621	5	1 324	256
11	21	2	3	Bow Island Fm (2 817-2 825)	D-D'	- (3 658)	11	5	1 300	5	837	1 500
11	21	2	3	Bow Island Fm (2 755-2 775)	D-D'	- (4 015)	12	6	1 400	19	1 068	1 510
11	21	2	3	Bow Island Fm (2 817-2 825)	D-D'	- (3 658)	11	5	1 300	5	837	1 500
11	21	2	3	Bow Island Fm (2 755-2 775)	D-D'	- (4 015)	12	6	1 400	19	1 068	1 510

11	35	2	9	Sunburst ss (2 652–2 674)	C–C'	678 (930)	7	2	272	8	500	141
11	9	3	8	Lower Mannville Grp (2 750–2 785)	C–C'	10 390 (10 922)	12	18	3 163	46	4 891	2 786
11	9	3	8	Lower Mannville Grp (2 778–2 785)	C–C'	103 400 (63 601)	30	61	24 163	107	4 340	34 900
4	16	3	8	Bow Island Fm (2 087–2 092)	C–C'	5 850 (7 480)	35	0	2 474	186	2 813	1 972
4	16	3	8	?	C–C'	– (6 547)	12	5	2 210	47	2 178	2 095
7	17	3	8	Blairmore Grp (2 774–2 799)	C–C'	7 690 (9 901)	30	0	3 326	224	3 843	2 466
11	21	3	8	Bow Island Fm (2 084–2 089) (2 137–2 142)	C–C'	5 950 (8 589)	18	0	2 739	9	4 526	1 284
11	21	3	8	Bow Island Fm (2 084–2 089) (2 137–2 042)	C–C'	6 120 (9 098)	14	10	3 299	3	4 238	1 527
11	21	3	8	Bow Island Fm (2 137–2 142)	C–C'	5 950 (8 361)	5	4	2 689	6	4 306	1 345
11	22	4	8	Bow Island Fm (2 132–2 165)	C–C'	– (3 288)	19	absent	1 058	520	1 215	476
11	16	11	11	Milk River Fm (400–?)	B–B'	4 534 (4 851)	16	6	1 764	9	815	2 241
12	14	12	12	Bow Island Fm (2 162–2 235)	B–B'	– (9 317)	19	16	3 468	110	854	4 850
12	14	12	12	Bow Island Fm (2 290–2 362)	B–B'	– (8 365)	23	15	3 057	110	1 060	4 100

[1]The first value is measured at 110°C; the figure in brackets is calculated.

FIGURE 1. DRIFT WATER LEVELS IN THE PAKOWKI LAKE AREA



To accompany Report 74-4

SCALE 1:250,000

Miles 5 0 5 10 Miles

Kilometres 5 0 5 10 15 Kilometres

LEGEND

Thalweg of buried valley, approximate

Lake or slough, perennial

Lake or slough, seasonal

Stream, perennial

Stream, intermittent

Surface water divide

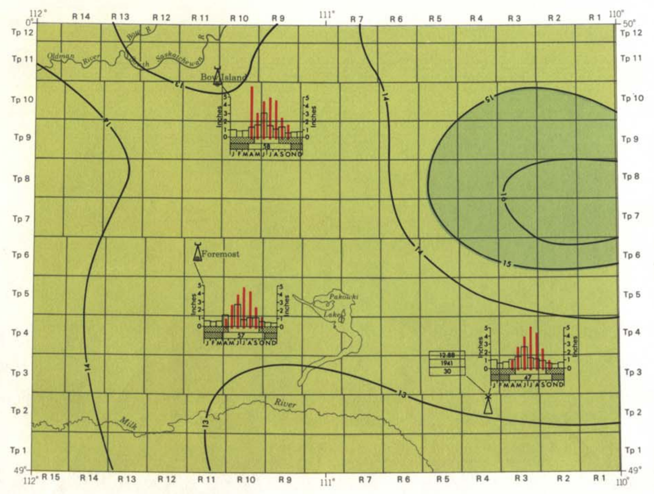
Drift water level contour defined — 2900 —

Direction of groundwater flow

Data control point

Alberta RESEARCH COUNCIL

METEOROLOGY

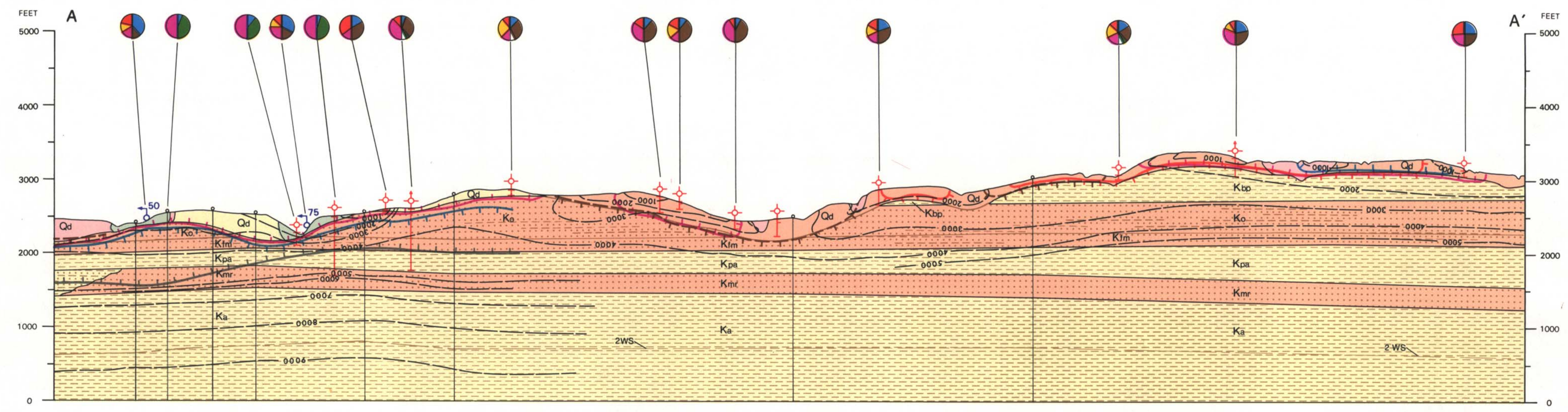


LEGEND

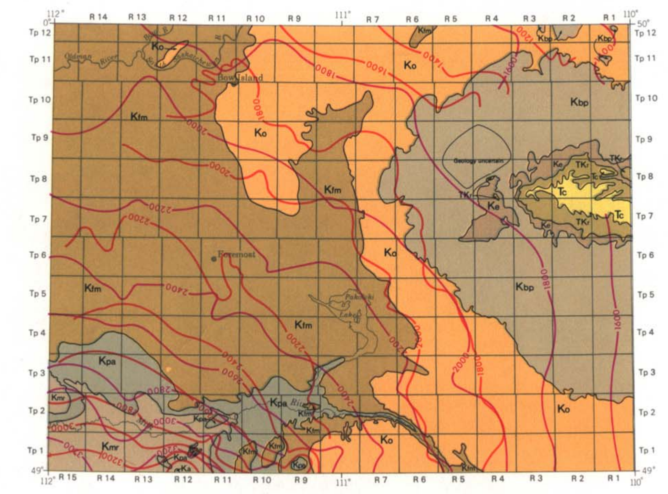
- Isohyet, mean annual precipitation in inches
- Mean annual precipitation in inches:
  - less than 15
  - 15 - 20
- Meteorological station
- Standard rain gauge only
- Precipitation data:
  - Mean annual precipitation in inches
  - Year of commencement of observations
  - Number of years of record used to calculate mean annual precipitation
  - Mean monthly potential evapotranspiration*
  - Mean monthly precipitation
  - Period when surface is usually snow covered
  - Period with mean daily temperature below freezing (0°C)
  - Figure indicates percentage of mean annual precipitation falling as rain

Sources of data:

Climatic maps of Alberta (Longley, 1968); Monthly Record of Meteorological Observations (Meteorological Branch, Canada Department of Transport); and Provisional Evaporation Maps of Canada, Department of Transport Circular 4531 (Bruce and Weisman, 1967).



GEOLOGY



LEGEND

- Tc — Cypress Hills Formation: *conglomerate, minor sandstone*
- TKr — Ravenscrag Formation: *sandstone, clay, mudstone*
- Ke — Eastend Formation: *sandstone, shale, coal beds*
- Kbp — Bearpaw Formation: *shale, sandstone*
- Ko — Oldman Formation: *sandstone, siltstone, mudstone, shale*
- Kfm — Foremost Formation: *sandstone, siltstone, mudstone, shale*
- Kpa — Pakowki Formation: *shale, minor sandstone*
- Kmr — Milk River Formation: *sandstone, shale*
- Ka — Alberta Group: *shale, minor sandstone*
- Rock unit boundary
- Structure contour on top of Milk River Formation
- Structure contour on top of Alberta Group

MAIN MAP LEGEND

Topography

Surface contours (interval 100 feet):
- elevation
- depression

Geology

- Geological boundary
- Thalweg of buried valley, approximate

QUATERNARY
- Qd — Unconsolidated deposits

TERTIARY
- Tc — Cypress Hills Formation

TERTIARY-CRETACEOUS
- TKr — Ravenscrag Formation

CRETACEOUS
- Kfc — Frenchman Formation
- Ke — Eastend Formation
- Kbp — Bearpaw Formation
- Ko — Oldman Formation
- Kfm — Foremost Formation
- White Specks Marker (2WS)
- Kpa — Pakowki Formation
- Kmr — Milk River Formation
- Ka — Alberta Group
- Kmv — Mannville Group
- Base of Fish Scale Zone (BFSc)

Lithology

- Sand
- Gravel
- Sand and gravel
- Sandstone
- Shale
- Siltstone
- Conglomerate

Hydrography

- Lake or slough, perennial
- Lake or slough, seasonal
- Stream, perennial
- Stream, intermittent
- Marsh
- Surface water divide
- Area of noticeable salt precipitates

Hydrogeology

- Spring, flow rate unknown
- Spring, flow rate known (imperial gallons per minute)
- Nonpumping water level contour in Milk River sandstone (elevation in feet) and vertical component of groundwater movement:
  - defined
  - approximate
- Direction of groundwater flow
- Groundwater divide
- Boundary of area of artesian flow

Groundwater Probability†

Range of average expected yield of wells (in imperial gallons per minute)

- Probable: estimated from quantitative information (pump tests, bail tests, etc.)
- Possible: estimated from qualitative information (flow regime, lithology, etc.)

100-500
25-100
5-25
1-5
< 1

- Yield area boundary

†The indicated average expected yields to wells are predictions based on the best data available at the time of map compilation; due to data shortcomings and special conditions, local discrepancies between predicted and actual yields are inevitable. Multi-aquifer completion may be necessary to obtain the yield indicated.

Wells and other Artificial Works

- Water well
- Water well, flowing
- Water well, nonproducing
- Well, shallow depth
- Water well, 20-year safe yield calculated from apparent transmissivity
- Water well, 20-year safe yield calculated from a good bail test or a short pump test
- Water well, 20-year safe yield calculated from a pump test of sufficient length to reflect regional hydraulic conditions
- Adjacent wells
- Seismic shothole reported to have flowed, unknown depth
- Seismic shothole reported to have flowed, known depth

Depth Scale — FEET: 0, 100, 200, 300, 400 — Depth to water; Depth of well or seismic shot hole

- Location of Alberta Research Council test well — ARC
- Spring catchment
- Structure test hole*
- Line of hydrogeological profile — A A′

*Vertical line portion of oil, gas, or other exploratory test well symbols on hydrogeological profiles indicates well depth; dashed portion indicates surface casing interval.

Hydrochemistry

Calcium, Magnesium, Sodium + potassium (Cations) | Carbonate + bicarbonate, Sulfate, Chloride, Nitrate (Anions) — 0, 50%, 100%

Note: When the yellow Mg pie sector is absent, Ca + Mg are represented as a unit by the red pie sector

Total dissolved solids in parts per million:
- defined
- approximate

Isogram along which calcium + magnesium constitute 60 percent of total cations*; teeth indicate direction of lesser calcium + magnesium content:
- defined
- approximate

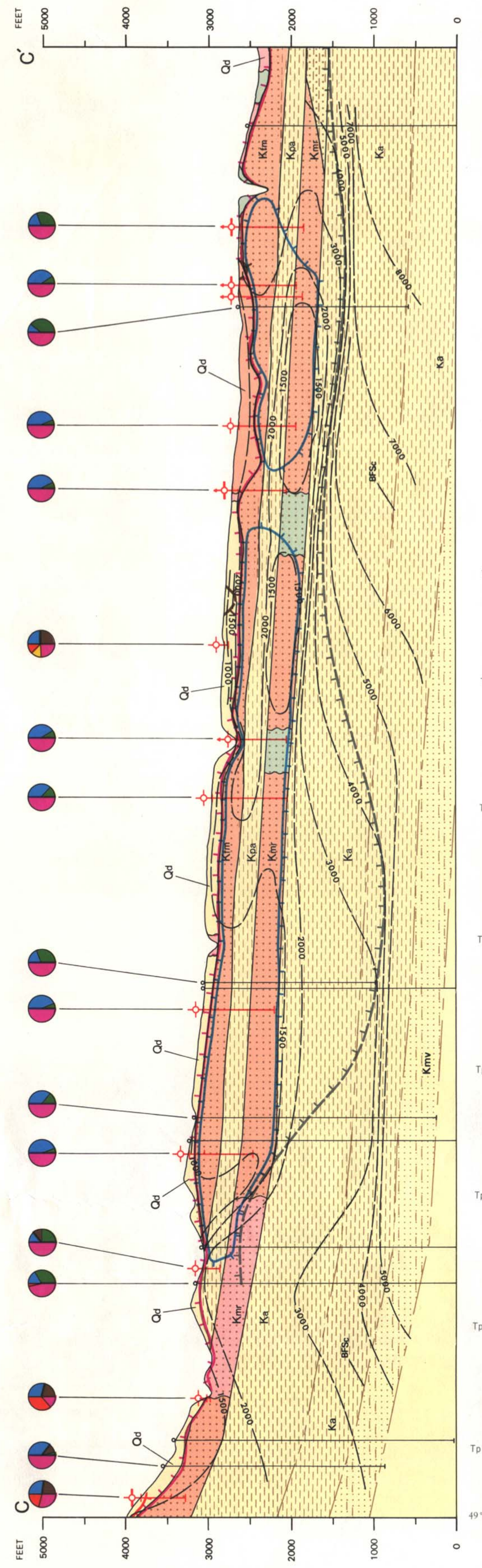
Isogram along which sodium + potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium + potassium content:
- defined
- approximate

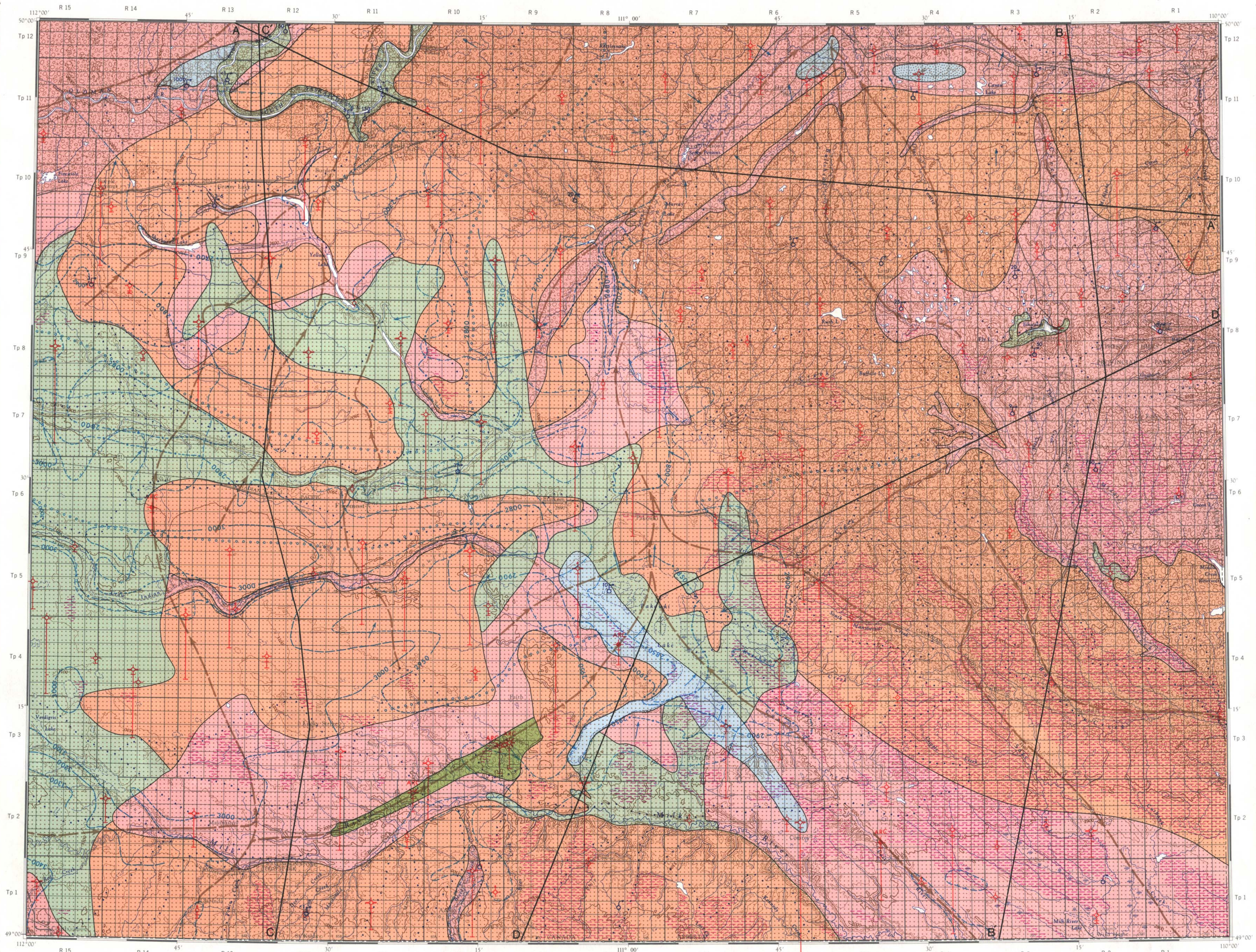
Isogram along which carbonate + bicarbonate constitute 60 percent of total anions*; teeth indicate direction of lesser carbonate + bicarbonate content:
- defined
- approximate

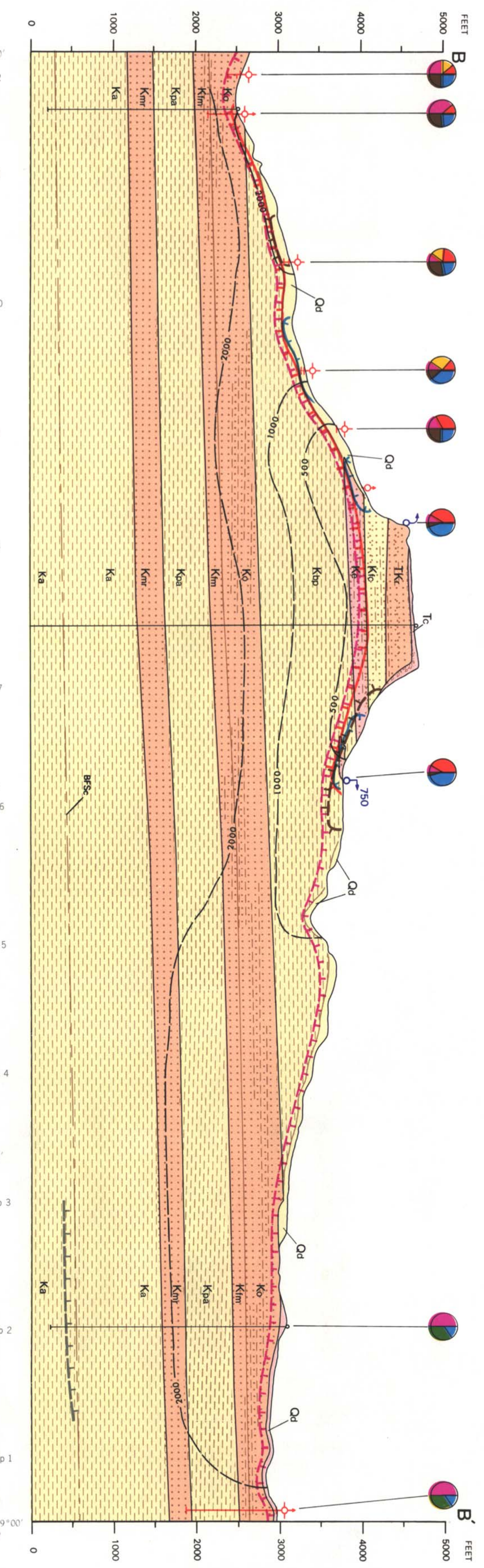
Isogram along which sulfate constitutes 60 percent of total anions*; teeth indicate direction of lesser sulfate content:
- defined
- approximate

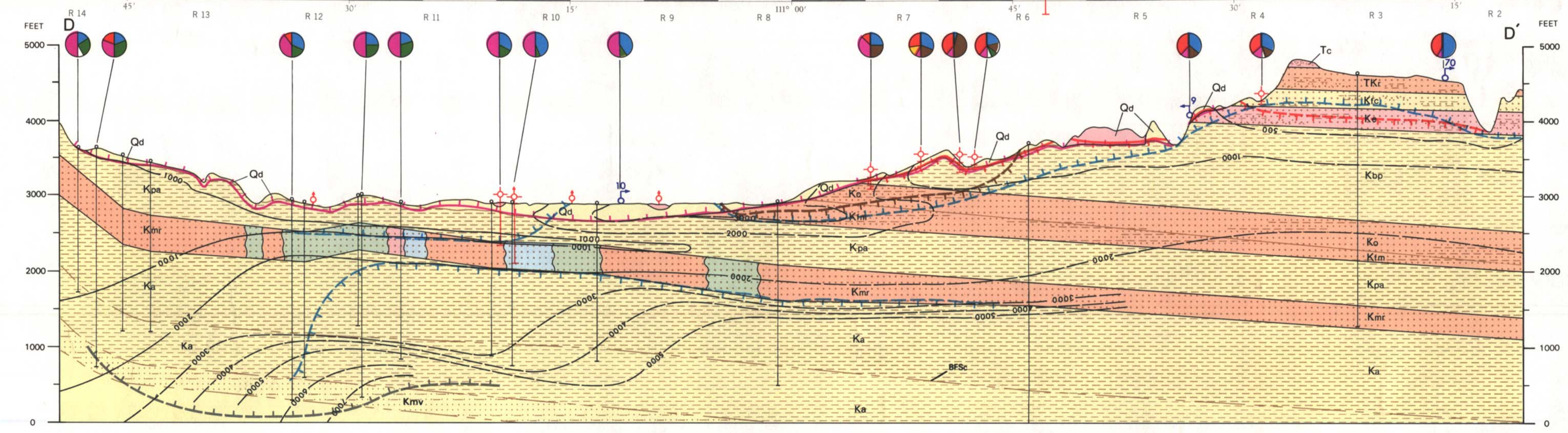
Isogram along which chloride constitutes 60 percent of total anions*; teeth indicate direction of lesser chloride content:
- defined
- approximate

*Determined on equivalents per million basis.

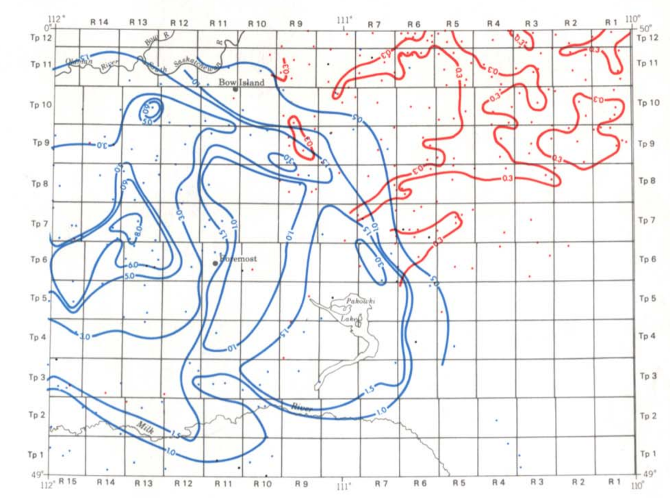








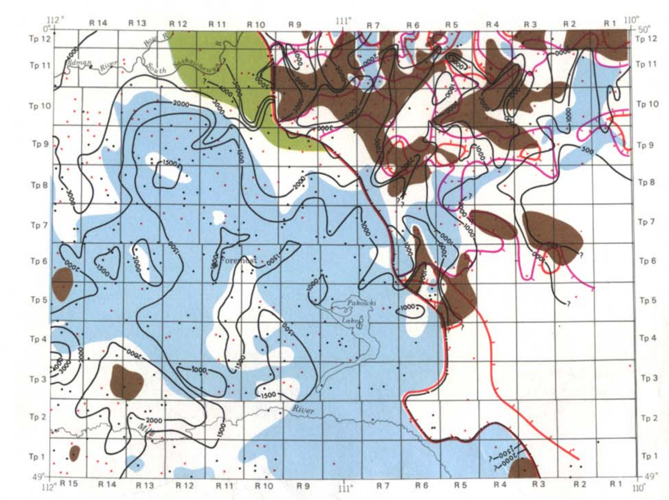
IRON AND FLUORIDE CONTENT



LEGEND

- Iron content in parts per million
- Fluoride content in parts per million
- Data control point marking the location of a well with a chemical analysis:
  - for iron
  - for fluoride
  - for iron and fluoride

HYDROCHEMISTRY

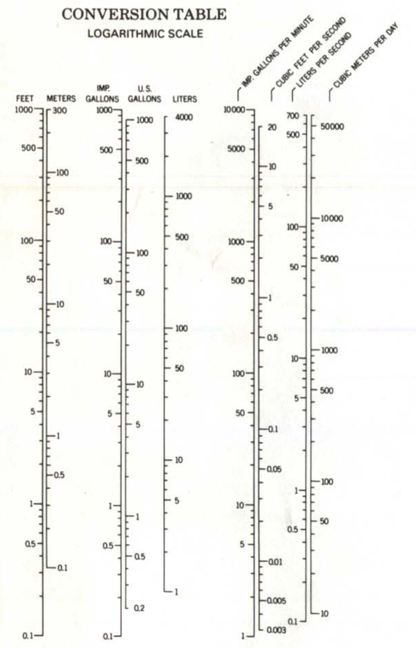


LEGEND

- Data control point marking the location of a chemical analysis of water:
  - in drift
  - in bedrock
- Total dissolved solids in parts per million
- Bicarbonate + carbonate constituting over 60 percent of total anions*
- Sulfate constituting over 60 percent of total anions*
- Chloride constituting over 60 percent of total anions*
- Isogram along which calcium + magnesium constitute 60 percent of total cations*; teeth indicate direction of lesser calcium + magnesium content
- Isogram along which sodium + potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium + potassium content
- Line east of which hydrochemistry is based on drift waters and west of which hydrochemistry is based on Milk River and other bedrock waters

*Determined on equivalents per million basis.

CONVERSION TABLE
LOGARITHMIC SCALE



SCALE 1:250,000 — Miles 5 0 5 10 15 20 Miles — Kilometres 5 0 5 10 15 20 25 30 Kilometres

All elevations in feet above mean sea level.

Vertical exaggeration of the hydrogeological profiles is approximately 40X.

An expanded legend and explanatory notes for use with this hydrogeological map series is available from the Alberta Research Council, Edmonton, Alberta, Canada.

Map to accompany Report 74-4.

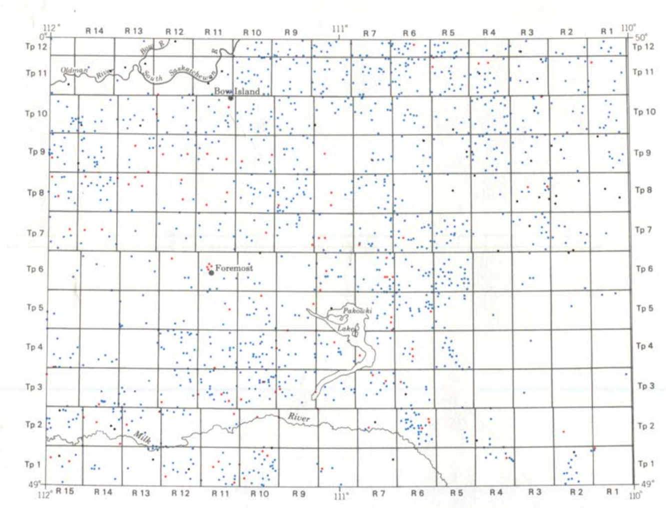
Hydrogeology by D. Borneuf 1971, based on data collected in 1971.

Cartographic editing by F. Smith and A. Campbell

HYDROGEOLOGICAL MAP FOREMOST ALBERTA

NTS 72E

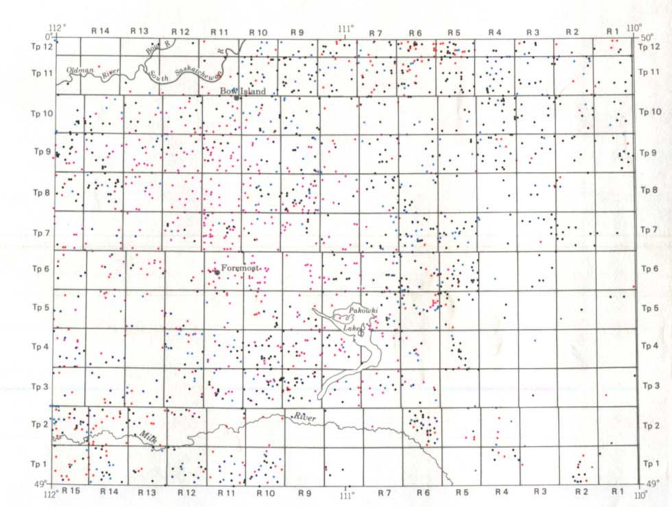
DATA DENSITY



LEGEND

- Data control point marking the location of a well with water level information only
- Data control point marking the location of a well with yield information (i.e. production tests)
- Data control point marking the location of a spring

WELL DEPTH



LEGEND

Well depth in feet:
- 0-50
- 50-100
- 100-200
- 200-500
- 500-1000
- >1000

Published 1976