Report 77-2

Hydrogeology of the Calgary-Golden area, Alberta

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HYDROGEOLOGY OF THE CALGARY-GOLDEN AREA, ALBERTA

ABSTRACT

The hydrogeology of the uppermost 1000 ft (about 300 m) of strata in the Calgary-Golden map area is described. The maps and profiles were constructed from existing data and from data collected by field survey, drilling, and testing operations. The 20-year safe yields are mostly over 5 igpm (about 0.4 l/sec) and at several places are over 100 igpm (about 8 l/sec). Only at specific locations of concentrated discharge or induced infiltration are yields over 500 igpm (about 38 l/sec). All of the best aquifers — the Paleozoic limestones, Paskapoo sandstones and shales, and the Quaternary sands and gravels — are very capricious and uneven in yield, depending on the presence or absence of karstic solution channels or fracturing, the silt content, structural and depositional features, topographic position, and recharge conditions. Gravelly terrace deposits can be entirely dry or can supply over 500 igpm (about 38 l/sec). In the mountains the groundwater table may be deeper than 1000 ft (about 300 m) so even rock masses of high porosity may be classified as having less than 1 igpm (less than 0.1 l/sec) of yield.

Water quality is good over most of the area. Total dissolved solids are usually less than 1000 ppm. The chemical character of the water is usually calcium-magnesium bicarbonate or sodium bicarbonate. Undesirably high total dissolved solids and sulfate contents exist along the eastern margin and in the southeastern corner of the map area and also at isolated locations farther west.

Some thermal and mineral springs have calcium sulfate (gypsum) type chemistry and some radioactivity. Hydrogen sulfide gas in groundwater is known at several localities in the mountains.

In the sparsely populated parts of the area, including the high mountains, the evaluation of geology and topography were fundamental tools in the estimation of hydrogeological characteristics.

INTRODUCTION

The Calgary-Golden map area (NTS 82O-82N) is located in southwestern Alberta between longitude 114° west and the British Columbia-Alberta border and latitudes 51° and 52° north. It lies within Tps 23 to 35, Rs 1 to 23, W 5th Mer, and covers about 7300 sq mi (18,900 km^2).

About one third of the map area falls within Banff National Park and small reserves belonging to the Stony and Sarcee Indians. The Camp Sarcee Military Reserve and Red Lodge, Big Hill Springs, and Bow Valley Provincial Parks are also within the map area.

The Banff Hot Springs inspired the Canadian Government to establish the first Canadian National Park in 1885. From this seed grew the flourishing Parks system of the present day. Nowadays two spas are located at these hot springs.

Two main highways of the province, Nos. 1 and 2, cross the area along its southern and eastern margins, respectively. Highways 1, 2, 1A, 2A, 27 to Sundre, and 93 from Lake Louise to Jasper are fully paved. Gravel roads provide good access to the eastern third of the map area, and the Forestry Trunk Road winds its way through the Foothills between the Bow and Clearwater Rivers. Approximately half of the map area can be reached only by helicopter or on foot.

The vegetation of the Rocky Mountains and Foothills consists of altitudinally zoned alpine meadows and lodgepole pine, white spruce, and Engelmann spruce forests. In the mountains there are also barren patches of rock and icefields. East of the Foothills are mixed aspen-spruce (white and black) forests, willow-aspen scrublands, and parklike grasslands with aspen poplar groves. In the eastern half of the map area most of the land is used for farming, so very little original vegetation remains (Government and University of Alberta, 1969).

Settlements (population figures as of 1975) within the map area with surface waterworks include Calgary (pop. 453,812), Banff (pop. 3208), Canmore (pop. 1712), Cochrane (pop. 1208), and Crossfield (pop. 685). Those settlements that utilize groundwater are: Olds (pop. 3606), Didsbury (pop. 1995), Airdrie (pop. 1437), Sundre (pop. 1014), Carstairs (pop. 982), Bowden (pop. 617), and Cremona (pop. 20) (Alberta Environment, 1976).

A 1:50,000 scale Hydrogeological Information Atlas covering the entire map area was prepared by A. T. Lytviak in 1972. Fieldwork began in 1972 and was completed in 1976. Three hundred and sixty-two water samples were collected for hydrochemical analysis. The field survey included helicopter traverses, test drilling, aquifer testing, and documentation of natural groundwater discharge features. A detailed field survey of the Canmore area was carried out by Ceroici and Prasad (1977) and 21 testholes were drilled.

The accompanying maps and profiles were constructed in the winter of 1972-1973 and in 1976. Their legend is explained in Badry (1972).

PREVIOUS WORK

Groundwater studies were conducted by Meyboom (1961) in the Calgary area, Tóth (1966) in the Olds area, Tokarsky (1973) in the Morley Indian Reserve, Nielsen (1975) in Banff National Park, and Ceroici and Prasad (1977) and Ceroici (1977) in the Canmore corridor. Groundwater recharge observations were made at an instrumented experimental site in Calgary by Freeze and Banner (1970).

The thermal and mineral springs of the area were investigated by van Everdingen (1972).

Regional groundwater studies which included the Calgary area were published by Hitchon and Shaw (1960), Le Breton and Jones (1962), Brown (editor, 1967), Curcio (1967), Nielsen (1969), and Ozoray (1977a). Water well records for part of the area were published by Geiger *et al.* (1968).

Some data regarding surface waters were published by Thomas (1956) and Laycock (1957). A terrain analysis of Banff National Park was conducted by Reimchen and Bayrock (1975).

ACKNOWLEDGMENTS

Data and unpublished manuscripts were made available to us by the Energy Resources Conservation Board; Parks Canada; Pacific Petroleum Ltd.; Alberta Department of Energy and Natural Resources; Shell Canada Ltd.; Canadian Superior Oil Ltd.; Underwood, McLellan and Associates Ltd.; J. D. Mollard and Associates Ltd.; and Amoco Canada Petroleum Company Ltd. Permission to use some restricted roads and carry out helicopter traverses was given by Banff National Park authorities.

Test drilling and aquifer tests were conscientiously carried out by Forrester Water Well Drilling Ltd., Red Deer; Kinsella Drilling Ltd., Innisfail; and Webster Drilling Ltd., Calgary. Assistance in both field and office work was provided by A. T. Lytviak and C. I. Henry. The water samples collected during fieldwork were analyzed by the Provincial Analyst and by J. R. Nelson, Alberta Research Council.

The manuscript was critically read by D. A. Hackbarth, G. M. Gabert, and R. Green. The authors gratefully acknowledge the help given by them. They also thank R. W. Swenson for drafting the maps and Mrs. S. P. Cane and Mrs. B. Jeremic for typing the report.

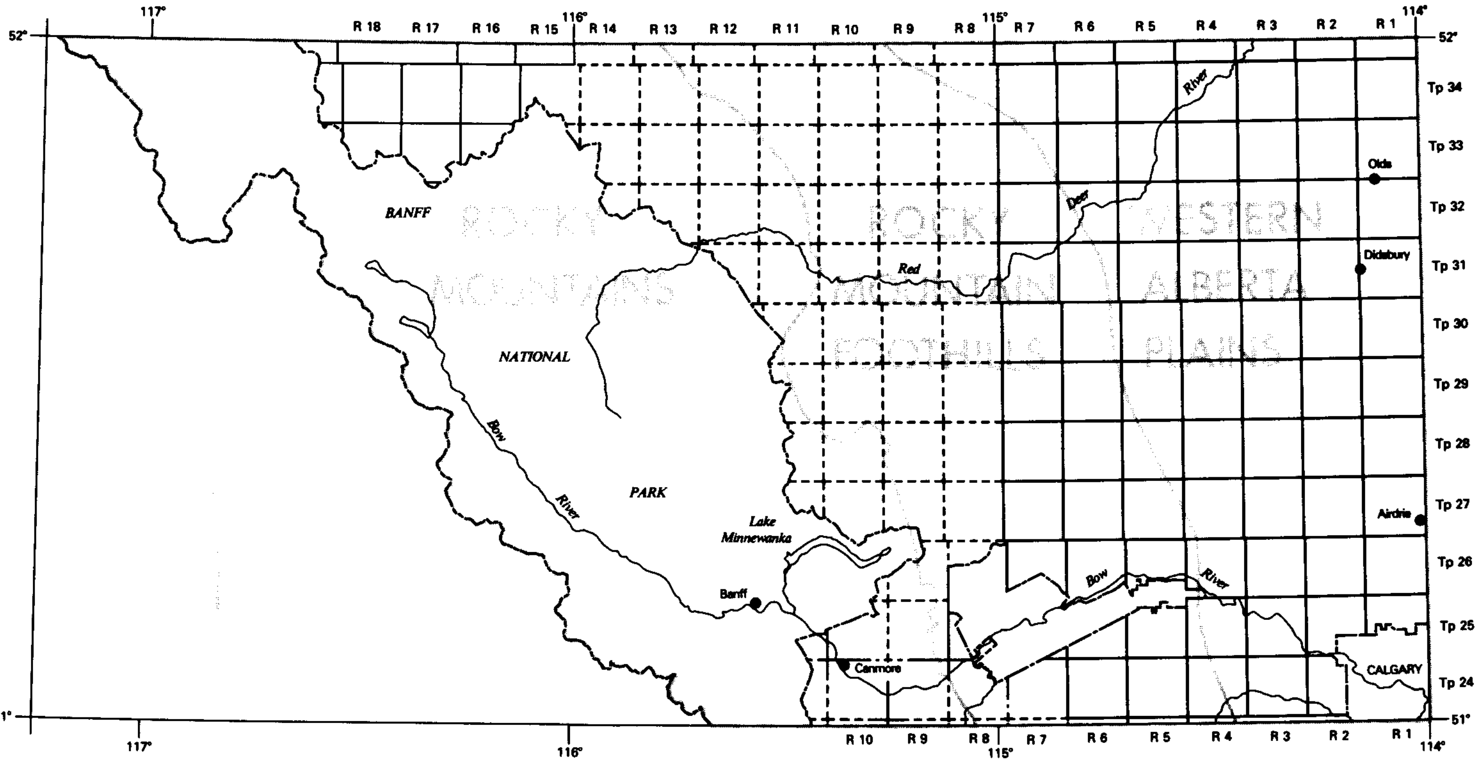


FIGURE 1. Sketch map of the physiographic regions, Calgary-Golden area

TOPOGRAPHY AND DRAINAGE

The map area includes parts of three physiographic regions: the Rocky Mountains, Rocky Mountain Foothills, and Western Alberta Plains (Fig. 1, after Government and University of Alberta, 1969). The Rocky Mountains are high mountains [peak elevations usually above 7000 ft (about 2100 m) amsl] with rugged appearance, many sharp ridges and peaks, steep slopes, abundant bedrock outcrops, and some glaciers. The Foothills are mountains of medium height or hills [peak elevations mainly between 5000 and 7000 ft (about 1500 and 2100 m) amsl] with much softer topography than the Rocky Mountains. The Western Alberta Plains are rolling plains lower than 5000 ft (about 1500 m) amsl with flat-topped, gentle elevations and generally broad, gently sloped (occasionally, however, sharply cut) valleys. Bedrock outcrops are few in the plains, and are found in stream banks and gullies.

The highest surface elevation in the area is the summit of Mount Temple at 11,626 ft (3544 m) amsl and the lowest elevation, about 3040 ft (927 m), is in the northeast corner of the map area. In the southeast, where the Bow River leaves the map area, the elevation is about 3360 ft (1024 m).

The map area is drained by the Saskatchewan-Nelson-Hudson Bay drainage system. The British Columbia-Alberta border which forms the western boundary of the map area is also the main continental divide or watershed. The surface water divides of the watersheds of the North Saskatchewan, Red Deer, and Bow Rivers as well as those of some of their tributaries, are presented on the main map. A small area of pitted terrain around the Lochend Lake has no natural surface drainage.

The base flow of the rivers is derived from groundwater discharge. The base flow conditions of the Elbow River at Calgary were analyzed by Meyboom (1961). He found that the annual groundwater contribution to the Elbow River flow amounts to 2.05 in (52.1 mm) over the entire basin. About 42 percent of the normal total river flow between August and April is generated by groundwater and 73 percent of this originates from bank storage.

The biggest lake of the area is Lake Minnewanka, which lies in an ice-modified pre-Wisconsin age valley. Innumerable small lakes of glacial origin are present throughout the area.

CLIMATE

According to the Koeppen climatic zone classification, as applied by Longley (1972) to the Prairie Provinces, most of the map area has a microthermal climate with short, cool summers. The eastern edge of the map area has a long, cool summer with at least four months with mean temperatures of 10°C or more.

Table 1. Temperature, Precipitation, and Potential Evaporation

			Olds	Calgary	Kananaskis	Lake Louise
Mean Temperature:	January	°F	11.9	14.2	15.4	6.3
		°C	-11.2	-9.9	-9.2	-14.6
	July	°F	61.0	62.0	57.6	54.4
		°C	16.1	16.7	14.2	12.5
	Annual	°F	37.3	38.4	36.8	31.9
		°C	2.9	3.6	2.7	0.0
Mean Annual Precipitation:		inches	18.21	17.44	25.09	30.37
		mm	463	443	637	771
Mean Annual Potential Evaporation:		inches	27.5	28.0	25.0	14.01
		mm	698	771	635	356
Length of record in years			30	30	21	30

Continuous, long-term meteorological observations are available from Calgary, Banff, Olds, Kananaskis, Lake Louise, and Exshaw (Canada Department of Transport, 1967). Partial records, usually only of precipitation from May to September for the last eight years, are available from eight additional localities (Stashko, 1971). The annual precipitation at these localities was calculated by assuming that the partial precipitation record represents the same proportion of the annual precipitation as measured (May to September) at the nearest long-term meteorological station. From long-term meteorological records it would appear that the last few years have been more humid than the long-term average; however, the calculated annual precipitation from partial records was not adjusted accordingly. Isohyets from Longley (1972) were modified according to data obtained from the partial precipitation records, and are presented on the meteorological side map. The highest mean annual precipitation within the map area was recorded at Lake Louise, where the 30-year average is 30.37 in (771 mm). Due to the lack of meteorological data from the mountainous parts of the map area and also the expected highly variable conditions, isohyets are not continued into these areas on the meteorological map.

From the end of October to the end of April snow usually covers the entire map area (Potter, 1965). The duration of snow cover in the Rocky Mountains is highly dependent on local conditions and no data are available. At Lake Louise 64 percent of the annual precipitation falls as snow.

Potential evapotranspiration, estimated from the maps of Bruce and Weisman (1967) and calculated by the Thornthwaite method, exceeds precipitation in the months May to October and exceeds mean annual precipitation except at Kananaskis in June, September, and annually; and at Lake Louise in September, October, and annually.

Areally characteristic meteorological data from four stations are given in Table 1. These are from Olds in the northeast plain, Calgary in the southeast plain, Kananaskis in the south-central Front Ranges, and Lake Louise in the west-central Main Ranges.

GEOLOGY

Geological investigations in the map area commenced in the last century (Dawson, 1885). Since then over 25 geological maps and reports describing various parts of the map area have been published. Especially valuable are the field guidebooks of the Alberta Society of Petroleum Geologists.

The major resources of the area are oil, natural gas, and coal. Other mineral resources of lesser importance include clay and shale, dolomite, phosphate, silica sand, sulfur from natural gas, and limestone.

BEDROCK GEOLOGY

The geological side map is based primarily on the *Geological Map of Alberta* (Green, 1972) and on *Structure of the Southern Canadian Cordillera* (Wheeler, editor, 1972, Fig. 2-1).

Within the Plains portion of the map area, gently dipping Mesozoic and younger rocks extend from the surface to more than 1000 ft (300 m) below the surface. As shown on the side map (contours after Irish and Havard, 1968), the very thin Upper Cretaceous Whitemud and Battle Formations dip about 8 m/km to the west in the northern part of the area, and about 12 m/km to the northwest in the southern part of the area. The overlying Paskapoo Formation, the main bedrock aquifer of the Plains, is similarly inclined or horizontal. Local block faulting may be present but is of little hydrogeologic importance in the Plains area.

The Rocky Mountains and Foothills together form the aptly named "disturbed belt". The complicated geology and structure of this belt are represented on the geology side map and on the profiles in a simplified way. In the Front Ranges of the Rocky Mountains Paleozoic rocks are dominant; Proterozoic rocks outcrop within the Main Ranges along the British Columbia-Alberta border. A number of northwest-striking thrust faults (the more important ones are shown on the side map) divide the disturbed belt into long, narrow structural units. Within the major units the rocks may be folded, block faulted, and imbricated.

The Proterozoic Miette Group strata consist predominantly of gray and brown slate with feldspathic pebble conglomerate beds (Cook, 1975). The Lower Paleozoic consists mainly of limestone and dolomite with some shale; however, the basal Cambrian Gog Group strata consist mainly of quartzite with minor limestone, sandstone, and shale. The Upper Paleozoic, including the Upper Devonian, contains mainly limestone and dolomite, with some shale, sandstone, anhydrite, and chert.

The Triassic strata consist of siltstone, with some limestone, dolomite, and gypsum. The Jurassic-Cretaceous Fernie, Kootenay, and Nikanassin Formations consist of shale, siltstone, cherty and phosphatic dolomite, coal, and glauconitic sandstone and shale. The Lower Cretaceous Blairmore Group contains sandstone and shale with minor conglomerate and coal in commercial quantities. The Upper Cretaceous Alberta Group consists of shale, sandstone, siltstone, and minor coal. The Upper Cretaceous-Paleocene Brazeau Formation is composed of sandstone, mudstone, some tuff, and coal.

The Paleocene Paskapoo Formation in the northeast and Porcupine Hills Formation to the southeast consist mainly of cherty, calcareous sandstone, siltstone, and mudstone with minor conglomerate, limestone, coal, and tuff beds. The Paskapoo and Porcupine Hills Formations are the only bedrock units seen in outcrop in the Plains portion of the map area. The subsurface marker bed at the base of the Paskapoo Formation is the thin Upper

Cretaceous Whitemud and Battle Formations, consisting of bentonitic sandstone, mudstone, and siliceous tuff.

SURFICIAL GEOLOGY

In much of the map area surficial deposits are less than 50 ft (15 m) thick. Deposits up to 200 ft (60 m) thick may be encountered in the northeastern quadrant of the map area, and elsewhere along some rivers and preglacial buried valleys. Drift thickness maps of small sections of the map area were published by Meyboom (1961) and Tóth (1966).

Both Laurentide and Cordilleran glacial deposits are found within the map area (Tharin, 1960; Stalker, 1977) and include: lacustrine and glaciolacustrine sands, silts, and clays; outwash, esker, and kame sands and gravels (sometimes very coarse and usually quite silty); minor eolian deposits; and several varieties of till. Loose, unsorted colluvial accumulations are common in the Rockies at the foot of mountain ranges and on valley flanks, and thickness of these deposits exceeds 40 ft (12 m) over large areas (Reimchen and Bayrock, 1975). Tóth (1966) found colluvial landslide deposits in short buried gullies near Olds. There are also river terrace deposits and Recent alluvium.

Those streams of the area associated with thick sand and gravel deposits — the Bow, Ghost, Elbow, Red Deer, lower Little Red Deer, and lower Fallentimber Rivers — more or less follow their preglacial valleys (Stalker, 1961; Farvolden, 1963). The sand and gravel aquifers along these persistent river courses are shown on the map and profiles. Channel fills consist of sand, gravel, sandy silt, and silt, and the ground moraines of overriding glaciers are represented by till (for example, in the Bow Valley fill downstream of Calgary; Stalker, 1961). Buried valleys probably exist between the Little Red Deer and Fallentimber Rivers near Big Prairie and along lower Dogpound Creek (Stalker, 1961), and are likely filled with sand and gravel under till or silt.

Along the Bow River, Stalker (1968) recognized nine terraces in addition to the channel fill lying below the present level of the river; the topmost terrace is situated 330 ft (100 m) above the river. Each terrace is covered by sand and gravel deposits ranging in thickness from a mere veneer to 90 ft (27 m).

The river valleys in the Rocky Mountains and the Foothills contain a considerable thickness of porous fill. In fact, the well-known "hoodoos" at Banff are erosionally carved drift deposits. A Council testhole near Canmore (Lsd 3, Sec 26, Tp 24, R 10, W 5th Mer) penetrated 231 ft (70 m) of the gravel, sand, silt, and clay beds of the Bow Valley fill without reaching bedrock. A driller reported that at Exshaw (Lsd 8, Sec 22, Tp 24, R 9, W 5th Mer) a well 400 ft (122 m) deep stopped in drift. On valley flanks are found talus, landslide deposits, and alluvial fans (Ceroici and Prasad, 1977).

A number of interstadial or postglacial spillways are located along the eastern margin of the map area. These are mainly northwest-southeast directed, semiburied or abandoned valleys which may contain elongated lakes, or small misfit or temporary creeks. The deposits in these valleys consist of till, glaciofluvial deposits (usually silty) and perhaps some sand and gravel in the deeper layers.

HYDROGEOLOGY

DATA SOURCE AND SELECTION

Water well drillers' reports giving well location, total depth, depth to nonpumping water level, and brief lithological descriptions are available from the Alberta Research Council data file. Bail test and pump test data of sufficient accuracy to give calculated values of transmissivity and 20-year safe yield were available for 94 water wells. These data were supplemented by 213 apparent yield values calculated from aquifer tests in which only the nonpumping water level and total drawdown at the end of the test were recorded.

Data from 195 springs, 1155 wells with water level observations, 64 testholes with electric or lithological logs or both, and 898 hydrochemical analyses were also used during map compilation.

The strikingly uneven distribution of the hydrogeological data is shown on the data density side map. In some localized areas hydrogeological observations were too numerous to be presented on the data density map.

TEST DRILLING AND AQUIFER TESTS

To supplement existing data and to facilitate evaluation of apparent transmissivity and yield values, test drilling or aquifer testing or both were carried out at nine localities (Appendix).

GROUNDWATER PROBABILITY

The total probable 20-year safe yield from the upper 1000 ft (about 300 m) of strata is shown on the main map by color-coded areas.

For the calculation of transmissivity from pump test data, Jacob's modified nonequilibrium formula was used:

$$T = \frac{2640}{\Delta s}$$

where T = transmissivity in imperial gallons/day/ft (igpd/ft), Q = pumping rate in imperial gallons/min (igpm), Δs = drawdown in ft/log cycle of minutes.

In some instances, only the length and rate of bail or pump tests, and the total drawdown are given. These data are often observed during the development of a well and, in the absence of better data, an apparent transmissivity can be calculated from these observations (Farvolden, 1961; Ozoray, 1977b). Experience shows that apparent transmissivity values can give a valuable indication of regional variations in relevant hydrological properties of rocks.

For the calculation of the 20-year safe yield of a well the following formula was used:

$$Q_{20} = \frac{TH}{2110}$$

where Q_{20} = 20-year safe yield in igpm; it is defined as the rate at which the well can be pumped continuously for 20 years without the water level dropping below the top of the producing aquifer; T = transmissivity or apparent transmissivity in igpd/ft; H = total available drawdown in feet, usually taken as the difference between static water level and the top of the producing aquifer.

The yield areas of the main map and profiles were defined with the following constraints:

(a) for the most part only apparent 20-year safe yield values were available;

(b) the available data were usually only from the shallowest aquifer satisfying the local water demand;

(c) data differed depending on different drilling and developing techniques, and on individual testing habits, even in the same locality and aquifer.

To offset these shortcomings, the more accurate data were considered first, then yields were extrapolated into adjacent areas on the basis of similar geologic and topographic conditions. Additional data were obtained in areas with scarce or poor data distribution from the drilling and testing program (Appendix).

Yields, in areas where quantitative data are absent, are defined as "possible" (Badry, 1972) and are indicated by the lighter shades of color. These estimates are based on qualitative information such as electric well logs, topography, lithology, and consideration of natural groundwater discharge phenomena.

To assign proper yield ranges, not only the nature of the data but also the variability of relevant natural phenomena must be considered. Facies differences, tectonic pattern, and orography result in different yield averages from area to area from the same geologic formation. Moreover, individual wells within a short distance of each other may perform very differently. For example, various hydrogeological consultants investigated five localities along the Bow River. At two of these sites, near Calgary, aquifer tests indicated high transmissivity values and the possibility of induced infiltration into the surficial deposits from the nearby river. At three sites near Cochrane yields of only 1 to 2 igpm (less than or a little more than 0.1 l/sec) were obtained. At the industrial plant in Exshaw two wells were drilled very close to each other in sand and gravel deposits; one was practically dry and the other (catching the underflow of a tributary valley) produced several hundred igpm. Some geological formations are discussed here in detail to elucidate the causes of this diversity.

The yield and lithology shown on the main map are of the drift in areas of thick and permeable fluvial and glaciofluvial deposits: that is, in the river valleys, along some buried channels, and on terraces and kames. Some of these deposits are discontinuous, and form lensy channel fill. The pore spaces among the sand grains are commonly clogged by clay or silt. Clean sand and gravel deposits of considerable thickness and extent which receive abundant recharge from the adjacent bedrock (for instance, from karstic limestone), or surface water bodies (bank storage of flood water, infiltration from lakes or rivers) may have extremely high yields. Such is the case in the Bow Valley near Exshaw (see profile D-D'). Wherever the fluvial-glaciofluvial deposits are mainly silt, or the sand is clay-clogged, or the gravel is well-drained without having adequate recharge (Appendix, testhole No. 9), the yield is low. Yields from the drift are low in the Bow Valley west of Cochrane.

All other yield estimations shown on the map are for the bedrock. The main bedrock aquifer of the Plains portion of the area is the Paskapoo Formation. The hydrogeological properties of the Paskapoo Formation near Olds were investigated in detail by Tóth (1966). Only the sandstone beds may contain significant intergranular porosity (pores among the sand grains are often filled with cementing materials, in this case calcareous material). The sandstones are not continuous in thickness or extent: lenses and truncated beds are often found. The main sandstone unit itself disappears north of Highway 27 due to facies change. Moreover, the intergranular porosity is considerably reduced by the presence of unevenly distributed montmorillonite (a clay mineral, the main component of the aquifuge rock bentonite). A tectonic groundwater barrier was also found: a fault plane, likely made slick by clay minerals. Porosity is increased, however, by fracturing due to tectonic events (perhaps only to a lesser degree), ice drag, and subsurface slumping; one might also add isostatic movements, valley rebound, and stress changes due to uneven compaction, ice loading, and ice unloading. Fracture porosity can also be found in the coal and shale beds. Fracturing is dependent on the physical rock properties: under the same stress conditions rigid and brittle coal will fracture more and soft and plastic shale less than a sandstone. Fracture porosity is more likely to remain open and unclogged in coal and sandstone than in shale. Both intergranular (primary) and fracture (secondary) porosity of the Paskapoo Formation near Olds are unevenly distributed. The data, although more sparse in other areas, indicate that the same is true of the Paskapoo Formation throughout the map area.

Data on the Brazeau Formation are scarce in the area. This unit is lithologically similar to the Paskapoo Formation and it is likely that its hydrogeological properties are also similar. In the disturbed belt tectonic features (tectonic groundwater barriers, high fracture porosity, non-horizontal bedding planes) must be prominent in these aquifers. Alberta Group strata also have their effective permeability due to tectonic influences.

The main aquifers in the Rocky Mountains part of the area are the Paleozoic limestones and dolomites. Intergranular porosity is low in old limestones but fracture porosity may be quite high. Some areas are also affected by karst features which develop when the limestone dissolves in water, a phenomenon enhanced by the presence of CO_2. Inside the limestone masses integrated conduit systems may develop, which perhaps include water-filled or presently dry caves. Well-developed karst is characterized by big but very unevenly distributed groundwater resources; groundwater flow is speedy but the water mainly moves through these integrated conduits, so discharge is concentrated at a few big springs. The Cordilleran (Rocky Mountains and Foothills) karst is geologically young because the glaciation and associated vertical movements disrupted the old karst systems; however, points of concentrated discharge (karst springs) have already developed (Ozoray, 1977a).

Yield categories were assigned on the main map and profiles in the following manner:

(a) over 500 igpm (about 38 l/sec) for some Quaternary sands and gravels along rivers and for small areas of Paleozoic carbonates where concentrated spring discharge occurs;

(b) 100 to 500 igpm (about 8 to 38 l/sec) for some Quaternary sands and gravels, Paskapoo sandstones and shales, and Upper and Lower Paleozoic carbonates;

(c) 25 to 100 igpm (about 2 to 8 l/sec) for some Quaternary sands and gravels, Paskapoo sandstones and shales, and Upper and Lower Paleozoic carbonates;

(d) 5 to 25 igpm (about 0.4 to 2 l/sec) for various Quaternary deposits and for various Proterozoic to Paleocene sandstone and shale, shale and sandstone, or shale and siltstone aquifers;

(e) 1 to 5 igpm (about 0.1 to 0.4 l/sec) for till, silty alluvium and some other Quaternary deposits; for silty and unfractured sandstone and shale, shale and sandstone, or shale aquifers of Paleocene to Lower Mesozoic age;

(f) less than 1 igpm (less than 0.1 l/sec) can be found mostly where the groundwater level is deeper than 1000 ft (about 300 m) as, for example, the margin of high plateaus, isolated peaks and narrow, high ridges (see profiles A-A' and D-D'); locally some well-drained gravels or rocks of very low porosities also come into this category.

Because of the capriciousness of the aquifers throughout the area, sizeable waterworks should be planned only after detailed field studies similar to those done at Olds (Tóth, 1966); such studies should include long (at least 2 weeks) pump tests. Problem areas in the Plains, where yields will be extremely low, are those where unfractured shale and montmorillonitic (bentonitic) sandstone underlie thin or clayey-silty drift. Some of these areas, located mainly along the eastern margin of the map area, are shown on the hydrogeological map. Hilltops, ridges, and escarpments are also disadvantageous places for groundwater extraction.

The groundwater problem areas in the Mountains are mainly those where the groundwater level is extraordinarily deep and fluctuating. Areas where the bedrock is slate, quartzite, or shale are also of low yield. The presence or absence of tectonic features and the degree of karstification (dissolution enhancement of fractures, integration of conduits) should also be taken into consideration in the Mountains when development of the groundwater is planned.

HYDROGEOLOGICAL PROFILES

Four hydrogeological profiles were constructed. The horizontal scale is 1:250,000; the vertical scale 1:12,192 (1 mm to 12.2 m, or 40 ft); vertical exaggeration is about 20 times. The profiles show the 20-year safe yield of the important rock units without distinguishing the individual aquifers. The color-coded main map shows the sum of the yields of the formations in the upper 1000 ft (about 300 m). However, because of the logarithmic scale of the yield categories (refer to map legend), these essentially delimit the highest ranked formation.

Stratigraphy, generalized aquifer lithology, generalized flow directions, groundwater chemistry, and important observation points (wells, springs, testholes) are shown on the profiles.

GROUNDWATER LEVELS AND FLOW SYSTEMS

Both groundwater levels and directions of flow are indicated on the main map. Some flow systems are also indicated in a generalized way on the profiles.

The groundwater levels are subdued replicas of the topography: they dip from the Mountains towards the Plains and from water divides towards valleys. In the east half of the map area, water levels from wells in the most commonly used aquifers were contoured, that is water levels from wells in the Paskapoo Formation and in the upper 50 to 150 ft (15 to 46 m) of the drift. Groundwater contours are not presented for the western (mountainous) half of the area because of sparse control, steep slopes, and complex geology.

Groundwater flow systems can be thought of as having three parts or "limbs". In the descending limb, under the recharge area, the vertical component of the groundwater movement is downward (that is, hydraulic head decreases with depth). In the middle or lateral limb groundwater movement is predominately horizontal. In the ascending limb, under the discharge area, the water moves upward (hydraulic head increases with depth). The direction of groundwater flow is indicated on the main map by arrows and by symbols superimposed on the groundwater contours. In the map area local, intermediate, and regional systems are sometimes situated one above the other (Tóth, 1962). In some areas the systems mix, as is the case under the Banff Hot Springs. There are also pockets of stagnant groundwater. The flow regime in any area will influence other hydrogeological phenomena such as the hydrochemistry.

AQUIFER LITHOLOGY

The lithology of the locally most important aquifer is symbolized on the main map and profiles. In most cases the lithology of the most important aquifer is also the major or gross lithology of the geological formation in which it is found.

AREAS OF FLOWING WELLS

Areas of flowing wells and shotholes are shown on the hydrogeological map. They are situated on the lower slopes of hills and in valley bottoms and are widespread along the lines of sudden changes in slope angle. There are many more narrow belts where flowing conditions are likely but where wells have not been drilled. These areas are not shown on the map.

Flowing wells in the Calgary vicinity are located in the discharge areas of shallow local flow systems. Typically in these areas, the piezometric head initially increases with depth and then reverses gradient and decreases with depth. This indicates that the local flow systems are superimposed upon deeper, larger flow systems. The boundary between the shallow and deep flow system seems to be controlled by hydraulic rather than lithologic properties.

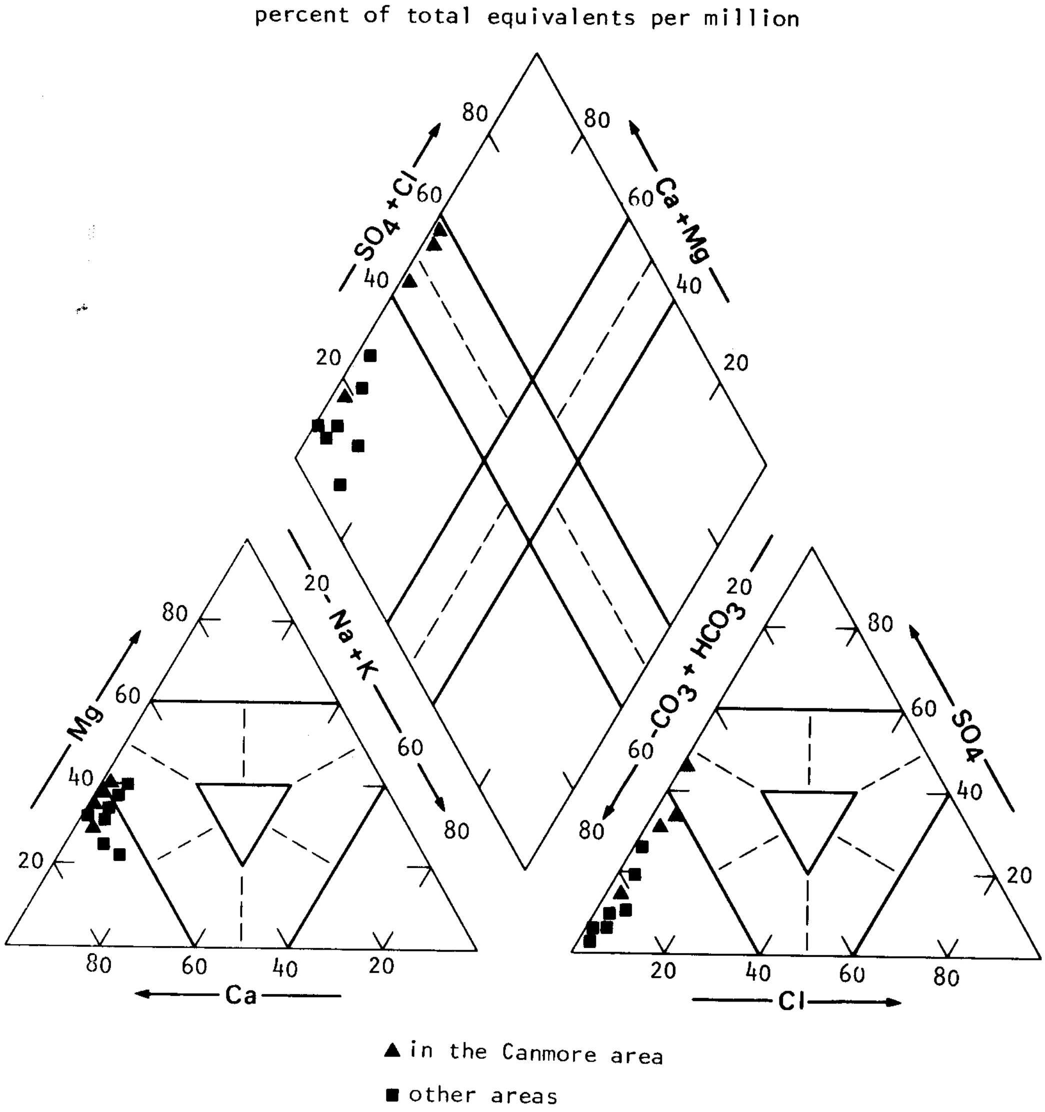


FIGURE 2. Chemical character of the karst springs, Calgary-Golden area (except sulfur springs)

SPRINGS

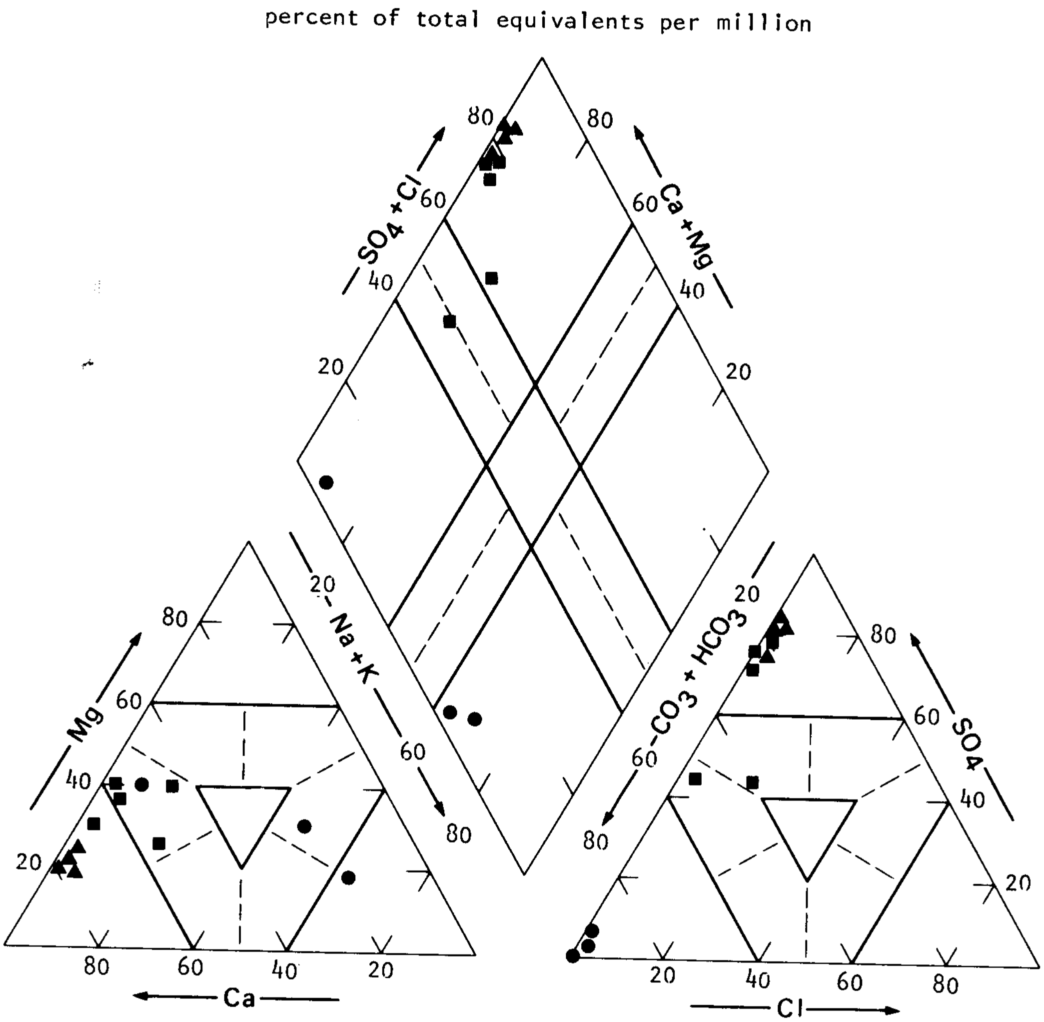
Numerous points of concentrated discharge, called springs, are found throughout the area. The various types represented include: karst springs, tectonically controlled springs, quasi-springs, contact springs, and seepages.

There are extensive limestone and dolomite surfaces in the Rocky Mountains which have been affected to some degree by karstification. Some large karst springs (water flowing along and from solution features) are known, such as the one on the south face of Mt. Wilson above the North Saskatchewan River crossing. The spring issues from a steep cliff in the side of a gully above the tree line. The flow rate is estimated to be 1000 to 5000 igpm (75 to 375 l/sec); the water source is glacial meltwater (Mt. Wilson Icefields). In the middle reaches of the Siffleur River, around Mt. Loudon, several smaller karst springs with discharge rates in the range of 50 to 150 igpm (about 4 to 12 l/sec) were observed. All these springs exist above tree line. Karst springs were also observed on the north flanks of Coronation Mountain, below the Freshfield Icefield. Dry or abandoned limestone caves were noted on the Ram River in the northeast corner of the Golden map area.

The karst springs of the area are of calcium-magnesium bicarbonate chemical character (Fig. 2) with less than 200 ppm total dissolved solids content. The low-lying karst springs around Canmore contain somewhat more dissolved solids (up to nearly 500 ppm) and noticeably more sulfates (Fig. 2).

Tectonic control may result in high spring yields as in the case of the springs situated 3 miles (about 5 km) east of Exshaw on the south bank of the Bow River. This group of ponded springs has an estimated discharge of about 3000 igpm (225 l/sec) and is situated over the subcrop of the McConnell Thrust Fault. Farther north, in the Brazeau-Canoe River map area, similar springs are found at the intersection of the Brazeau River and the McConnell Thrust Fault (Barnes, in preparation).

The interaction of karstic and tectonic processes controls the Banff Hot Springs which are located on the Sulphur Mountain Thrust Fault, and some of these springs issue from solution cavities. The groundwater that feeds the Hot Springs moves through limestones, dolomites, sandstones, and shales. The waters of the springs are of calcium sulfate (gypsum) chemical character (Fig. 3) and smell (most strongly!) of hydrogen sulfide (H_2S) gas. The springs have a very mild radioactivity (Elworthy, 1926). The Hot Springs have an average total flow of about 750 igpm (57 l/sec). The eight springs have individual differences (van Everdingen, 1972) in elevation [5196 to 4593 ft (1584 to 1400 m) amsl], yield [250 to 20 igpm (19 to 1.5 l/sec)], temperature (about 45.5 to 31°C), and total dissolved solids content (1700 to 700 ppm). The individual springs also show seasonal variations in yield, temperatures, and chemistry (likely because of variable mixing rates of the hot water with the cold, more dilute, calcium-magnesium bicarbonate type water of a local, shallow ground-



▲ hot sulfur springs

■ cold or warm sulfur springs

● cold springs with faint H_2S smell, with low dissolved salts content

FIGURE 3. Chemical character of the sulfur springs, Calgary–Golden area

water flow system) (van Everdingen, 1970). The Hot Springs feed two bathing facilities which are frequented tourist spots; there is only one other spa in Alberta. The Banff Hot Springs were the first (November 25, 1885) publicly protected area in Canada; from this grew Banff National Park and, indeed, the entire Canadian National Park system. Because of this distinction, the springs are scientifically well studied (Satterly and Elworthy, 1917; Elworthy, 1918, 1926; Warren, 1927; Haites, 1959; van Everdingen, 1969b, 1970, 1972).

There are also warm sulfur springs near Banff (Stoney Squaw Spring, Vermilion Lake Spring) and cold sulfur springs at Canmore, on the Panther River, and on the Clearwater River. These springs are chemically similar to the hot sulfur springs but contain more magnesium and less sulfate (Fig. 3). Some cold springs with no significant sulfate content may also have a faint H_2S smell; these are well separated on the chemical diagram (Fig. 3) from the true sulfur springs.

Above Johnson Canyon on Johnson Creek lie the Ink Pots, a group of seven strongly bubbling spring pools which together yield about 400 igpm (30 l/sec). These pools received their name because two of them have a greenish, milky appearance. The Ink Pots issue from drift-veneered shales and siltstones of the Triassic Sulphur Mountain Formation. The chemical character of the water is calcium carbonate, and total dissolved solids content is 253 ppm. Van Everdingen investigated the pools (1969a) and found, using models, that the coloration and milky appearance are due to differential suspension of fine sand and silt. This condition is a consequence of the grain size distribution of pool sediment; of the shape and size of the pool and outlet; and of the flow velocity of the issuing groundwater. That the milky appearance is not due to water chemistry is supported by the fact that there are similar looking, bubbling, silty springs in northern Alberta which are chemically very different from the Ink Pots (Ozoray, 1974).

Large quasi-springs, similar to those of the boreal taiga-muskeg region (Ozoray, 1974), also issue from the muskegs in the Foothills. Like the springs flowing from drift in the Mountains, these are calcium carbonate type. Total dissolved solids content is usually below 250 ppm. The biggest quasi-spring of the area, near the Harold Creek, has a flow rate of about 2000 igpm (150 l/sec) and contains only 66 ppm total dissolved solids.

Numerous springs in the Mountains issue from various drift materials such as gravel and sand, colluvium, talus or moraine accumulation at the contact of bedrock and drift, on valley bottoms, or at points where slope changes. These springs may even form groups or lines along the toe of talus slopes, around high cirques, or at other similar locations. Yield varies from spring to spring and occasionally can be very high: a group with a total yield of about 4000 igpm (300 l/sec) has been observed. Seasonal variation in yield is common and many springs are only temporary. A temporary spring was observed to issue from a paved highway causing recurrent pavement damage: a good example of the engineering importance of hydrogeological phenomena. Spring waters are of calcium-magnesium bicarbonate

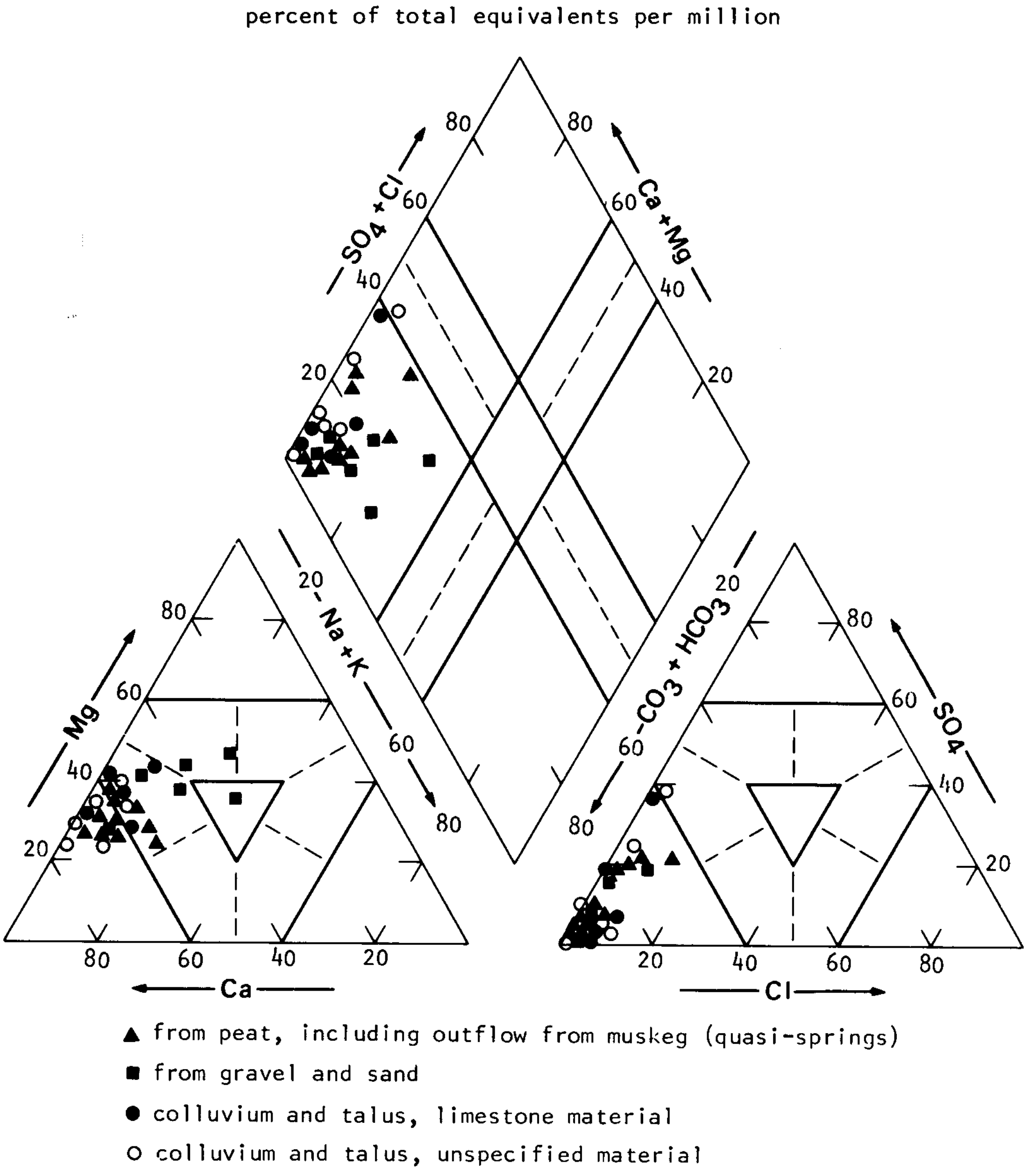


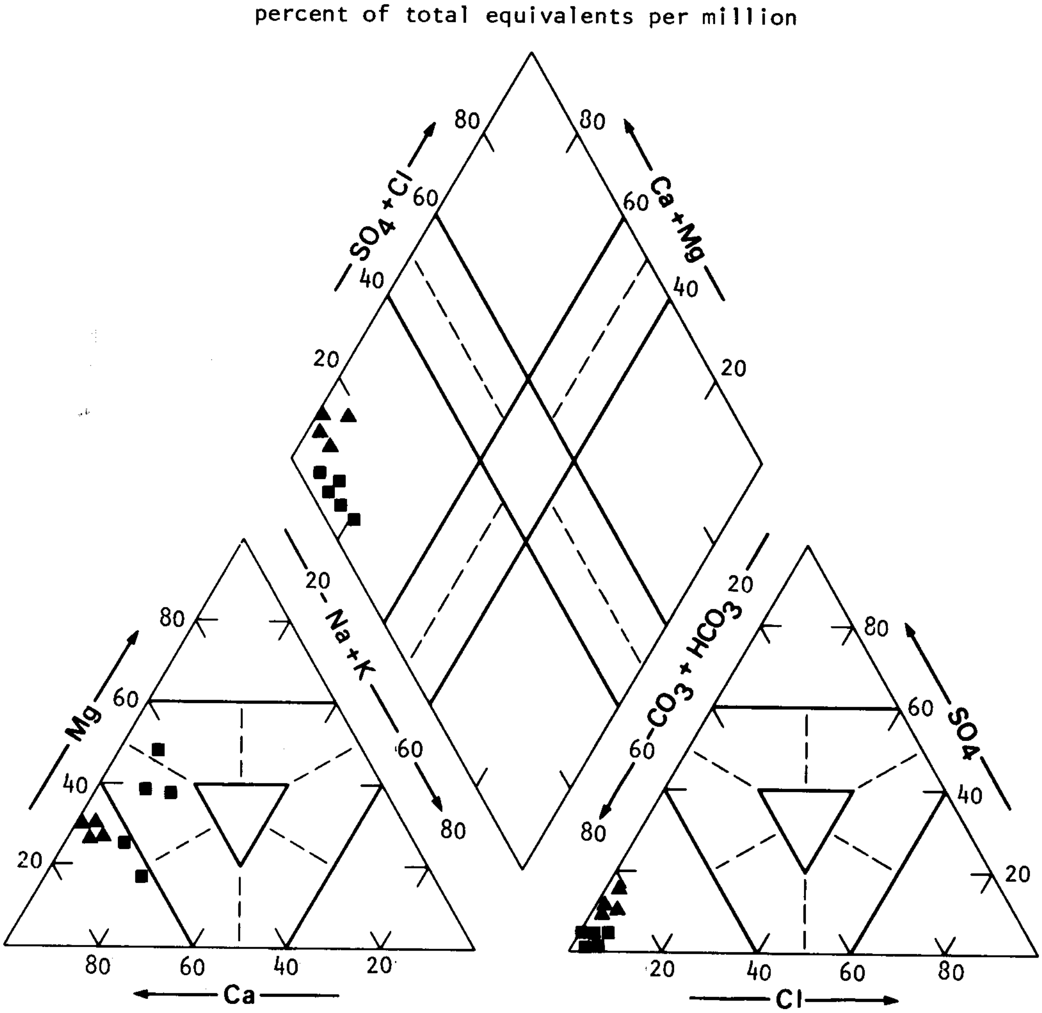
FIGURE 4. Chemical character of springs, originating from mountain drift, Calgary-Golden area

type (Fig. 4) and total dissolved solids content is usually below 300 ppm. These springs are chemically very similar to the karst springs (Fig. 2) which is quite understandable: the talus material is often limestone, and the mixed drift materials also contain plenty of carbonates.

Several springs, along the streams, yield water from bank storage. Chemical data of bank storage springs (along the Wilson Creek, Ghost, and Clearwater Rivers) form a very compactly situated, tightly grouped set of data points on figure 5, in the calcium bicarbonate field. Total dissolved solids contents of these springs are low (126 to 208 ppm).

Tufa-depositing springs are found in all physiographic regions in the Calgary-Golden area and are comparable to similar springs found in the Wabamun Lake area (Ozoray, 1972). The spring water is cold (3 to 5°C) and contains surprisingly small quantities of total dissolved solids, usually about 250 ppm. Chemically the water is calcium-magnesium bicarbonate type (Fig. 5). Both the low sodium and the high magnesium percentages show that the springs are the discharge points of short, local flow systems. The springs may issue from gravel, from drift composed of limestone fragments, or from drift-veneered Paskapoo sandstone. The location is usually a patch of open meadow. Sometimes there is a discharge point 50 to 100 ft (15 to 30 m) higher up on a gentle slope or higher terrace where the vegetation is larch or black spruce trees and clumps of Labrador tea and sphagnum moss. At this upper discharge point the water is dark with humic acid, and calcareous deposits are not found. The same water, emerging at the lower discharge point, starts to deposit travertine, but does not have a significantly higher total dissolved solids content. It is thought that at the upper discharge point the acidic condition of the soil inhibits precipitation of the carbonates, but that the water becomes aerated as it flows rapidly downslope to the second discharge point allowing precipitation of the carbonates. As well, biological activity (algae?) may promote travertine precipitation. A regularly situated group of tufa-depositing springs such as the "boulder tuft springs" of the Mt. Robson-Wapiti area (Barnes, 1977) was not found in the Calgary-Golden area. The boulder tuft springs issue from weathered Paskapoo sandstone just below the edge of the Tertiary escarpment.

There are spectacular tufa deposits near Cochrane in the Bighill Springs Provincial Park. The main spring originates from Paskapoo sandstone. Some of the water is swallowed by massive tufa fill in the middle part of the valley and comes to light again as secondary springs from the tufa. The really interesting phenomenon is an arched, 6 foot-high tufa dam, closing the upper part of the valley. There is no lake presently behind the dam because the creek cuts through at its northeastern-most side. The single arch of the dam does not show the usual scallop-form lobes common to other tufa dams (such as dams in the Plitvice Lakes in the Croatian Karst or the Tetarata in New Zealand). The material of the Bighill Springs tufa dam must have been deposited from water aerated by falling through one single obstacle closing the entire valley. There is no sign of a geological obstacle



▲ bank-storage springs
■ tufa-depositing springs

FIGURE 5. Chemical character of the bank-storage and the tufa-depositing springs, Calgary-Golden area

such as a volcanic dyke or an outcrop of a tilted, hard bed of rock, and nothing which could point to human origin (that is, an ancient Indian construction). Most likely the original, long-vanished obstacle was a beaver dam. (The author should like to congratulate the little boy, quite ridiculed by the park warden, who instinctively identified the tufa dam as a "beaver dam": although it is not one at present, it may have been one.)

In the Plains part of the area (a rolling land) a number of springs are found at the feet of slopes, at the heads of side-valleys and dales, or in gullies. These are often small and seasonal, perhaps only semi-diffuse, seepages or wet meadows on flat valley bottoms. Some fair-sized contact springs, however, originate from the outcrop or subcrop of Paskapoo sandstones under thin drift. The biggest springs are the previously discussed tufa-depositing Bighill Springs which together yield about 500 igpm (nearly 40 l/sec). The chemical type of sandstone springs in the Plains (Fig. 6) is calcium bicarbonate with 300 to 500 ppm total dissolved solids content. Sandstone springs in the Mountains are similar, but data for Mountain springs are not shown in the figure. The total dissolved solids content of the Paskapoo sandstone springs in another part of the Western Alberta Plains (Mt. Robson-Wapiti area; Barnes, 1977) seems to be related inversely to altitude. Such a relationship was not found for the Calgary-Golden area.

Water in springs issuing from terrace gravel in the Plains (such as the spring at Cochrane, shown on profile D-D') is of the calcium bicarbonate type (Fig. 6) and has a total dissolved solids content of 300 to 500 ppm. These springs do not differ either in chemistry or in appearance from the gravel springs of the mountain valleys (Fig. 4). The numerous, mostly small, springs and seepages issuing from the more or less thick non-gravelly drift (mainly till, glaciolacustrine silt, or silty sand) of the Plains are also of calcium bicarbonate type (Fig. 6) with a usually higher total dissolved solids content of 300 to 1000 ppm. There are some springs rich in sodium sulfate in the southeast corner of the area (Fig. 6) which have total dissolved solids contents of about 1500 ppm.

HYDROCHEMISTRY

A hydrochemistry side map has been constructed based on 898 chemical analyses of groundwater from the locally most used aquifer (including 195 analyses from springs). The variation in chemical composition in vertical and horizontal directions is shown on the hydrogeological profiles.

As mentioned previously, the flow regime in an area affects the chemistry of the water. As the water infiltrates into the ground, it starts to dissolve soluble materials. This process is helped by the CO_2 which the water picks up from the soil and the root zones of plants. Along the groundwater flowpath, the most soluble materials are dissolved first, then as time progresses the less soluble materials also come into solution. Waters

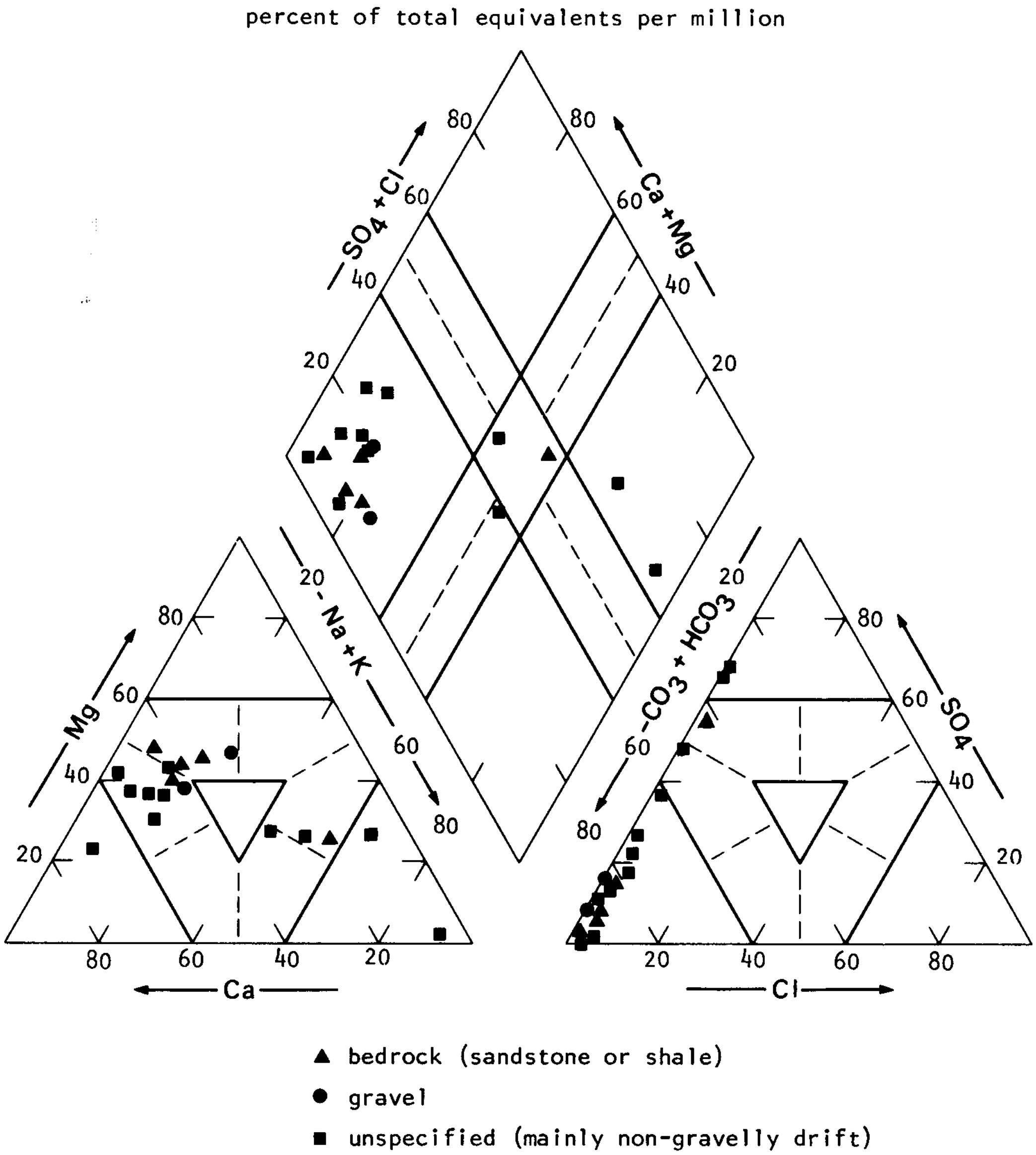


FIGURE 6. Chemical character of springs, Plains region of the Calgary-Golden area

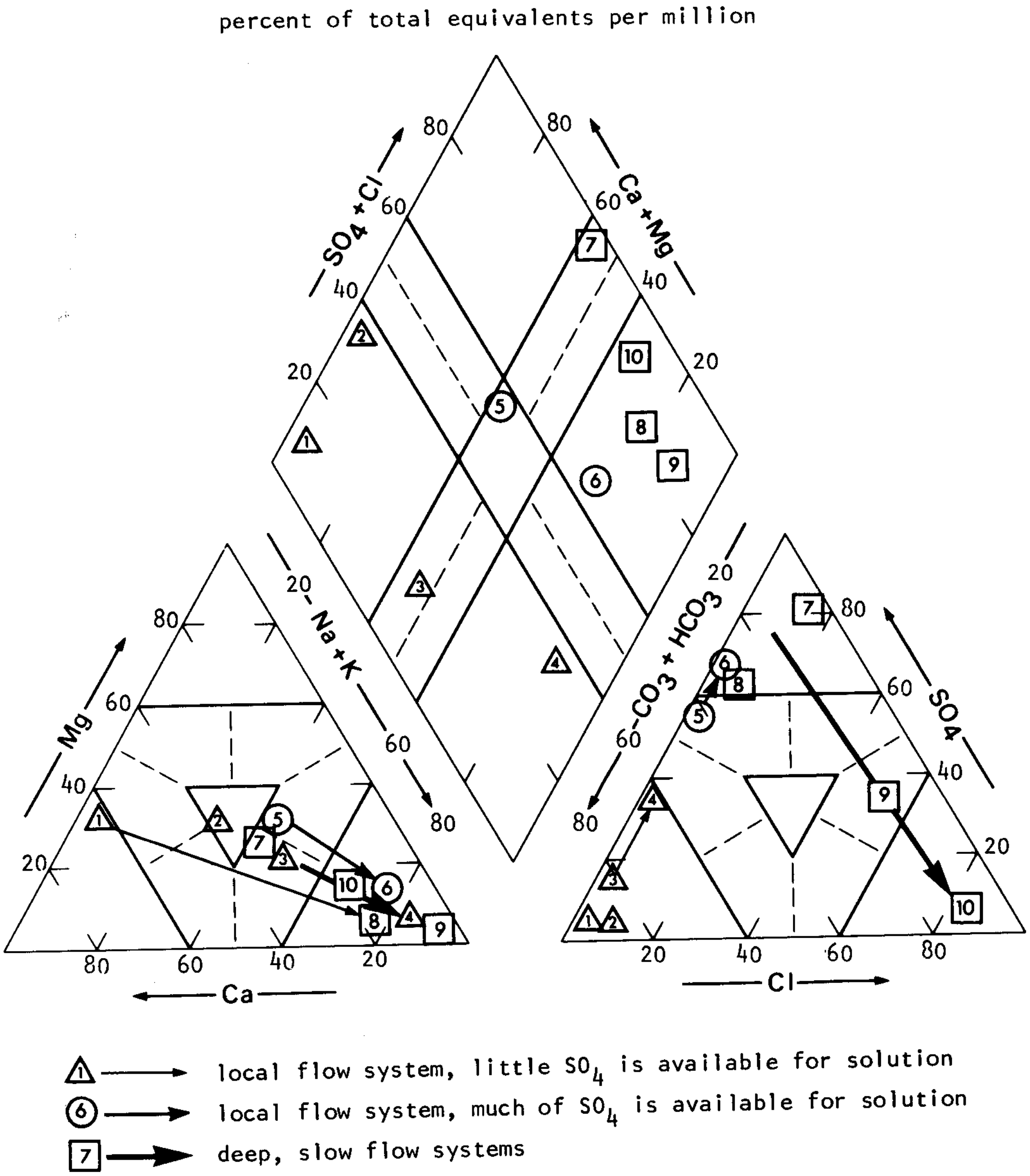


FIGURE 7. Change of chemical character of groundwater along flow path and with depth

containing CO_2 first dissolve calcium (Ca), then magnesium (Mg) as bicarbonate ions form; later more and more sodium (Na) enters into solution. The quantity of bicarbonate anion (HCO_3^-) formed is limited for practical purposes by the amount of CO_2 the infiltrating water has first picked up. However, the absolute concentration of the other anions, sulfate (SO_4^{--}) and chloride (Cl^-), if available, may increase at all points along the flowpath.

Consequently, along the flowpath of the groundwater system, the quantity of the total dissolved solids (measured in parts per million, ppm) usually keeps on increasing while the chemical character changes from calcium bicarbonate toward calcium-magnesium bicarbonate. If the water remains underground for a longer period, as is the case for a longer local or an intermediate flow system, the change continues toward sodium bicarbonate; if sulfate is available, the water becomes increasingly sulfatic. The common chloride minerals are very soluble in water and are readily removed by relatively fast flowing local or intermediate flow systems in the area.

The deep flow systems move very slowly; in some cases their contained water changes very slowly during long geological times. In some geological structures groundwater may become for practical purposes trapped. The chemistry of the deep groundwaters (formation waters) changes from the mixed cations sulfate type toward the sodium chloride (common salt) type.

Pockets of stagnant groundwater in between flow systems change their water slowly and have higher total dissolved solids content, and also higher sodium, sulfate, and chloride percentages than the neighbouring flow systems.

These processes as applied to the map area are represented on figure 7. The data points show analyses of groundwater samples (Table 2) taken from descending, lateral, and ascending limbs of local flow systems with little available sulfates; lateral and ascending limbs of local flow systems with abundant sulfates; and from deep formation waters. The samples were not taken along the very same flow system: because of cost considerations, existing data had to be used. However, the data adequately characterize the phenomena. Three general trends are apparent, as shown by the arrows on figure 7:

(1) toward sodium bicarbonate waters in shallow, relatively fast flow systems with little available sulfate supply;

(2) toward sodium sulfate waters in similar systems of abundant sulfate supply;

(3) toward sodium chloride waters in deep, slow flow systems.

These considerations make understandable the chemical picture shown on the profiles. The zone of the short, local flow systems contains calcium or calcium-magnesium bicarbonate type waters. The fast local systems penetrate deeper in the Mountains (because of the

Table 2. List of Groundwater Samples Shown on Figure 7

Serial No.	Location (W 5th Mer)				Depth of Well		Aquifer	Flow System	Limb of Flow System	Total Dissolved Solids, ppm	Chemical Character
	Lsd	Sec	Tp	R	ft	m					
1	9	13	34	2	98	30	drift	local	descending	418	Ca/HCO_3
2	13	25	30	1	130	40	Paskapoo	local	lateral	744	mixed/HCO_3
3	14	12	30	4	96	29	Paskapoo	local	lateral	612	Na-Ca/HCO_3
4	1	32	26	1	78	24	Paskapoo	local	ascending	986	Na/HCO_3
5	14	8	28	2	60	18	drift	local	lateral	1,744	Na-Mg/SO_4-HCO_3
6	5	14	25	3	spring		drift	local	ascending	1,572	Na/SO_4
7	12	11	30	11	1,896	578	Mississippian	deep	?	5,689	Na-Ca/SO_4
8	11	29	33	10	2,140	652	Mississippian	deep	?	3,647	Na/SO_4
9	12	9	34	9	2,425	739	Devonian	deep	?	6,042	Na/Cl-SO_4
10	5	31	34	9	1,318	402	Devonian	deep	?	16,148	Na/Cl

higher relief energy) so the calcium-magnesium bicarbonate zone is also deeper in the Mountains than under the Plains. Along the longer local and intermediate flow systems of the Plains the water type changes into that of sodium bicarbonate. Where more soluble sulfate is available (in the southeastern and eastern parts of the Plains region, at greater depths and along the deeply-penetrating Mountain thrust faults), sulfate type groundwaters are found. Chloridic groundwater is found only at considerable depth; for example, in the Mountains near the Red Deer River the upper boundary of the chloridic groundwater is 1500 ft (about 500 m) below surface as shown on profile A-A'.

Total dissolved solids contents are more than 1000 ppm (except in isolated cases) along the eastern margin and in the southeastern corner of the map area. However, over most of the area total dissolved solids contents are usually below 1000 ppm and commonly below 500 ppm.

The predominant anion over most of the area is bicarbonate; elsewhere it is sulfate. High sulfate content usually coincides with areas of high total dissolved solids content. The predominant cations in the Mountains are calcium and magnesium, while in the Plains sodium is often dominant.

Hydrogen sulfide (H_2S) can be found in the water of many springs and wells in the Rocky Mountains and Foothills, and can be recognized by its rotten egg smell. Hydrogen sulfide, although giving an unpleasant odor to the water, is not harmful in drinking water. In some countries natural spring waters of high H_2S content are bottled for human consumption.

Public health standards usually specify the maximum acceptable quantity of dissolved iron (Fe) in household water, mainly because people object to the iron staining of appliances, and to the reddish brown color and iron taste of water with high iron content. The Canada Department of National Health and Welfare (1969) proposes a 0.3 ppm limit on the level of dissolved iron in drinking water, but states as an "objective" less than 0.05 ppm. Out of 150 spring waters analyzed for iron content, only 14, that is less than 10 percent, had iron contents exceeding the 0.3 ppm acceptable level. It is more difficult to characterize the dissolved iron content of groundwater tapped by wells. The data available are for untreated well waters (although public and private water supplies are often treated to avoid excessive iron content). The dissolved iron content of the untreated well water depends, however, not only on the natural iron content of the groundwater but also on the ability of the water to dissolve iron it contacts, the materials used to construct the well, and the way the well is operated (for example, whether or not pumping is continuous). The dissolved iron data vary markedly within small areas. For example, near Olds (Tóth, 1966) dissolved iron content of well-water samples ranged from none to 5.5 ppm. Samples from a single well in the Olds area [drilled in Paskapoo sandstone, to a depth of 385 ft (56 m)] after 2 hours of bailing and 4, 23.5, 72, and 132 hours of pumping contained the following quantities of dissolved iron: none, 3.9, 5.5, 0.8, and 3.0 ppm. In general, the dissolved iron content is unevenly distributed in the groundwater, and groundwater with excessive iron content is found only in small areas in the southeastern and eastern parts of the Calgary-Golden area in both drift and bedrock waters.

The Canadian standards (Canada Department of National Health and Welfare, 1969) state that the amounts of natural fluorine (F), in the form of fluoride ion (F^-) in drinking water should not exceed 1.5 ppm; otherwise it may cause dental problems. Too low a fluoride content is also unhealthy for the teeth; however, the use of fluoridized toothpaste can protect the population against this source of tooth decay. For artificially fluoridized drinking water, an optimum of 1.2 ppm fluoride content is proposed by the standards, with a ± 0.3 ppm tolerance. Out of 184 spring water samples, analyzed for fluoride ion, only two had excessive fluoride contents; all others had less fluoride than the optimum. Forty well waters were selected to represent different aquifers and different limbs of the groundwater flow systems. Five of the samples contained excessive, none optimal, and 35 less than optimal quantities of dissolved fluoride ion. The distribution of the dissolved excessive fluoride content seems to be random, with the one exception that none of the high fluoride values are in waters from the ascending limb of a flow system.

CONCLUSIONS

The two most often used aquifers within the map area are the Paskapoo Formation (sandstones and shales) and surficial sands and gravels. Yields from the Paskapoo Formation may vary over very short distances, but are usually more than 5 igpm (0.4 l/sec). At several locations, yields over 100 igpm (8 l/sec) were obtained. Yields from Quaternary and Recent sands and gravels are more capricious, particularly in the mountainous areas. The availability of groundwater from these deposits is governed by their topographic position, recharge potential, and silt content. As a result yields vary from less than 1 igpm (0.1 l/sec) to more than 500 igpm (38 l/sec). The carbonate rocks of the Rocky Mountains are theoretically good aquifers. However, the generally high relief of carbonate terrains results in the groundwater table being too deep for any practical purpose. In low-lying areas karstic solution conduits may result in highly localized flow and concentrated discharge. Utilization and development of such discharge points (springs) for water supply purposes is probably more practical than attempting to develop water wells in limestone and dolomite aquifers.

Water quality over most of the area is good. Total dissolved solids content is usually below 1000 ppm and often below 500 ppm. The predominant hydrochemical facies are calcium-magnesium bicarbonate and sodium bicarbonate. Along the eastern margin and in the southeast corner of the map area, and in isolated localities farther west, high total dissolved solids are found associated with high sulfate concentrations. Surface contamination may be a local problem. Groundwater releasing hydrogen sulfide gas to springs and well water is known at many places in the Rocky Mountains and Foothills. The hot and mineral springs of the area are an unusual groundwater resource with recreational potential.

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APPENDIX. AQUIFER TESTS AND TEST DRILLING

1. Location: SW quarter, Sec 10, Tp 34, R 5, W 5th Mer
Owner: Mr. F. Overgaard
Contractor: Kinsella Drilling Ltd., Innisfail

Depth of well: 70 ft (21.3 m)

Lithological log: 0-38 ft (0-11.6 m) Quaternary till with some sand
38-70 ft (11.6-21.3 m) Paskapoo shale with sandstone

Tests: pumping: 800 min
rate: 5 igpm (0.38 l/sec)
recovery: 720 min

Observation well: distance: 150 ft (45.7 m)
depth: 103 ft (31.4 m)
automatic recorder

Aquifer parameters: transmissivity (T): 530 igpd/ft (9.14×10^{-5} m^3/sec/m)
original available drawdown (H): 12 ft (3.7 m)
20-year safe yield (Q_{20}): 3 igpm (0.23 l/sec)
storage capacity (S): 4.73×10^{-5}

2. Location: NW quarter, Sec 9, Tp 33, R 5, W 5th Mer
Owner: Mr. Dunwoody
Contractor: Forrester Water Well Drilling Ltd., Red Deer

Depth of well: 125 ft (38.1 m)

Lithological log: 0-10 ft (0.3 m) Quaternary till
(observation well) 10-127 ft (3-38.7 m) Paskapoo shale with some sandstone

Tests: pumping: 6200 min
rate: 6 igpm (0.457 l/sec)
recovery: 5760 min
remark: also two bail and recovery tests and one 60 min preliminary pump test on the pumping well and one bail and recovery test on the observation well

Tested interval: 75-125 ft (22.9-38.1 m), slotted casing

Observation well: distance: 100 ft (30.5 m) to the north
depth: 127 ft (38.7 m)
remark: drilled for the ARC

Aquifer parameters: transmissivity (T): 420 igpd/ft (7.25×10^{-5} m^3/sec/m)
original available drawdown (H): 40 ft (12.2 m)
20-year safe yield (Q_{20}): 8 igpm (0.61 l/sec)
storage capacity (S): 1.86×10^{-6}

3. Location: SE quarter, Sec 1, Tp 31, R 2, W 5th Mer
Owner: Mr. H. Epp
Contractor: Forrester Water Well Drilling Ltd., Red Deer

Depth of well: 182 ft (55.5 m)

Lithological log: 0-22 ft (0-6.7 m) Quaternary clay
22-182 ft (6.7-55.5 m) Paskapoo shale

Tests: pumping: 720 min
rate: 6 igpm (0.45 l/sec)
recovery: 720 min
remark: also a bail and recovery test

Aquifer parameters: transmissivity (T): 210 igpd/ft (3.62×10^{-5} m^3/sec/m)
original available drawdown (H): 10 ft (3 m)
20-year safe yield (Q_{20}): 1 igpm (0.08 l/sec)

4. Location: Lsd 4, Sec 27, Tp 34, R 5, W 5th Mer
Owner: Mr. J. Neil (James River Bridge store)
Contractor: Forrester Water Well Drilling Ltd., Red Deer

Depth of well: 85 ft (25.9 m)

Lithological log: 0-30 ft (0-9.1 m) Quaternary sandy clay
30-49 ft (9.1-14.9 m) Quaternary gravel
49-85 ft (14.9-25.9 m) Paskapoo shale

Tested formation: Paskapoo shale (the locally contaminated Quaternary gravel was sealed off)

Tests: bailing: 120 min
rate: 13 igpm (0.99 l/sec)
recovery: 120 min

Aquifer parameters: transmissivity (T): 150 igpd/ft (2.59×10^{-5} m^3/sec/m)
original available drawdown (H): 52 ft (15.8 m)
20-year safe yield (Q_{20}): 3.6 igpm (0.27 l/sec)

5. Location: SW quarter, Sec 18, Tp 34, R 2, W 5th Mer
Owner: Seventh Day Adventists
Contractor: Forrester Water Well Drilling Ltd., Red Deer

Depth of well: 110 ft (33.5 m)

Lithological log: 0-18 ft (0-5.5 m) Quaternary till
18-110 ft (5.5-33.5 m) Paskapoo shale and sandstone

First test: pumping: 720 min
rate: 100 igpm (7.6 l/sec)
recovery: 720 min

Second test: pumping: 60 min
rate: 180 igpm (13.6 l/sec)
recovery: 60 min

Aquifer parameters: transmissivity (T): 4400 igpd/ft (7.59 x 10^{-4} m^3/sec/m)
original avaiable drawdown (H): 20 ft (6.1 m)
20-year safe yield (Q_{20}): 42 igpm (3.18 l/sec)

6. Location: SE quarter, Sec 24, Tp 34, R 6, W 5th Mer
Owner: Mr. H. Lung
Contractor: Forrester Water Well Drilling Ltd., Red Deer

Depth of well: 75 ft (22.9 m)

Lithological log: 0-41 ft (0-12.5 m) Quaternary clay and quicksand
41-75 ft (12.5-22.9 m) Paskapoo shale, fractured

Tests: bailing: 120 min
rate: 26 igpm (1.97 l/sec)
recovery: 120 min
remarks: only the shale was tested

Aquifer parameters: Data from the bail test could not be analyzed
Transmissivity and Q_{20} were not calculated

7. Location: Lsd 10, Sec 10, Tp 28, R 1, W 5th Mer
Owner: Amoco (Crossfield Gas Plant)
Contractor: Webster Drilling Ltd., Calgary

Depth of well: 170 ft (42.7 m)

Lithological log: 0-20 ft (0-6.1 m) Quaternary clay
20-170 ft (6.1-42.7 m) Paskapoo shale with some sandstone

Tests: bailing: 120 min
rate: 12 igpm (0.91 l/sec)
recovery: 120 min

Aquifer parameters: transmissivity (T): 400 igpd/ft (6.90 x 10^{-5} m^3/sec/m)
original available drawdown (H): 40 ft (12.2 m)
20-year safe yield (Q_{20}): 7 igpm (0.53 l/sec)

8. Location: Lsd 10, Sec 10, Tp 28, R 1, W 5th Mer
Owner: Amoco (Crossfield Gas Plant)
Contractor: Webster Drilling Ltd., Calgary

Depth of well: 85 ft (25.9 m)

Lithological log: 0-20 ft (0-6.1 m) Quaternary clay
20-85 ft (6.1-25.9 m) Paskapoo shale with some sandstone

Tests: bailing: 120 min
rate: 15 igpm (1.1 l/sec)
recovery: 120 min

Aquifer parameters: transmissivity (T): 600 igpd/ft (1.03 x 10^{-4} m^3/sec/m)
original available drawdown: 40 ft (12.2 m)
20-year safe yield (Q_{20}): 12 igpm (0.91 l/sec)

9. Location: Lsd 6, Sec 36, Tp 25, R 7, W 5th Mer (Morley Indian Reserve)
Contractor: Kinsella Drilling Ltd., Innisfail

Depth of hole: 64 ft (19.5 m)

Lithological log: 0-53 ft (0-16.2 m) Quaternary boulders, gravel, silt and sand
53-64 ft (16.2-19.5 m) Cretaceous Alberta Group, dark shale

Remark: ARC testhole to test the higher gravel terrace of the Bow River
No water was encountered

LEGEND

Isohyet, mean annual precipitation in inches (cm) .... — 18(46) —

Mean annual precipitation in inches (cm):

15-20 (35-50)	🟩
20-25 (50-65)	🟦
25-30 (65-80)	🟦

Meteorological station .... ⍋

Standard rain gauge only .... ⍋

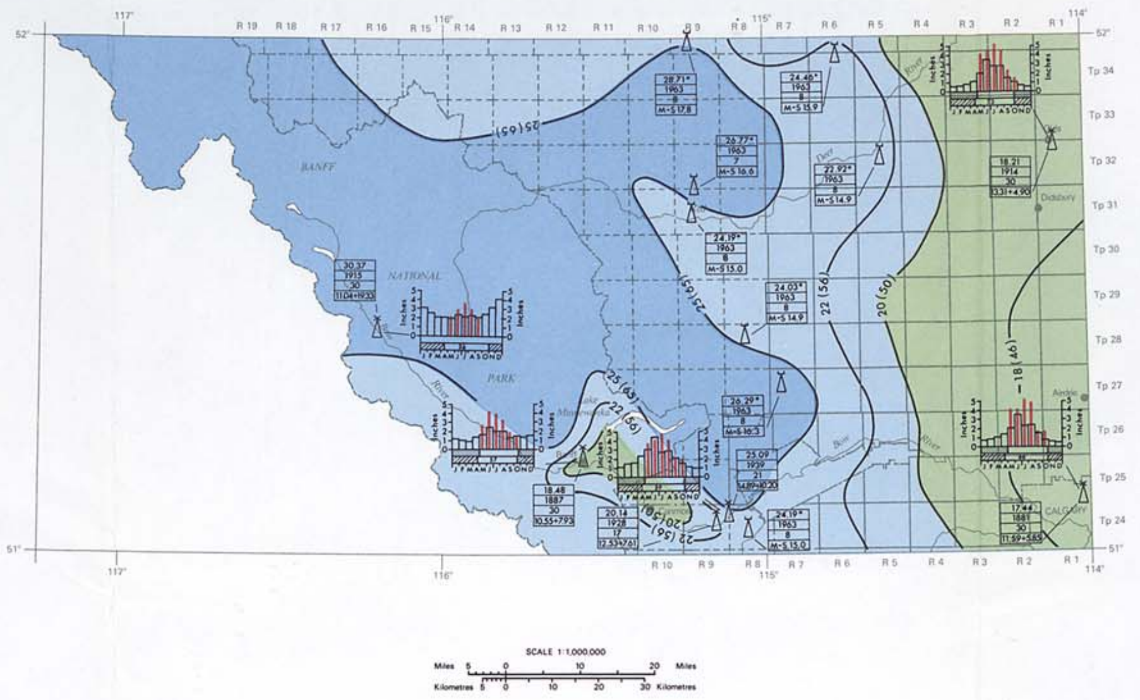
Precipitation data:

- Mean annual precipitation(estimated) in inches
- Year of commencement of observations
- Number of years in average
- Precipitation as rain + snow in inches
- Mean monthly potential evapotranspiration
- Mean monthly precipitation
- Period when surface is usually snow-covered
- Period with mean daily temperature below freezing
- Figure indicates percentage of mean annual precipitation falling as rain

Sources of data:

Climatic Maps of Alberta (Longley, 1968); Provisional Evaporation Maps of Canada (Bruce and Weisman, 1967); Temperature and Precipitation Tables for the Prairie Provinces (Canada Department of Transport, 1967); Snow Cover, Climatological Studies No. 3 (Canada Department of Transport; Potter, 1965); A Catalogue of Climatological Stations in Alberta (Canada Department of Transport Publication DS 21065; Potter, 1965); Precipitation Means, Alberta Forestry Stations, May 1963-1970 (Stashko, 1971).

METEOROLOGY MAP



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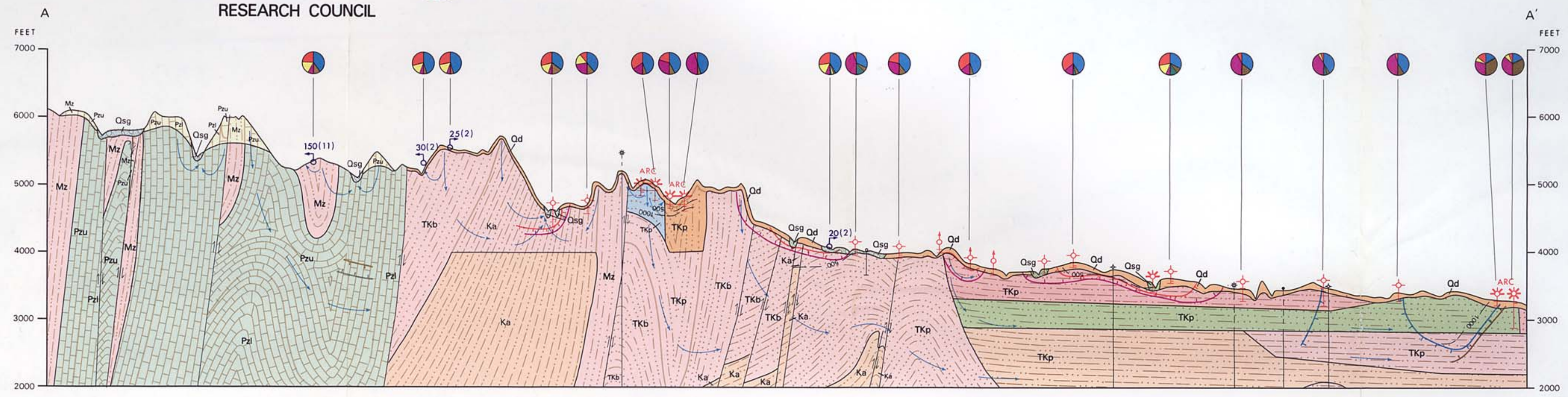
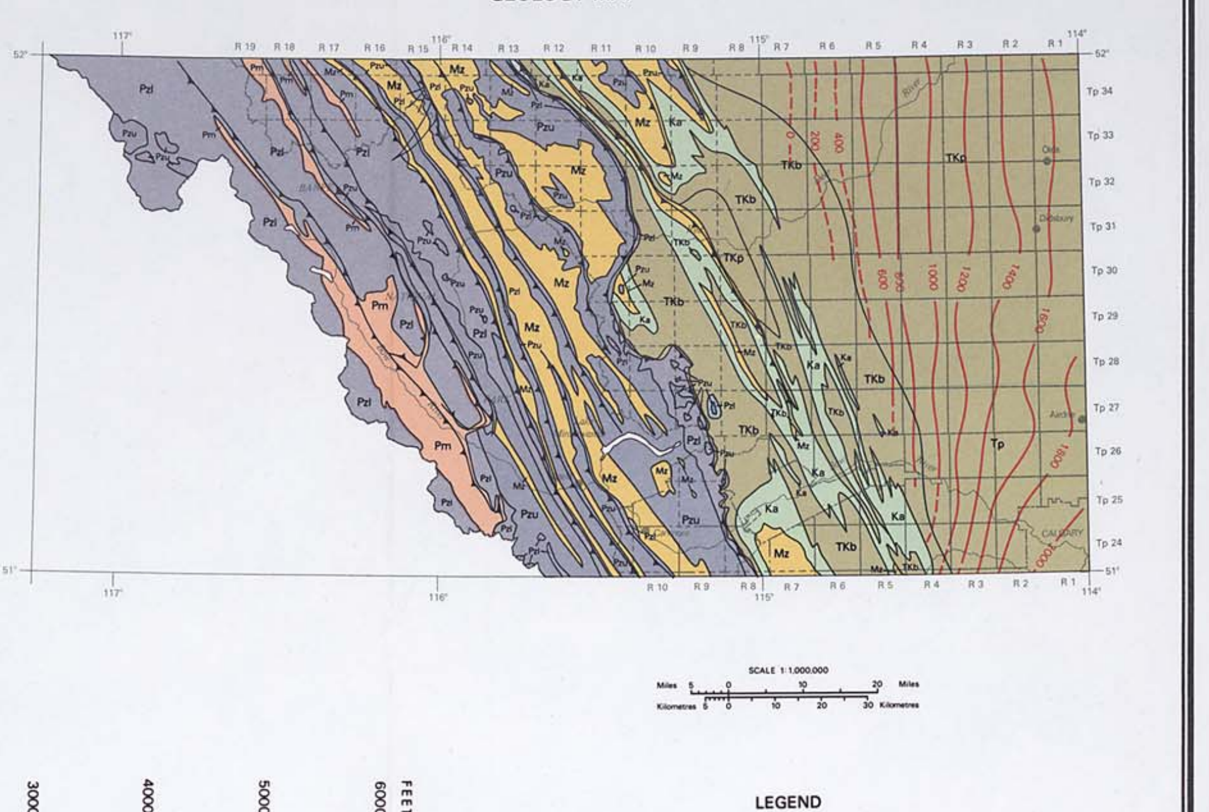


GEOLOGY MAP



LEGEND

TKp/Tp	Paskapoo and Porcupine Hills Formations: *thick-bedded, calcareous, cherty sandstone; siltstone and mudstone; minor conglomerate; thin limestones, coal, tuff beds; nonmarine.*
TKb	Brazeau Formation: *thick-bedded, chloritic and feldspathic sandstone and black mudstone; some tuff and coal beds; nonmarine*
Ka	Alberta Group: *fissile silty shale; some thin-bedded, cherty sandstone; some thick-bedded quartzose sandstone; thin coal beds; thin beds of concretionary ironstone*
Mz	Mesozoic: *siltstone; dolomitic siltstone and limestone; some sandstone beds; some conglomerate*
Pzu	Upper Paleozoic: *argillaceous limestone and dolomite in part cherty and stromatoporoidal, in part biostromal; calcareous shale; some sandstone beds*
Pzl	Lower Paleozoic: *thick-bedded quartzite and quartzose sandstone with limestone lentils; dolomite and limestone; calcareous and siliceous shales*
Pm	Precambrian (Miette Group): *argillite; argillaceous sandstone, grit; conglomerate; minor dolomite, limestone, and shale*

Rock unit, formation boundary ....

Structure contour on the top of Whitemud and Battle Formations .... — 1400 —

Fault ....

Thrust fault .... ▲▲▲▲▲

MAIN MAP LEGEND

Topography

Surface contours and elevation in feet (interval 500 feet) .... — 3000 —

Geology

Geological boundary ....

QUATERNARY

Qd	Unconsolidated deposits
Qsg	Sand and gravel

TERTIARY - CRETACEOUS

TKp	Paskapoo Formation
TKb	Brazeau Formation

CRETACEOUS

Ka	Alberta Group

MESOZOIC

Mz	Undifferentiated

PALEOZOIC

Pzu	Upper
Pzl	Lower

Lithology

- Sand and gravel ....
- Sandstone ....
- Quartzite ....
- Siltstone ....
- Shale ....
- Limestone ....

Hydrography

- Lake or slough, perennial ....
- Glacier ....
- Stream, perennial ....
- Stream, intermittent ....
- Surface water divide .... • • • • •
- Area inundated during floods ....

Hydrogeology

Spring, flow rate unknown ....

Spring, flow rate shown in igpm (l/s); and temperature of the water shown in degrees Celsius .... 165(13) 15.4°C

Nonpumping water level contour (elevation in feet followed by metres in brackets) and vertical component of groundwater movement .... Upward flow 2400(730) Downward flow

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 (l/sec)

Probable: estimated from quantitative information (pump tests, bail tests, etc.)

Possible: estimated from qualitative information (flow regime, lithology, etc.)

igpm	(l/sec)
more than 500	(>38)
100-500	(8-38)
25-100	(2-8)
5-25	(0.4-2)
1-5	(0.1-0.4)
< 1	(<0.1)

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. Multiaquifer completion may be necessary to obtain the yield indicated.

Wells and Other Artificial Works

Depth Scale

- Water well, nonflowing ....
- Water well, flowing ....
- Non-producing well ....
- 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 ....
- Locations of Alberta Research Council test well .... ARC
- Oil well* .... •
- Gas well* .... ✲
- Abandoned well* drilled for oil or gas .... ✦
- Depth of exploratory well ....

*The vertical line portion of oil, gas or other exploratory test well symbols indicates the well depth; the dashed portion indicates the surface casing interval where applicable or where known (otherwise, a solid line is used).

Spring catchment .... □

Line of hydrogeological profile .... A——A'

Hydrochemistry

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 of million, approximate: .... -- 500 --

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

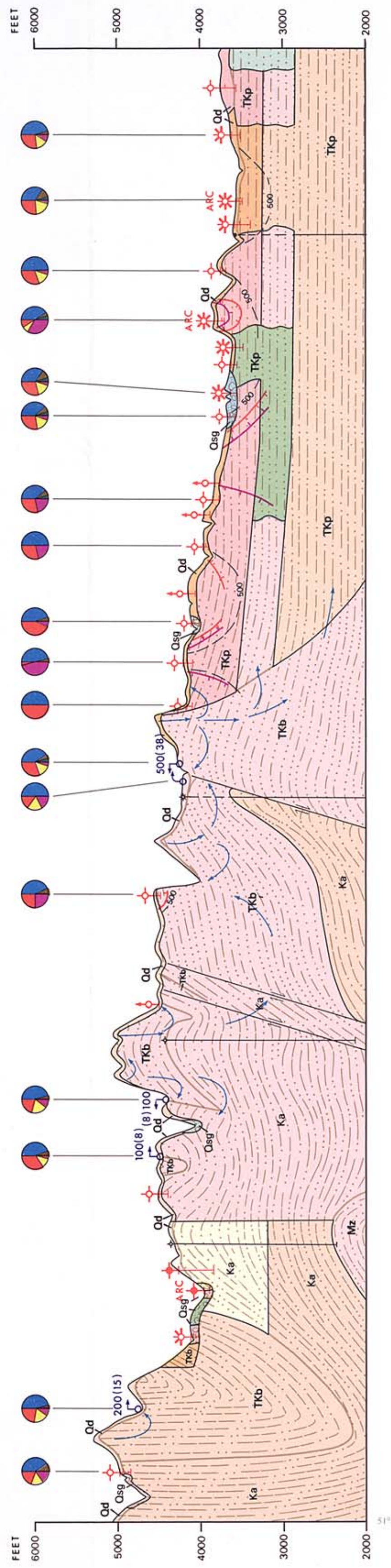
Isogram along which sodium + potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium + potassium content, defined: ....

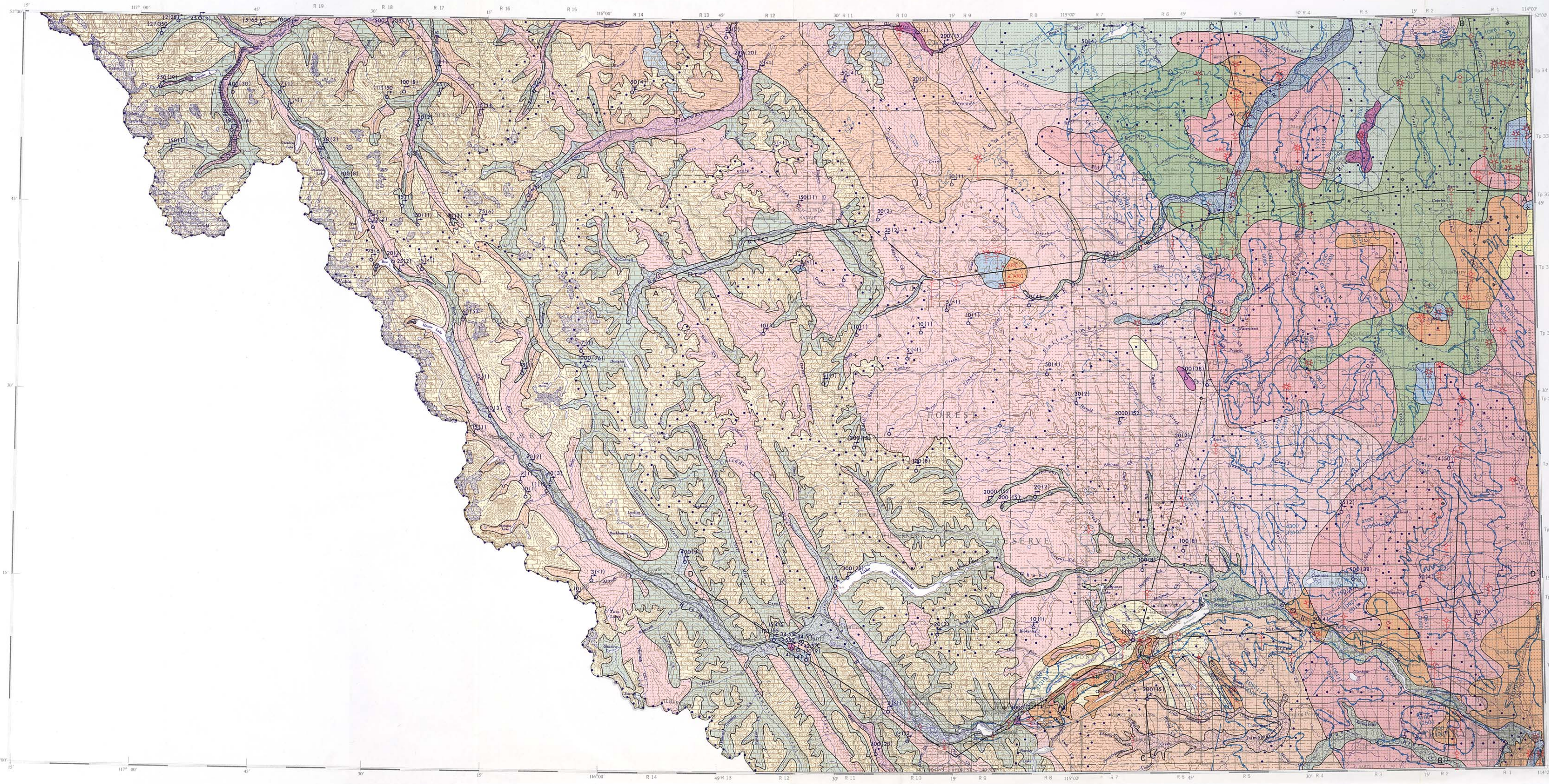
Isogram along which carbonate + bicarbonate constitute 60 percent of total anions*; teeth indicate direction of lesser carbonate + bicarbonate content, defined: ....

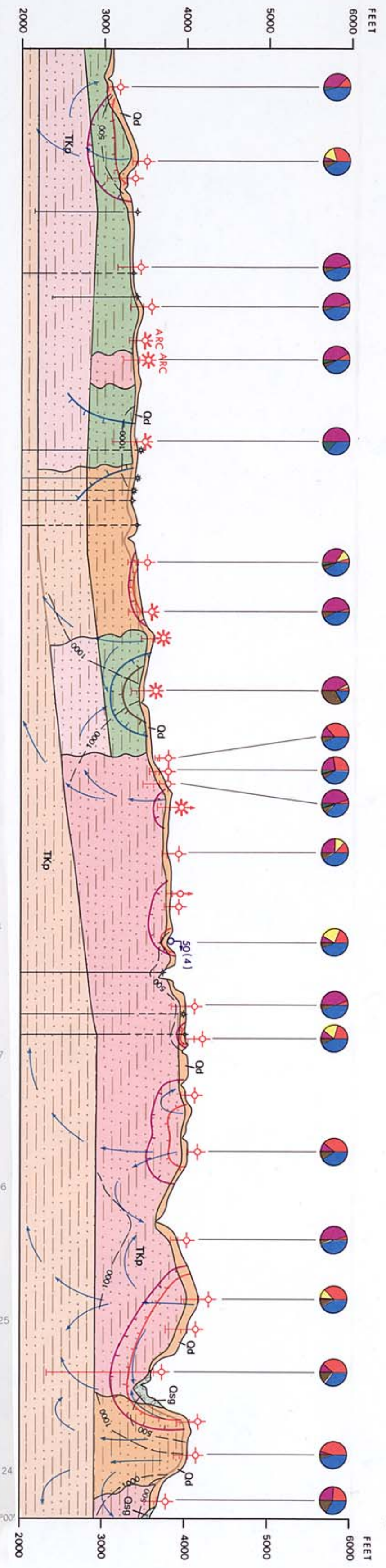
Isogram along which sulfate constitutes 60 percent of total anions*; teeth indicate direction of lesser sulfate content, defined: ....

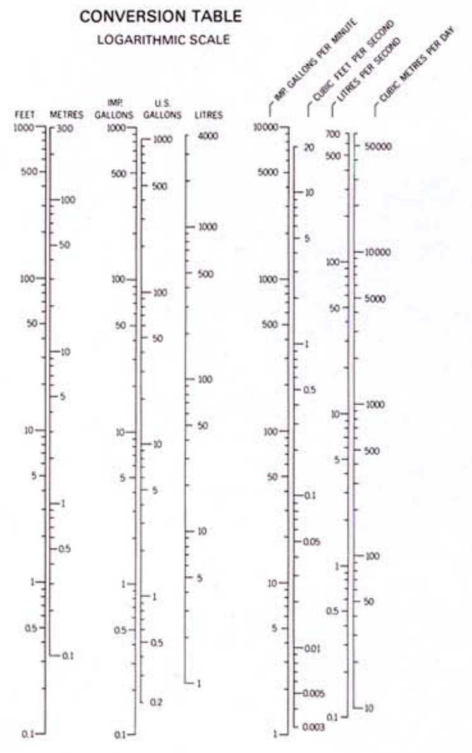
Isogram along which chloride constitutes 60 percent of total anions*; teeth indicate direction of lesser chloride content, defined: ....

*determined on equivalents per million basis

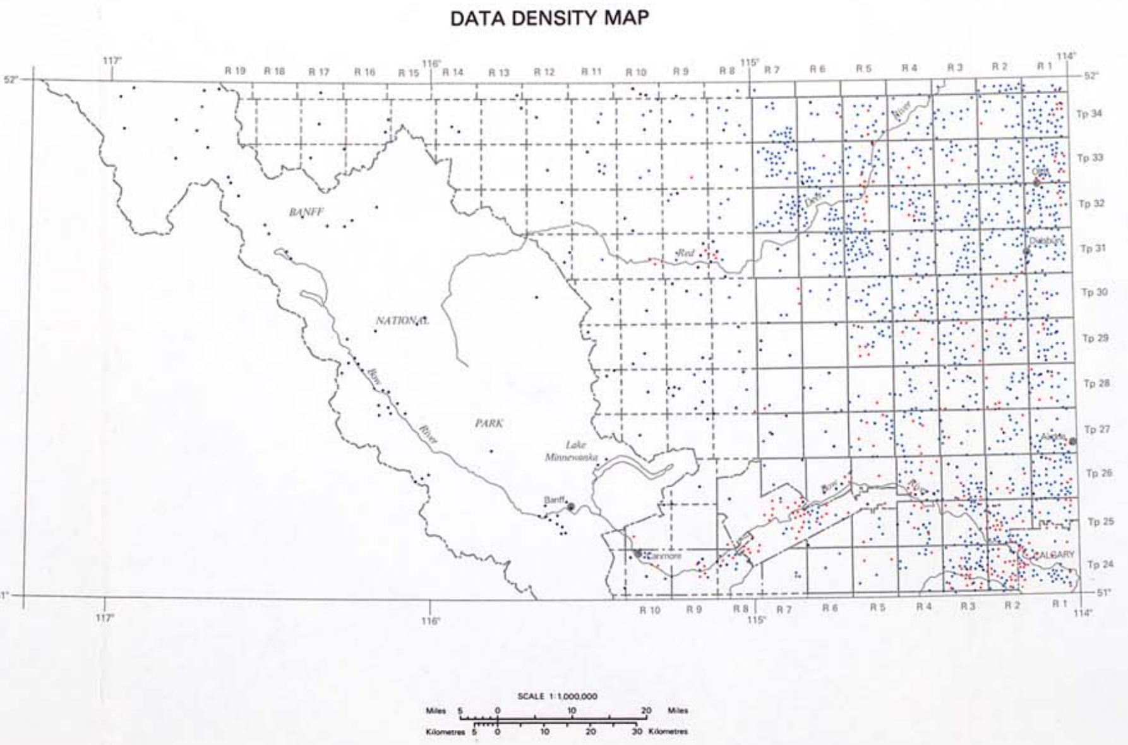








DATA DENSITY MAP

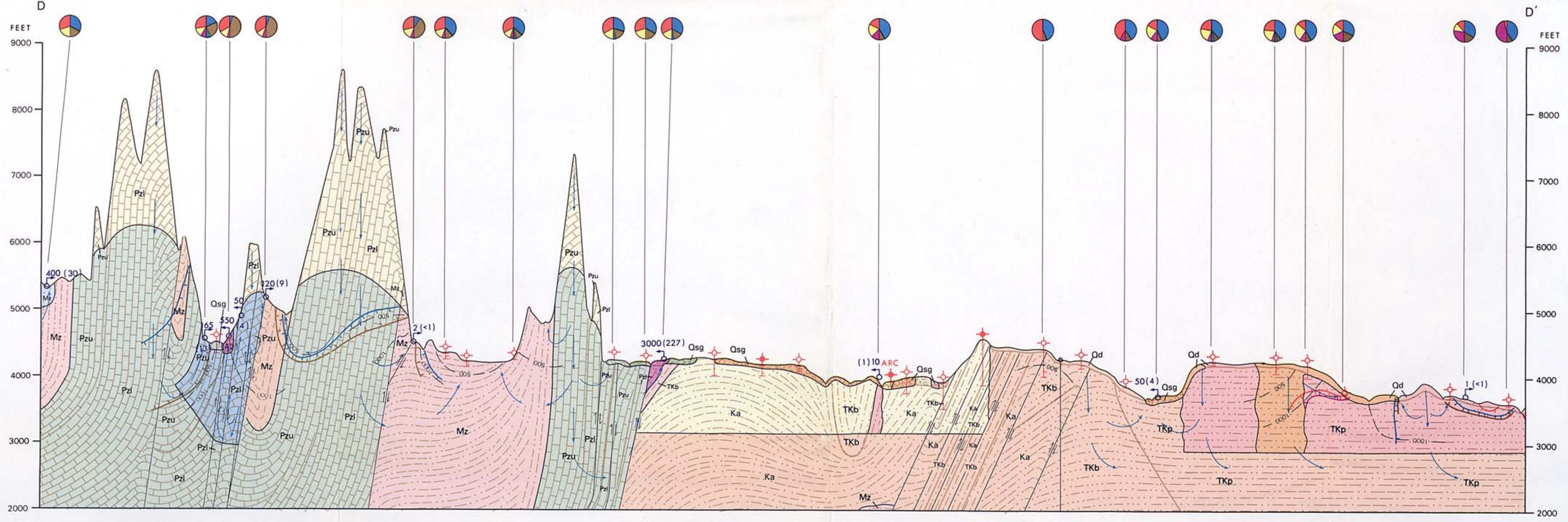


LEGEND

Data control point marking location of a well with water level information only .... •

Data control point marking location of well with yield information (i.e. production tests) .... •

Data control point marking the location of a hydrogeological surface feature .... •



All elevations in feet above mean sea level.

Vertical exaggeration of the hydrogeological profiles is approximately 21X.

An expanded legend and explanatory notes (Report 72-12) for use with this hydrogeological map series is available from Alberta Research Council, Edmonton, Canada.

Map to accompany Report 77-3.

Hydrogeology by G.F. Ozoray and R. Barnes

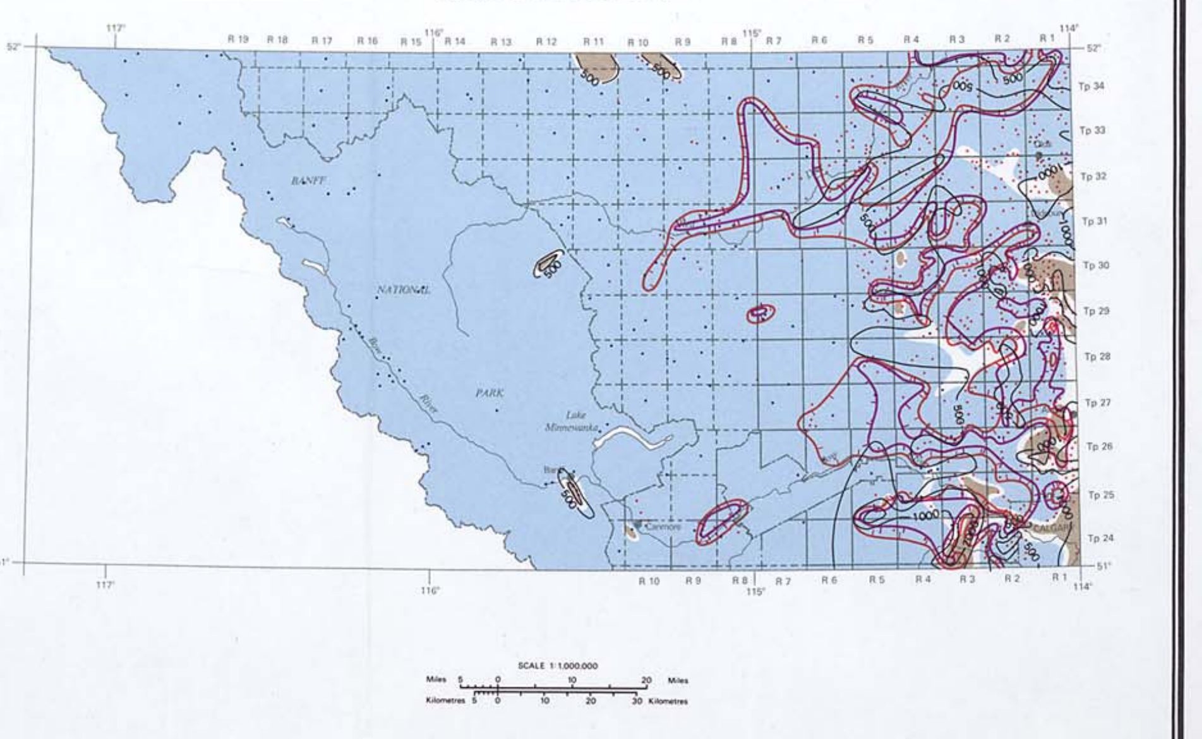
Drawn by R. W. Swenson.

Cartographic editing by A. R. Campbell.

HYDROGEOLOGICAL MAP
CALGARY–GOLDEN
ALBERTA

NTS 82N-O

HYDROCHEMISTRY MAP



LEGEND

Data control point marking the location of a well with a chemical analysis .... •

Data control point marking the location of a spring with a chemical analysis .... •

Total dissolved solids in parts per million, defined: .... — 500 —

Carbonate + bicarbonate constituting over 60 percent of total anions* .... 🟦

Sulfate 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, defined: ....

Isogram along which sodium + potassium constitute 60 percent of total cations*; teeth indicated direction of lesser sodium + potassium content, defined: ....

* determined on equivalents per million basis

Base map provided by Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa; modified by Surveys Branch, Alberta Transportation, Edmonton.

Published in 1978