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Hydrogeology of the Brazeau—Canoe River area, Alberta

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ABSTRACT

The hydrogeology of surficial aquifers and shallow bedrock aquifers of the uppermost 500 ft (150 m) of strata in the Brazeau-Canoe River map area is described. Lithology, geologic structure, topographic position, and climate are the major elements of the hydrogeological regime.

Within the Rocky Mountain Main Ranges and Front Ranges limestone and dolomite are the dominant rock types. A synthesis of the geologic and geomorphologic characteristics of these rocks indicates that conduits and fractures are the major mode of storage and transmission of groundwater. Conduit and fracture permeability is likely to be better developed and more widespread in the Main Ranges than in the Front Ranges. The shaly, thin-bedded Banff and Exshaw Formations, the Fairholme Group, and the Lyell, Pika, and Mt. White Formations are the most prospective carbonate aquifers of the map area when present in topographically low positions.

Thrust faults have a strong influence on valley position and extend for many miles along strike. They have the potential of directing groundwater flow from distant sources toward localized surface discharge points within the valley floors. The valley floors serve as regional and local groundwater drains.

The most prospective bedrock aquifers of the Foothills belt occur in the Upper Cretaceous Blairmore Group. Fracture permeability is well developed in thick sandstone units and coal beds. Yields between 25 and 100 igpm (1.9 to 7.6 l/sec) may be obtained from these aquifers in topographically low positions. The black carbonaceous shales of the Upper Cretaceous Alberta Group are the least prospective aquifers of the map area.

The Upper Cretaceous to Tertiary Brazeau Formation extends to depths of greater than 1000 ft (300 m) in the Western Alberta High Plains. Intergranular and fracture porosity have a patchy distribution within these clayey and sometimes bentonitic sandstones and mudstones. Well yields are correspondingly variable, but generally fall into the range 5 to 25 igpm (0.4 to 1.9 l/sec).

The valley floor glaciofluvial and alluvial sand and gravel deposits are the most prospective aquifers of the map area. Groundwater availability and yield potential are dependent on the topographic position, permeability, saturated thickness, and recharge characteristics of these deposits.

With the exception of the local occurrence of calcium-magnesium sulfate type groundwater in the Front Ranges (which can contain over 2000 ppm total dissolved solids), groundwater quality is excellent throughout the map area, and total dissolved solids contents rarely exceed 500 ppm.

INTRODUCTION

This report contains supplementary discussion and explanation of regional and local hydrogeologic conditions in the map area. It is suggested that the map user study the report prior to viewing the maps.

The Brazeau-Canoe River map area (NTS 83C and 83D) covers approximately 5890 sq mi (15250 km^2) between latitudes 52° and 53° north and longitude 116° west and the Alberta-British Columbia provincial boundary. On the basis of the Canadian land survey system, the area includes Tps 35 to 46, Rs 14 to 28, W 5th Mer (NTS 83C) and Tps 39 to 46, Rs 1 to 5, W 6th Mer (NTS 83D).

About half of the map area lies within Jasper and Banff National Parks and Whitegoat Wilderness Provincial Park, which are best described as wildlife preserves with limited recreational usage. The Bighorn Indian Reserve is located in Tp 39, R 16, W 5th Mer, and the remainder of the map area falls within the Rocky Mountain Forest Reserve.

The town of Jasper (population 3563 in 1976) and the hamlet of Nordegg (population 97 in 1971) are the only permanent residential centers within the map area. Jasper is a thriving tourist center and a major division point cum terminal on the Canadian National transcontinental railway line. Nordegg, on the other hand, is often described as a ghost town — a remnant of a once prosperous coal mining district. Brazeau Collieries Ltd. closed down mining operations at Nordegg in 1955-56. The mine was operated for 45 years and attained maximum production in 1941 (0.4 million tons). About 10 years after the mine closure the town of Nordegg became the "Nordegg Gaol" and has been "off-limits" to the general public ever since.

The remains of another once prosperous coal mining district are to be found in Tp 46, Rs 23 and 24, W 5th Mer. Mountain Park Collieries Ltd. commenced mining operations here in 1911. The peak production was 1.1 million tons in 1949 and the mine and town of Mountain Park were demolished around 1954. Renewed interest in the coal reserves of the Rocky Mountain Foothills has led to extensive exploration in recent years, but there were no active coal mines in the map area at the time of writing.

Oil and gas exploration is active and three designated gas fields lie within the map area. These are: the Stolberg gas field in Tp 42, R 15, W 5th Mer; the western tip of the Brazeau River gas field in Tp 46, Rs 14 and 15, W 5th Mer; the Lovett River gas field in Tp 46, Rs 18 and 19, W 5th Mer.

Other than a few small logging operations, the area is essentially undeveloped, uncultivated, and unspoilt.

Access is somewhat limited. Highway 16 passes through Jasper and the Yellowhead Pass into British Columbia in the northwest corner of the map area. Highway 11 passes through Nordegg and follows the North Saskatchewan River across the southeast corner of the area to the junction with Highway 93 (the Icefields Parkway) at North Saskatchewan River Crossing. Highway 93 forms the north-south link between Jasper and Highway 11, and continues south to Banff. All three of these highways are paved. To the northeast the Forestry Trunk Road links Highways 16 and 11 between Hinton (to the north of the map area) and Nordegg. The Forestry Trunk Road is gravelled and open most of the year; however, several minor roads leading off the Trunk Road and affording access to oil and gas exploration sites, logging camps, and forestry lookout towers are passable only in dry weather.

Work on the accompanying hydrogeological map started in March, 1976, at which time pertinent hydrogeological data were restricted to records of about 30 water wells, 14 springs, and 50 hydrochemical analyses. Field work began in June and was completed by October, 1976. During this period 45 water wells were documented. Steady-rate pump tests of greater than 6 hours' duration had been carried out on 10 of these wells. Bail tests and pump tests in which only the initial water level and total drawdown were recorded had been carried out at 28 of these wells. Three hundred and eighty-four groundwater-generated surface features were documented; where possible, water samples were collected, and groundwater discharge rates measured with a portable V-notch weir. Two hundred and twenty-one hydrochemical analyses of groundwater, and 34 hydrochemical analyses of surface water were completed.

During the field season all passable roads were traversed, and the more inaccessible areas were visited by helicopter. Three test wells were drilled and four aquifer tests conducted (see Appendix).

The distribution of water wells within the map area is very uneven and most are less than 150 ft (46 m) deep. Jasper obtains its water supply from Cabin Lake, situated 2 mi (3.2 km) west of the townsite. The Nordegg Gaol also obtains its water supply from a small surface catchment. The tourist facilities near Nordegg and the residents of the Bighorn Indian Reserve utilize groundwater supplies.

Elsewhere, occasional wells have been drilled to supply oil and gas exploration camps, logging camps, and recreational areas. One or two recreation areas within Jasper and Banff National Parks and the tourist facility at North Saskatchewan River Crossing in Tp 35, R 20, W 5th Mer, obtain their water supply from springs and seepages.

PREVIOUS WORK

D. C. Ford of the Geography Department, McMaster University, Ontario, investigated various aspects of karst hydrology within the map area. He studied the Wilcox Pass karst (1967), the Alpine karst of the Mt. Castleguard-Columbia Icefields area (1971a), and characteristics of limestone solution in the southern Rocky Mountains of Alberta (1971b).

M. C. Brown of the University of Alberta Geography Department investigated the karst hydrology of the lower Maligne basin (1970).

Various hydrogeological consultants have been active in the area. These include Balzer (1968), who carried out permeability testing of sand and gravel deposits in the North Saskatchewan River valley at the Bighorn Dam site; Clissold (1969) investigated possible groundwater sources in the Nordegg area and carried out preliminary hydrogeological inspections of two sites adjacent to the Cline River on Highway 11; Nielsen (1975) prepared groundwater potential maps of Banff National Park at a scale of 1:50,000.

The Water Quality Branch of Environment Canada documented surface water chemistry in Banff and Jasper National Parks (1972-75).

ACKNOWLEDGMENTS

C. Henry of the Alberta Research Council assisted in the collection of field data and map compilation.

All-Rite Drilling Ltd. of Innisfail and Robsco Drilling of Barons carried out test drilling and aquifer tests.

Without the cooperation and advice of Parks Canada staff at Calgary, Banff, and Jasper the project could not have been completed.

In conjunction with the Brazeau-Canoe River project, Mr. D. Bernard of the Alberta Research Council carried out hydrogeological mapping of the highway corridors of Jasper National Park (1976-77). His work is incorporated into this report and allowed the author to spend more time in the less accessible parts of the map area.

Others, whose help is gratefully acknowledged, include staff of the geochemical laboratories of Alberta Research Council for performing chemical analyses of water samples, and water well drillers who submitted reports on wells drilled within the map area.

The report was typed by Mrs. S. P. Cane and critically read by G. M. Gabert and G. F. Ozoray.

TOPOGRAPHY, DRAINAGE, AND VEGETATION

The map area is divided into four physiographic regions (Atlas of Alberta, 1969), with boundaries trending northwest, parallel to the continental divide and regional geologic strike. This fourfold subdivision also forms a convenient framework for the discussion of stratigraphy, geologic structure, hydrogeology, and hydrochemistry of groundwaters. From southwest to northeast these regions are:

1. The Main Ranges of the Rocky Mountains.
2. The Front Ranges of the Rocky Mountains.
3. The Rocky Mountain Foothills.
4. The Western Alberta High Plains.

(See also hydrochemistry side map).

The Main Ranges are characterized by precipitous, castellated massifs, numerous permanent icefields, and broad U-shaped valleys. Local relief averages 6000 ft (1829 m) and Mt. Columbia at 12,294 ft (3747 m) (Tp 37, R 25, W 5th Mer) is the highest point in Alberta. Drainage patterns within the Main Ranges are dendritic but some of the larger massifs, such as the Trident Range immediately south of Jasper, have radial drainage patterns. The plateau icefields of the continental divide are a major source of surface runoff. Rivers flow in a northeast direction from the divide into the northwest-trending trunk valleys of the Athabasca, Sunwapta, and North Saskatchewan Rivers.

The Front Ranges are characterized by well-developed valley-and-ridge topography oriented northwest-southeast parallel to geologic strike. The mountain ridges have serrated, dogtooth outlines and precipitous walls dropping steeply into narrow flat-bottomed valleys. The rivers are commonly deeply entrenched in narrow, steep-sided gorges within the flat valley bottoms as are, for example, Maligne River (downstream of Medicine Lake), Rocky River to the north, and Cline River to the south. Local relief is about 4000 ft (1219 m) with the mountain peaks ranging from 9000 to 10,000 ft (2743 to 3048 m) in elevation. Drainage patterns within the Front Ranges are markedly trellised. The trunk valleys of the Athabasca River to the north, the Brazeau River in the central region, and the North Saskatchewan River to the south trend northeast, perpendicular to geologic strike. Tributaries to these rivers flow northwest or southeast, parallel to geologic strike.

The boundary between the Front Ranges and Rocky Mountain Foothills is marked by the northeast-facing scarp of the Nikanassin Range to the north and the First Range and Ram Range in the central and southern regions. This scarp is a significant topographic feature and, apart from the narrow strike-oriented Bighorn Range within the Foothills, marks the northeast limit of the typically rugged scenery of the Rocky Mountains.

Within the *Rocky Mountain Foothills* a subdued, undulating valley-and-ridge topography is indicative of the more easily weathered, clastic bedrock strata underlying this region. Local relief is between 1000 and 1500 ft (305 to 457 m) with topographic highs situated around Mountain Park to the north [Cadomin Mountain, 7877 ft (2400 m)], the Bighorn Range in the central area [8500 ft (2590 m)], and the Brazeau Range (near Nordegg) to the southeast [6500 to 7000 ft (1981 to 2134 m)]. All of these topographically-high areas mark geologic inliers of Paleozoic limestones. Drainage patterns within the Foothills are trellised, though less angular than those in the Front Ranges. The Brazeau and North Saskatchewan Rivers flow out of the narrow, steep-sided valleys of the Front Ranges onto the broad, braided flood plains of the Foothills belt.

The northeast corner of the map area is only a small portion of the *Western Alberta High Plains*. Here the topography is characterized by rolling hills and broad, open valleys. Small remnants of a once extensive Tertiary erosion surface or plateau are seen in the headwaters of Elk River in Tps 45 and 46, Rs 16 and 17, W 5th Mer. This northeast-sloping erosion surface is preserved on the tops of hills above the 4400 ft (1340 m) contour. Local relief is about 400 ft (122 m) and the area is poorly drained, resulting in the development of abundant muskeg.

The headwaters of the Athabasca River (Arctic drainage system) compete with the headwaters of the Brazeau and North Saskatchewan Rivers (Hudson Bay drainage system) along a major surface water divide which extends from the Columbia Icefields north to Mountain Park, then east along the northern edge of the map area (see main map).

The vegetation of the area is basically of two types (Atlas of Alberta, 1969). Altitudinally-zoned lodgepole pine, white spruce, and Engelman spruce are the dominant tree species in the Western Alberta High Plains, Foothills, and valley bottoms of the Front Ranges and Main Ranges. Within the high alpine meadows of the Front and Main Ranges various plant species are found such as Arctic wintergreen, lousewort, Lyells saxifrage, and alpine cress. The Athabasca River valley around Jasper and the North Saskatchewan River valley upstream of Abraham Lake host local occurrences of aspen, spruce, and prairie grass meadows.

CLIMATE

According to the Köppen system of classification, the climate of the map area is microthermal and is characterized by short, cool summers with the mean temperature of the warmest month above +10°C and below +22°C, and the mean temperature of the coldest month below -3°C. Less than 4 months of the year have mean temperatures of +10°C or more (Longley, 1972). Those parts of the Rocky Mountain Main Ranges and Front Ranges where permanent icefields are found cannot be included in this climatic zone as at those places an arctic type climate must prevail with the mean temperature of the warmest month below +10°C and about 90 percent of the annual precipitation falling as snow. This is in fact borne out by observations at the Columbia Icefields meteorological station in Jasper National Park, where the mean monthly temperature for August (the warmest month) is +9.3°C.

Continuous, long-term meteorological observations are available from Jasper and Nordegg. Continuous, short-term observations (1970 to 1977) were obtained from the Park Warden's Service, Jasper National Park, for the West Gate station (Highway 16), Maligne Lake station, Sunwapta station (at Poboktan Creek), and the Columbia Icefields station. Partial records, usually only for precipitation from May to September, are available from three Alberta Forestry lookout towers. The annual precipitation at these stations was calculated by assuming that the sum precipitation from October to April was the same proportion of the total annual precipitation as observed at the nearest long-term meteorological station (in this case Nordegg).

Isohyets from Longley (1972) were extended into the map area using data obtained from partial precipitation records and data presented on the Edson area hydrogeological map (NTS 83F) (Vogwill, in prep.), and are presented on the meteorological side map. Due to highly variable meteorological conditions within the Rocky Mountains and to an insufficient number of control points, isohyets are not presented for these parts of the map area.

A summary of meteorological data from Columbia Icefields, Jasper, and Nordegg is presented in table 1.

Table 1. Temperature, Precipitation, and Potential Evapotranspiration

	Columbia Icefields	Jasper	Nordegg
Mean Temperature (°C)			
January	-13.0	-12.2	-11.8
August	+9.3	+14.0	+11.2
Annual	-6.1	+ 2.8	+ 1.0
Mean Annual Precipitation			
inches	41.4	15.84	21.73
mm	1052	402	552
Mean Annual Potential Evapotranspiration			
inches	-	18.7	14.36
mm	-	475	365

Mean annual pan evaporation within the map area is between 25 and 30 in (635 to 889 mm); 85 to 90 percent of this occurs between the months May to October (Bruce and Weisman, 1967).

Potential evapotranspiration was calculated by the Thornthwaite method from meteorological observations at Nordegg and Jasper. Elsewhere, exceedingly low heat index values made the formula inapplicable.

The climate of the Rocky Mountains is highly variable. Partial rain-shadow conditions are probably responsible for the low values of mean annual precipitation recorded at Jasper and Maligne Lake stations. Altitude is also an important factor: the period of maximum precipitation at Jasper and Maligne Lake occurs between May and August as rain, while the period of maximum precipitation at higher altitudes (West Gate, Sunwapta, and Columbia Icefields stations) occurs between November and March as snow. Also, mean annual precipitation increases with altitude, as shown by records from the West Gate, 3717 ft (1133 m) above mean sea level (AMSL); Sunwapta, 5200 ft (1585 m) AMSL; and Columbia Icefields, 6500 ft (1981 m) AMSL, where mean annual precipitation is 23.02 in (585 mm), 25.4 in (643 mm), and 41.4 in (1052 mm) respectively.

BEDROCK GEOLOGY AND STRUCTURE

The stratigraphy, lithology, and structure of bedrock units exposed within the map area are described in numerous geological reports and maps dating back to the end of the last century (McConnell, 1887). The following is a summary of the work of MacKay (1929, 1940, 1943), Douglas (1956), Price and Mountjoy (1970), Green (1972), Mountjoy and Price (1974), and Jackson (1975). The geology presented on the main map and geological side map is based primarily on the "Geologic Structure of the Canadian Rocky Mountains between Bow and Athabasca Rivers" (Price and Mountjoy, 1970, Fig. 2-1) and the "Geological Map of Alberta" (Green, 1972). The Rocky Mountain geology is highly simplified and many of the boundaries shown on the main map and geological side map are fault contacts, though the faults are not represented. Major thrust faults are represented on the hydrogeological profiles, though due to vertical exaggeration (1:21) the physical disposition of these features is purely schematic, as are geological structures and depth relationships within each thrust sheet.

Bedrock units ranging from Precambrian to Tertiary age outcrop within the map area. The stratigraphy, lithology, and distribution of these rocks are summarized in table 2.

Table 2. Generalized Stratigraphy of the Brazeau-Canoe River Map Area

ERA	PERIOD	GROUP	ROCK UNIT	THICKNESS (metres)	GROSS LITHOLOGY	MAP SYMBOL	MAJOR AREA OF OUTCROP
	TERTIARY	Brazeau Fm	Paskapoo Fm		thick-bedded chloritic sandstones and blocky mudstones	TKb	WESTERN ALBERTA HIGH PLAIN
MESOZOIC	UPPER CRETACEOUS		Horseshoe Canyon Fm	600-1000			
			Belly River Fm				
		Alberta Gp	Wapiabi Fm	300-500	shale, siltstone, ironstone	Ka	FOOTHILLS
			Cardium Fm	90	quartzose sandstone, carbonaceous shale		
			Blackstone Fm	250-460	silty shale		
	LOWER CRETACEOUS	Blairmore Gp	Mtn Park Fm	120-150	cherty and calcareous sandstone, coal, minor shale	Mz	
			Luscar Fm	300-600			
			Cadomin Fm		conglomerate		
			Nikanassin Fm	300-620	cherty sandstone, minor shale		
	JURASSIC		Fernie Gp	210-360	shale, minor limestone		FRONT RANGES
	TRIASSIC		Spray River Gp	210-770	siltstone, minor limestone		
PALEOZOIC	PERMIAN-PENNSYLVANIAN		Rocky Mountain Gp		quartzose sandstone, siltstone, minor carbonates	Pzu	
	MISSISSIPPIAN	Rundle Gp	Mt Head Fm	75-125	massive limestone, dolomite, minor calcareous siltstone		
			Turner Valley Fm	50-130			
			Shunda Fm	60-120			
			Pekisko Fm	39-95			
			Banff Fm	150-230	thinly bedded limestone, shale, siltstone		
	UPPER DEVONIAN		Palliser Fm	220-280	massive dolomite		
			Alexo Fm	30-190	arenaceous dolomite		
		Fairholme Gp	Southesk/ Mt Hawk Fm	75-220	vuggy limestone, dolomite and mudstone		
			Cairn/Perdrix Fm	60-110	vuggy dolomite, limestone; pyritic, calcareous shale		
			Maligne and Flume Fm	50-90	argillaceous and cherty limestone		
	ORDOVICIAN		Skoki Fm	0-450	limestone, shaly limestone, calcareous shale	Pzl	
			Survey Peak Fm				MAIN RANGES
	CAMBRIAN		Lynx Gp	670-1260	limestone, dolomite, minor shale		
			Arctomys Fm	190-250	shale, thinly bedded limestone and dolomite		
			Pika Fm	160-220	flaggy limestone, dolomite		
			Eldon Fm	160-250	massive limestone with minor calcareous shale beds		
			Stephen Fm	470-610			
			Cathedral Fm				
			Mt White Fm		thinly bedded shale, limestone		
			Gog Gp	850-1750	thick-bedded quartzite	€	
PRECAMBRIAN	PROTEROZOIC		Miette Gp	4650	argillaceous sandstone, siltstone, shale, slate	Ꝑm	

The regional geologic setting and geologic structure of the Rocky Mountain Main Ranges, Front Ranges, and Foothills were graphically described by Price and Mountjoy (1970):

> The distinctly layered and strongly anisotropic mass of rock deposited within the Cordilleran miogeosyncline and on the shelf along the margin of the craton (Canadian interior plains) has been stripped along the layering from its crystalline basement. The mass (of rock) has moved upward and at least 125 mi (201 km) northeastward along an array of discrete, discontinuous, interleaved and overlapping thrust faults, out of the region now occupied by plutonic rocks of the eastern crystalline belt of the Cordillera (British Columbia), to where it is now stacked up on the flank of the craton in the thrust sheets typical of the Rocky Mountains. This process of northeasterly foreshortening involved more than 5 mi (8 km) of crustal thickenings, and probably took place during the interval from late Jurassic to Eocene.

Two main sequences of rocks are present:

1) A miogeosynclinal shelf sequence ranging in age from late Precambrian to late Jurassic and consisting mainly of shallow water marine carbonates with significant amounts of terrigenous, clastic rocks toward the base (Precambrian to Lower Cambrian). The total thickness of these deposits increases from about 6000 ft (1830 m) beneath the Western Alberta High Plains to probably more than 40,000 ft (12,190 m) in the region of the Rocky Mountain Main Ranges.

2) A clastic wedge sequence of late Jurassic to early Tertiary age, consisting of nonmarine, terrigenous detritus shed from the Cordillera and deposited on the flanks of the craton. The maximum aggregate thickness is about 20,000 ft (6096 m), preserved in the Rocky Mountain Foothills.

The four physiographic regions described previously also have distinctive stratigraphic and structural features:

1) *The Rocky Mountain Main Ranges* represent the structural and topographic culmination of the Southern Canadian Rocky Mountains. Precambrian and Lower Cambrian clastic deposits outcrop to the north and Middle to Upper Cambrian carbonates to the south. The clastic sequence is generally thick-bedded and well jointed, while the Cambrian carbonates are generally thin-bedded and often flaggy, with the exception of the Eldon, Stephen, and Cathedral Formations which are massive. The structural style of the Main Ranges is characterized by broad expanses of distinctly bedded, relatively flat-lying or gently dipping rocks disposed within thick, relatively flat thrust plates with characteristically broad, open folds. The northeast boundary of the Main Ranges is marked approximately by the Miette thrust fault.

2) *The Rocky Mountain Front Ranges* are characterized by the presence of Paleozoic carbonate strata, mainly of Devonian and Mississippian age, separated by valleys carved from the weaker Triassic-Jurassic shales and siltstones. The structural style is characterized by the presence of a series of homoclinal, southwest-dipping, imbricate thrust sheets. The northeast boundary of the Front Ranges is marked by the McConnell thrust fault (see geologic side map and main map).

3) *The Rocky Mountain Foothills* represent a relatively high structural level within the Rocky Mountains. The geologic succession consists of Lower Cretaceous Blairmore Group, Upper Cretaceous Alberta Group, and the Upper Cretaceous to Tertiary Brazeau Formation. These predominantly fine-grained argillaceous rocks occur in a structural style dominated by relatively flat thrust faults which bifurcate upwards into numerous splays. Occasional faulted inliers of Paleozoic carbonates occur within the Mesozoic succession; for example, the Bighorn Range and the Brazeau Range. Folds within individual thrust sheets are usually broad, open structures, and synclines are more common than anticlines. Brazeau Formation outliers are often preserved within these synclinal structures. The northeast boundary of the Foothills and the Rocky Mountain disturbed belt is marked by the Ancona thrust fault (see geologic side map).

4) A small portion of the *Western Alberta High Plains* lies in the northeast corner of the map area. The Upper Cretaceous and Tertiary rocks exposed here lie on the western edge of the West Canadian Interior Plains sedimentary basin. These rocks display minor structural contortions related to the Cordilleran orogenic period, but are generally flat lying to gently dipping and unfaulted.

The Brazeau Formation (which includes equivalents of the Paleocene Paskapoo Formation) extends from the surface to depths greater than 1000 ft (305 m) and is therefore the only bedrock unit within the High Plains portion of the map area which is of interest to this study.

SURFICIAL GEOLOGY

The surficial geology of the map area, with the exception of the Western Alberta High Plains region, has been mapped by Roed (1964), Reimchen and Bayrock (1975), Bayrock and Reimchen (1975), and Reimchen (1976). The work of Reimchen and Bayrock (1975), and Reimchen (1976) covers Banff and Jasper National Parks respectively and is presented in the form of terrain analysis maps.

Surficial deposits of hydrogeologic importance were differentiated on the basis of field observations and data presented on existing surficial geology maps. Important factors related to the occurrence of groundwater in surficial deposits are their topographic position, areal extent, grain size, saturated thickness, permeability, and recharge-discharge characteristics.

The following surficial deposits are represented on the main map, but the only differentiation is between valley fill (sand and gravel symbol) and valley wall (gravel symbol) deposits.

1) *Till (valley fill)* Bayrock and Reimchen (1975) subdivided the tills of the Rocky Mountain Foothills into three groups. Of these three, only the "young" till is of hydrogeological importance. The "intermediate" and "old" tills are of inconsequential thickness. The young tills are of Wisconsin age (Bayrock and Reimchen, 1975). They are stony, and contain a large proportion of limestone. The thicker deposits occur as end moraine, lateral moraine, and hummocky moraine, and are generally confined to the major trunk valleys. Clean, water-washed pea-gravel deposits are sometimes found interbedded with these tills.

2) *Glaciofluvial deposits (valley fill)* consist of sand and gravel deposited from glacial meltwater. They occur in all the major drainages of the map area. Within the Rocky Mountains these deposits are often dissected and reworked by the present-day drainage. In terms of areal extent, thickness, permeability, and recharge characteristics, these are the most important surficial deposits in the map area.

3) *Alluvial deposits (valley fill)* vary in grain size from sand and silt size particles in the smaller streams and tributaries, to cobbles and boulders in the major river valleys. Within the flood plains of the major river valleys, the gravels may be overlain by a few feet of sand and silt. *Alluvial fans (valley wall)* are cone or fan-shaped deposits found at the emergence point of a tributary stream into a major river valley. These deposits are generally very coarse-grained and consequently highly permeable. However, their topographic position and often small areal extent are detrimental to their groundwater storage capacity, and only the larger deposits are shown on the main map.

4) *Colluvium (valley wall)* In some of the major valleys of the Main Ranges and Front Ranges, mass wasting in areas with significant slopes results in the accumulation of rock debris in high-angle, wedge-shaped deposits extending up the valley sides. These deposits are widespread and have hydrogeologic characteristics similar to those of alluvial fan deposits. Significant colluvial deposits are found along the east side of the Sunwapta River valley, adjacent to the Endless chain ridge.

Most of the surficial deposits indicated on the main map are located within the major river valleys. These are local topographic lows in which deposition is the dominant geologic process. In contrast, at higher elevations, in tributary valleys, and above the tree line, a high energy environment prevails with steep slopes, extreme climatic conditions, and active glaciers contributing toward active degradation and rapid transportation of debris.

Clissold (1969) suggested that the broad valley occupied by Shunda Creek near Nordegg is a preglacial feature in which sand and gravel deposits may underlie the thin covering of till. A review of existing well data neither proves nor disproves the existence of such deposits. However, field observations indicate that this valley was once the route taken by a major valley glacier during the Wisconsin advance. It is unlikely that unconsolidated, preglacial gravel deposits could have survived the erosional forces of such events.

HYDROGEOLOGY

In terms of groundwater exploration and usage, the Brazeau-Canoe River map area is virgin territory. The data collected during the summer of 1976 from wells, springs, and geological observation of bedrock and surficial rock outcrops are mostly related to shallow, often highly localized groundwater systems. Within the Rocky Mountain Front Ranges, local and areally scarce surface discharge of groundwater with relatively high total dissolved solids content and above average temperatures is evidence of the existence of deeper flow systems. However, no deep testholes have been drilled, and therefore the regional significance and distribution of these groundwaters is unknown.

In the mountainous parts of the map area bedrock lithology, permeability, and structure are extremely variable, and the distribution and thickness of surficial deposits are very localized. This, together with rugged topography and a wet climate, results in a complex, high energy groundwater environment.

The synthesis and compilation of hydrogeological data from the area did, however, indicate certain fundamental characteristics of the regional hydrogeologic framework controlling groundwater movement, chemistry, and availability.

Data on the following topics are presented on the hydrogeological map.

AQUIFER LITHOLOGY

Within the Rocky Mountain Main Ranges and Front Ranges of the map area, carbonates are the dominant rock type. These consist of limestone, dolomite, and calcareous shale deposits which, owing to their relative abundance and peculiar "karst" features, will be discussed at some length.

To the author's knowledge, there are no water wells tapping carbonate aquifers within the map area; however, almost all the springs with flow rates greater than 1000 igpm (76 l/sec) and many more with flow rates in the hundreds, occur in carbonate terrains. Intergranular and vugular openings contribute to the transmission and storage of groundwater in carbonate rocks, but to a much lesser extent than do joints, fractures, bedding plane partings, and solution cavities. Once an integrated system of conduits becomes established, it is capable of draining vast quantities of water, as evidenced by the giant karst spring at the northern end of Maligne Canyon (Tp 45, R 1, W 6th Mer) which has a peak discharge of about 500,000 igpm (37,885 l/sec), and the "Big Springs" at the southern end of Castleguard meadows (Tp 36, R 23, W 5th Mer) which have a peak discharge rate of about 130,000 igpm (9850 l/sec) (Ford, 1969).

The discharge rates of most karst springs within the map area are highly variable: in some cases discharge may cease altogether during the winter months. Factors influencing fluctuations in the rate of discharge are:

1) The topographic position of the spring and its relationship with the local water table;

The position and shape of the water table surface and its relationship to topography is an important hydrogeological observation. However, in the carbonate terrains of the Rocky Mountains data are scarce and mostly circumstantial. Once an integrated system of fractures, bedding planes, and joints becomes established, chemically aggressive waters follow these avenues and dissolve strata within the region of water table fluctuations. Solution of carbonates below water table is possible in areas of concentrated recharge and discharge but to a lesser extent. The influence of water table position on the solution process is best seen in the groundwater discharge area. Karst springs in the Rocky Mountains most commonly occur at the base of valley walls. These discharge points are or were at (or possibly slightly below) water table level and reflect zones of active or once active solution which extended beneath adjacent uplands within the zone of water table fluctuations. Therefore the overall gradient of the conduit system is correlative with past or present water-table gradients. Cave exploration in the Rocky Mountains indicates that these gradients are generally quite gentle (1:40 over 10 mi (16 km) of the Maligne cave system; 1:37 over 6.4 mi (10.2 km) of the Castleguard cave system). The relationship between discharge points and the valley floor indicates that the valleys serve as regional and local groundwater drains. However, where valleys have been deepened due to glacial and postglacial erosion, the water table adjusts to the new and lower topographic base level, and the conduit system becomes underdrained and is consequently abandoned. During extended wet periods, such as the spring snowmelt, these abandoned conduits may act as overflow systems, and the discharge points are sometimes called wet-weather springs (Parizek, 1971). Within the map area wet-weather springs are usually the only visible evidence of large conduit systems and are of course unrelated to the present-day water table.

The existence of abandoned conduit systems resulting from lowering of the water-table level implies the development of a younger, deeper conduit system graded to the new valley floor base level. The existence of such systems is not obvious in the carbonate terrains of the map area. However, large point discharges do occur in recent colluvial and alluvial valley fill at the edge of many valleys underlain by carbonates. The large flow rates and localized nature of these discharge points make it inconceivable that the water is derived from the gravel deposits. Therefore it is thought that these discharge points are located over buried karst springs. The springs are often ponded and contain several deep, cone-shaped discharge holes, invariably on the upslope side of the pond. Another type is similar to a cone-shaped ink pot with a perfectly spherical lip.

2) *The nature and source of groundwater recharge to the system;*

In some cases the conduit system may have a more or less permanent source of groundwater recharge. A good example is the Maligne basin karst system (Brown, 1970), which is known to drain several large sinks, the main one being situated in the bed of Medicine Lake (Tp 45, R 27, W 5th Mer). Discharge rates at the Maligne Canyon springs fluctuate seasonally, but the springs are a permanent feature. The relationship between conduit system and water table is less easily defined here as huge volumes of water pass through the system between sink and spring with an average through-flow time of 40 hours for a minimum conduit length of 16 km. The possibility that the system is perched above water table cannot be resolved without test drilling.

Other sources of semipermanent groundwater recharge are the permanent icefields of the continental divide. Conduit systems which extend beneath the icefields, such as that feeding the "Big Springs" of Castleguard meadows, are often well integrated. However, recharge only occurs during the summer months when glacial meltwater enters the system. The "Big Springs" are known to cease flowing (Ford, 1970) during the winter freeze-up.

The more general aspects of geologic structure control the susceptibility of carbonate terrains to solution processes. Ford (1969) states that more active carbonate solution is often associated with relatively shallow-dipping strata (less than 5°). Dips within *the Front Ranges* are steep (30° to 60°) and sustained with depth. Conduit systems are rare in this area, and are oriented parallel to strike in areas of anomalously shallow dip (Maligne basin karst system). The steeply-dipping strata of the Front Ranges result in steep topographic gradients which induce rapid surface runoff. Therefore, less water enters the groundwater system and consequently less carbonate solution takes place.

There are, however, a number of large springs within the Front Ranges which are associated with carbonate rocks and also show a spatial relationship to major thrust fault zones. This relationship has been noted elsewhere in the Alberta Rocky Mountains (Ozoray and Barnes, 1976, in prep.). Thrust faults have a strong influence on valley development which in turn influences limestone solution and the direction of groundwater flow. Within the map area the following river valleys closely follow thrust fault zones: Rocky River, Beaver Lake valley, the Maligne River above Maligne Lake, Poboktan Creek, Jonas Creek, Cairn River, Restless River, the Brazeau River between Isaac Creek and Job Creek, Sunwapta River between Sunwapta Falls and Poboktan Creek, the North Saskatchewan River between Alexandra River and North Saskatchewan River Crossing, Cataract Creek, and McDonald Creek.

The thrust faults of the Front Ranges extend for many miles along strike, and therefore have the potential of exerting regional controls on permeability, thereby directing groundwater from distant sources toward localized surface discharge points. Thrust fault controlled springs may have relatively constant and large discharge rates and uniform chemical quality when compared to springs not controlled by faults.

Within *the Main Ranges* broad expanses of distinctly layered, relatively flat lying or gently dipping carbonate rocks are found. Extensive plateau areas are associated with the icefields of the continental divide and many valley floors in the southern half of the Main Ranges are underlain by carbonates. These areas are more susceptible to carbonate solution and the development of large integrated conduit systems than are the steeply-dipping strata of the Front Ranges.

The following is a summary of the pertinent hydrogeological observations related to groundwater availability in the carbonate terrains of the mountainous parts of the map area.

1) Carbonate solution cavities are likely to be better developed and more widespread in the Main Ranges than in the Front Ranges.

2) The topographic position of permanent karst springs is closely related to the water table. The springs are generally situated in valley bottoms and water table gradients are gentle compared to topographic gradients. Therefore there is little point in drilling for groundwater high on valley sides or in mountain passes and plateau lands, as local relief from valley floor to mountain peaks is about 6000 ft (1829 m).

3) Large solution cavities are unlikely to be encountered below water table, except in areas of concentrated discharge.

4) Should a major conduit system be intersected by a water well, groundwater stored in the interconnected openings may be quickly depleted during the early stages of pumping, but is slowly replaced by groundwater stored in vugular and intergranular openings. Therefore, the initial pump test data should not be used in any calculation of long-term yield capabilities.

5) Massive limestone and dolomite formations such as the Mississippian Rundle Group, Devonian Palliser Formation, and Cambrian Eldon, Stephen, and Cathedral Formations, though more susceptible to large conduit development (Ford, 1969) are less well fractured, jointed and bedding-plane parted than the more thin bedded, shaly Mississippian Banff and Exshaw Formations, Devonian Fairholme Group and Cambrian Lyell, Pika and Mt. White Formations. The latter strata are therefore the more prospective carbonate aquifers of the map area.

6) If a karst spring is being considered as a possible long-term source of water, its permanence and seasonal discharge should be monitored prior to the installation of the water supply system.

Within the Rocky Mountain Foothills the Alberta Group shales are poor aquifers with little or no intergranular porosity. The ability of these somewhat plastic shales to absorb the compressional and tensional strains accompanying folding and faulting results in little fracturing and therefore negligible secondary porosity. Several deep holes (500 to 600 ft) have been drilled in these shales; some have been reported to be dry. The Blairmore Group, on the other hand, contains thick, coarse-grained sandstone beds with calcareous and pyritic cements and occasional coal seams. The sandstones have little intergranular porosity, but are exceedingly incompetent and as a result highly fractured.

The Western Alberta High Plains are underlain by the Upper Cretaceous to Tertiary Brazeau Formation. The typical clayey salt and pepper sandstones of this unit contain patchy cementing materials, sometimes chloritic. In the headwaters of Elk River (Tps 45 and 46, Rs 16 and 17, W 5th Mer) remnants of the once extensive Tertiary erosion surface are preserved on the flat-topped hills. Here the rocks are weathered to depths of 100 to 150 ft (30 to 46 m). The weathered sandstones are loose, unconsolidated, and more permeable than the unweathered rocks which are very clayey and often bentonitic.

The surficial deposits of the map area, with the exception of tills, are exceedingly coarse-grained and unconsolidated. Within the Rocky Mountains they occur as valley fill and therefore underlie the more accessible areas. Due to their coarseness, they are highly permeable and are undoubtedly the most prospective aquifers of the mountainous areas. However, their aquifer characteristics, thickness, and areal extent are often inconsistent. Confined and unconfined aquifers as well as perched systems (particularly in valley wall deposits) may be encountered. The possibility of induced recharge from surface water bodies during pumping and the presence of aquifer boundaries make it imperative that well-controlled pump tests be carried out if long-term water supplies are to be developed from these aquifers.

GEOLOGIC STRUCTURE

Three structural features are presented on the main map in order to illustrate the relationship between geologic structure and hydrogeologic features.

1) The major synclinal axis of the southern Main Ranges. It should be noted that the North Saskatchewan River valley follows this fold axis and that a series of karst springs with flow rates ranging from 100 to greater than 1000 igpm occur within the river valley. This is an example of structural control of surface topography which in turn directs and concentrates groundwater flow patterns.

2) The Sulphur Mountain and McConnell thrust faults. A group of springs, discharging groundwater from a deep flow system, occurs at the intersection of the Sulphur Mountain thrust fault with the Brazeau River valley (Tp 41, R 21, Sec 23, W 5th Mer). The flow rates of those springs range from 5 to 15 igpm, and the groundwater is a calcium-magnesium sulfate hydrochemical type with total dissolved solids ranging from 1800 to 2200 ppm and with a discharge temperature of 13°C.

A large ponded, buried karst spring also occurs in Tp 41, R 21, in Sec 23. The discharge from this spring is probably more than 100,000 igpm, but was not measured. It is a permanent fault-controlled karst discharge point occurring adjacent to the Sulphur Mountain thrust fault. The water has a discharge temperature of 4°C, and is a calcium-magnesium bicarbonate-sulfate hydrochemical type with total dissolved solids of 310 ppm. Several springs of this type occur along the Sulphur Mountain and McConnell thrust faults. Flow rates are invariably above average and the springs are more permanent than discharge points not fault controlled.

INTERMITTENT OR SEASONAL STREAMS

Intermittent or seasonal streams occur without exception in topographically high carbonate terrains. They indicate areas where rapid infiltration of surface waters occurs, and therefore delineate local karst groundwater recharge zones. The water table is likely to lie at considerable depth in these areas, and they should therefore be avoided when selecting possible water-well sites.

NATURAL PONDS OR WATER HOLES

Natural ponds or water holes and large closed depressions with no surface outlets may contain permanent bodies of surface water (P). Where these features occur in carbonate terrains, they may represent highly localized points of groundwater recharge commonly called sink holes or dolinas. Many of these features have not been investigated or identified in the field, but are outlined on the 1:50,000 scale National Topographic Map Series.

SPRINGS

Springs presented on the main map and profiles include any natural groundwater discharge feature. Some of these discharge points are not easily identified on the ground due to their diffuse nature or ponding of the discharged water. Such discharge points were identified from the air or by peculiar hydrochemical characteristics. Groundwater discharge rates, where indicated, are generally estimates of the approximate order of magnitude. As a general rule, the higher the flow rate, the more inaccurate the estimate becomes.

Two unusual groundwater discharge features located on gravel terraces of the Brazeau River valley deserve special note. Neither of these features would normally be described as a spring, as both are ponded and have no permanent surface outlet. The larger of the two features is located in Tp 44, R 20, Secs 23 and 24, W 5th Mer. This physically striking and colorful group of lakes covers an area of about 1 sq mi. The lakes are situated on a glaciofluvial gravel terrace about 70 ft above and one half mile east of the Brazeau River. All of the lakes are shallow (2 to 3 ft) and the three largest have deep, central "discharge pits." The lake bottoms surrounding the "discharge pits" are white in color and consist of tiny spicules of calcium carbonate which form a crystal ooze. The water standing in the lakes has a total dissolved solids content of 150 to 200 ppm which consists mainly of calcium-magnesium bicarbonate. The calcium-magnesium ratio is in the range 1:1 to 1:2. The chemistry of the water at the point of discharge is not known. The groundwater is thought to originate from Lower Cretaceous Blairmore Group aquifers immediately beneath the contact with the Upper Cretaceous Alberta Group. The groundwater accumulates in the shallow lakes where calcium bicarbonate is precipitated. The lakes lose water by seepage through the surrounding gravels and evaporation at the lake surface.

In Tp 42, R 20, Sec 20, Lsd 5, a somewhat smaller, but equally striking ponded discharge point is observed. The pond is very shallow (1 to 2 ft), and again has a white bottom, which is thought to be the result of calcium carbonate precipitation. Underlying the white "precipitate" is a layer of black, oozing mud. Upwelling groundwater accumulates beneath the black mud and occasionally rises to the lake surface in a large bubbling mass, thereby pushing aside the white "precipitate" and depositing a ring of black mud around the point of emergence. Thus the bottom of the lake becomes covered with startling black-and-white botryoidal patterns. This groundwater discharge feature is located on the McConnell thrust fault and is thought to overlie a buried, fault-controlled karst spring.

The feature was visited in early September, 1976, at which time there was no surface discharge from the lake. However, a well-defined discharge channel does run from the lake into the Brazeau River, suggesting intermittent, possibly seasonal, outflow from the lake. The lake water is of the calcium-magnesium bicarbonate hydrochemical type with 25 percent (epm) of the anions being sulfate. The water has a total dissolved solids content of 172 ppm. The hydrochemistry is typical of karst groundwater of the Front Ranges.

AREAS OF ARTESIAN FLOW

Areas of artesian flow are known only in the Western Alberta High Plains region, as this is the only part of the map area where there has been extensive seismic drilling. Flowing shotholes are usually very shallow (less than 100 ft) and are situated on valley sides. Water wells in this area are deeper (200 to 500 ft) and do not flow; therefore artesian conditions are localized and originate from shallow confined bedrock aquifers. The confining layer is probably a thin covering of surficial deposits.

Flowing conditions are likely to be encountered in many topographically low positions within the folded and faulted rocks of the Rocky Mountains. In the Foothills belt, the synclinal structure of the Lower Cretaceous Blairmore Group rocks in particular induces the development of artesian conditions.

WELL YIELDS

The color-coded average expected well yields shown on the main map are based on the interpretation of geologic structure, lithology, topography and the occurrence and characteristics of natural groundwater discharge features. Existing water wells, some with pump test data, provided local control points, but due to complex bedrock geology and great local variation in lithology, water-well data were too scarce to have any regional significance.

The indicated average expected well yields for surficial aquifers are considered regionally representative. The hydrogeologically important surficial deposits occur almost exclusively in topographically low areas where they are likely to be fully saturated. Also, the surficial geology of the map area has been studied in relative detail compared to bedrock geology. The yield category indicates the quantity of water that may be obtained from a single, fully penetrating, water well.

Bedrock yields, based primarily on outcrop geology and natural groundwater discharge observations, cannot be applied to depths greater than 500 ft and are considered conservative. Where pump test data are available, the calculated 20-year safe yield (Q_{20}) is generally higher than the yield category in which the well occurs.

The allocation of yield categories to carbonate rocks is somewhat ambiguous and thoroughly regional. The permeability of carbonates can change considerably over very short distances; therefore a detailed hydrogeological inspection of proposed well sites could save considerable time and expense.

TEST DRILLING

During the summer of 1976 the Alberta Research Council drilled and pump-tested three test wells. Resistivity and self-potential wire-line electric logs were run in all three testholes which ranged in depth from 200 ft (61 m) to 460 ft (140 m). Council staff were also present during the drilling of a private water well at the David Thompson Resort (Tp 37, R 8, Sec 15, W 5th Mer) and subsequently ran a pump test at this site. Drilling and pump test results from these wells are summarized in the Appendix.

The private well at the David Thompson Resort intersected 170 ft (52 m) of till (probably lateral moraine) with 10 ft (3.2 m) of water-washed, pea gravel at 125 to 135 ft (38 to 41 m). The gravels were clean, and very coarse-grained and were the only water-bearing interval intersected. The well was cased and 10 ft (3.2 m) of stainless steel screen was set in the gravel interval. The well was developed until the water was clear. A 360-minute pump test was run at 8 igpm (0.6 l/sec). Analysis of the pump test indicated a 20-year safe yield of 20 igpm (1.5 l/sec) and the well was put into service. After about a week of continuous pumping at 15 igpm, the water became very dirty and the well was pumped dry. The history of this well serves to illustrate some of the problems involved in obtaining a water supply from the Rocky Mountain tills. In this case the top and bottom of the aquifer were not well known. As a result, the screen was set too high and fines from the till overlying the gravel slumped in on the screen, thereby sealing off the supply. The only way to ensure accurate and satisfactory positioning of the screen in such aquifers is to run wire-line electric logs of the hole prior to completion of the well. The top and bottom of the gravel interval could be pin-pointed by this method with an accuracy of ±6 in (152 mm).

The only thoroughly reliable pump test data available from wells developed in glaciofluvial sand and gravel aquifers within the map area were collected by Balzar (1968) during permeability testing in the North Saskatchewan River bed at the Bighorn Dam site (Tp 38, R 17, Sec 35, W 5th Mer). Test wells situated adjacent to the river intersected 120 ft (37 m) of glaciofluvial sand and gravel overlying sandstones and shales of the Blackstone and Mountain Park Formations. The upper 40 ft (12 m) of gravel was found to be very silty (probably reworked by the North Saskatchewan River) and static water levels in observation wells only 20 ft (6 m) from the river were 6 ft (2 m) below river level. This is probably due to fine silt and "rock flour" sealing the river bed, and substantially reducing infiltration of river water into the river bed gravels. This phenomenon is probably quite common in the mountain river valleys of the map area. It is important because induced infiltration from surface water bodies into adjacent surficial aquifers during pumping is often reported to be an important source of recharge to the aquifer, and can result in substantially higher long-term aquifer yields. At the Bighorn Dam site the upper 40 ft (12 m) of silty sand and gravel responded to pumping like a leaky artesian aquifer. Values of vertical permeability (k_v) for these deposits are in the range 7 to 45 igpd/ft^2 (0.34 to 2.2 m^3/d/m^2). Values of horizontal permeability (k_h) could not be calculated. Values of vertical permeability (k_v) for the underlying stratified sand and gravel deposits average 65 igpd/ft^2 (3.2 m^3/d/m^2) and are substantially lower than values of horizontal permeability which average 2300 igpd/ft^2 (112 m^3/d/m^2). Calculated values of transmissivity (T) range from 147,000 igpd/ft (7193 m^3/d/m^2) to 180,000 igpd/ft (8807 m^3/d/m^2) and the 20-year safe yield (Q_{20}) calculated for 10 ft (3 m) of drawdown ranges from 700 to 850 igpm (53 to 64 l/sec).

HYDROCHEMISTRY

GENERAL

The hydrochemistry of surficial and shallow bedrock groundwaters is summarized on the hydrochemical side map and accompanying Piper diagram and table. About 30 percent of the chemical analyses are from water wells ranging in depth from 30 to 500 ft and averaging 100 ft deep. The remaining analyses are of spring water.

The distribution of hydrochemically different groundwaters within the map area appears haphazard. This is due in part to the scarcity of hydrochemical analyses of groundwaters from bedrock aquifers greater than 50 ft deep. Had such analyses been available, a more unique distribution of hydrochemical facies would have been discernible. Available data indicate that the hydrochemistry of groundwaters from shallow bedrock wells is invariably different from the hydrochemistry of bedrock spring waters. Within the Rocky Mountain Foothills and Western Alberta High Plains, groundwater from bedrock aquifers over 50 ft deep is often of the sodium-potassium bicarbonate type, whereas bedrock spring waters are of the calcium-magnesium bicarbonate type. The ratio of hydrochemical analyses of groundwaters from bedrock aquifers over 100 ft deep to hydrochemical analyses of bedrock spring waters in this part of the map area is 1:4. Therefore the distribution is biased towards the calcium-magnesium bicarbonate type groundwaters.

Within the Front Ranges and carbonate terrains of the Main Ranges the dominant chemical constituents of groundwaters are calcium, magnesium, and bicarbonate, with up to 30 percent (epm) sulfates. The sulfates are thought to be derived from interbedded pyritic shale horizons, the Triassic Spray River Group and Jurassic Fernie Group shales. Locally these groundwaters display a gradual increase in sulfate concentrations passing through calcium-magnesium bicarbonate-sulfate type water into the somewhat rare and highly localized occurrences of calcium-magnesium sulfate type groundwaters. This apparently gradual chemical transition from bicarbonate to sulfate-rich groundwaters suggests that the waters belong to an interconnected flow system in which the proportions of bicarbonate to sulfate are directly related to residence time and depth of penetration. The occurrence of the sulfate-rich waters in topographically low areas supports this theory and the relatively warm (13°C) discharge temperatures suggest deep penetration.

Sulfate-rich groundwaters are thought to be more widespread at depth in bedrock aquifers of the Front and Main Ranges, but no chemical analyses are available to confirm this hypothesis.

Groundwaters from surficial aquifers are without exception of the calcium-magnesium bicarbonate hydrochemical facies.

All of the previously mentioned hydrochemical characteristics are graphically displayed on the Piper diagram presented with the main map.

Groundwater within the map area generally contains less than 1000 ppm total dissolved solids. Groundwaters with total dissolved solids varying from 400 to 1000 ppm are invariably of the sodium-potassium bicarbonate type and total dissolved solids greater than 1000 ppm are generally associated with the calcium-magnesium sulfate type groundwaters.

IRON CONCENTRATIONS

In those areas of the Main Ranges underlain by the Lower Cambrian Gog Formation, iron concentrations in groundwaters range from 0.5 to 1.0 ppm. Here, iron is available from ferruginous quartzites. Within the Foothills, groundwater from Blairmore Group aquifers, which contain abundant ironstone beds, may have iron concentrations ranging from 0.5 to 1.5 ppm. Elsewhere, including surficial aquifers, iron concentrations are less than 0.5 ppm.

FLUORIDE CONCENTRATIONS

The general range of fluoride concentrations over the entire map area is 0.1 to 0.2 ppm. Relatively high fluoride concentrations (1.5 ppm) were noted in the warm, sulfate-rich groundwaters of the Brazeau River valley (Tp 41, R 20, Sec 6).

CONCLUSIONS

The Brazeau-Canoe River map area is characterized by rugged topography, a highly variable climate, and complex geology. The hydrogeologic regime and distribution of prospective aquifers are closely related to these physical characteristics and are equally as variable and complex.

The peculiar "karst" weathering features of carbonate rocks defy regional characterization. Groundwater recharge and discharge in carbonate terrains are rapid and extremely localized. Groundwater residence times are short, but flow paths are often of great lateral extent. Careful and well-planned management is required in such areas if groundwater pollution is to be avoided; local hydrogeological analysis of topography, geology, and groundwater recharge and discharge phenomena is an important prerequisite to the development of permanent groundwater supplies.

The more prospective bedrock aquifers of the map area are thin-bedded fractured limestones, dolomites, sandstones, slate, and coal. Shale formations are indurated and less susceptible to fracture development, even when folded.

The highest well yields within the map area are obtained from glaciofluvial and recent alluvial sand and gravel deposits. Yields greater than 500 igpm (38 l/sec) may be available from these aquifers.

Groundwater quality in surficial and shallow bedrock aquifers is excellent. Groundwater with total dissolved solids content greater than 1000 ppm is usually of the calcium-magnesium sulfate hydrochemical type which, due to its pungent odor and laxative properties, is considered unsuitable for human consumption.

The town of Jasper is situated on a glaciofluvial gravel terrace adjacent to the Athabasca River. The thickness of these deposits is not known, but they are a major geological unit within the Athabasca River valley. Numerous small lakes near Jasper indicate a near-surface water table. Therefore the gravels are probably fully saturated and constitute a very prospective aquifer in which yields may be enhanced by induced infiltration from surface water bodies. Existing wells completed in this gravel aquifer indicate that the groundwater contains less than 500 ppm total dissolved solids and consists mainly of calcium-magnesium bicarbonate. The gravels are underlain by indurated Proterozoic sandstone, siltstone, shale, and slate which, unless thin-bedded, cleaved and fractured, are thought to be relatively impermeable.

Near Nordegg surficial deposits are thin or absent. Existing groundwater supplies are obtained from the Lower Cretaceous Blairmore Group. The bedrock strata dip steeply southwest and consist of thin-bedded sandstone, shale, coal, and conglomerate. Groundwater quality can vary considerably over short distances perpendicular to geologic strike (northwest to southeast) and groundwater with a strong sulfurous odor and high sulfate content has been encountered in test wells drilled in the less permeable shale and silty shale intervals. Due to steep dip and lateral continuity of bedrock units along strike, groundwater quality is unlikely to improve with depth or parallel to strike. Should undrinkable groundwater be encountered in test wells drilled in this area, additional well sites should be located in a northeast or southwest direction from the initial test well. More permeable sandstone or conglomerate aquifers may be intersected which, due to local recharge or more rapid groundwater movement, or both, may contain better quality groundwater.

The general scarcity of groundwater-based water supplies within the map area is directly related to the abundance of unpolluted surface waters and exceedingly low population density of the area. It cannot be attributed to a lack of prospective aquifers.

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APPENDIX. ALBERTA RESEARCH COUNCIL TESTHOLES

1. Location: Lsd 6, Sec 1, Tp 42, R 15, W 5th Mer
   Owner: Alberta Research Council
   Driller: Robsco Ltd.
   Total depth: 205 ft
   Status: abandoned

Depth (feet)	Lithology
0-15	brown clayey soil with bedrock fragments
15-50	dark grey calcareous siltstone with occasional pyritic and carbonaceous shale beds
50-60	grey-black shale
60-70	light grey calcareous siltstone
70-85	grey and blue fissile shale
85-110	medium- to fine-grained salt and pepper sandstone, becoming coarser at 95 ft
110-125	blue fissile shale interbedded with thin white bentonite and dark brown siltstone beds
125-130	medium- to fine-grained salt and pepper sandstone
130-205	grey-black fissile shale interbedded with thin bentonitic clay beds and silty shale beds

Geological unit: Upper Cretaceous Cardium Formation
Water-bearing intervals: 85-110 ft
125-130 ft
Construction: open hole 21-205 ft
Depth to water in finished well: 35 ft

Pump test:
- Length of drawdown record: 60 min
- Length of recovery record: 60 min
- Pumping rate: 5 igpm (0.38 l/sec)
- Available drawdown (H): 50 ft

Aquifer parameters:
- Transmissivity (T): 16 igpd/ft (0.24 $m^3/d/m$)
- 20-year safe yield (Q_{20}): >0.5 igpm (0.038 l/sec)

2. Location: Lsd 16, Sec 31, Tp 45, R 17, W 5th Mer
Owner: Alberta Research Council
Driller: All-Rite
Total depth: 460 ft
Status: abandoned

Depth (feet)	Lithology
0-10	brown sandy clay with occasional bedrock fragments
10-90	orange and grey medium- to coarse-grained clayey weathered sandstone with occasional thick beds of grey shale
90-108	orange-brown, fine- to medium-grained, clayey, weathered sandstone
108-120	medium-grained, grey salt and pepper sandstone
120-146	grey mudstone — slightly fissile
146-219	grey, finegrained, bentonitic siltstone
219-220	grey-brown calcareous shale — slightly fissile
220-325	grey, sandy clay — bentonic with occasional thin shale beds
325-440	orange-brown, fine-grained clayey sandstone — slightly bentonitic
440-460	dark grey shale — bentonitic

Geological unit: Upper Cretaceous to Tertiary Brazeau Group
Water-bearing interval: 90-108 ft
Construction: open hole 20-460 ft
Depth to water in finished well: 48 ft

Pump test:
Length of drawdown record: 300 min
Length of recovery record: 0 min
Pumping rate: 14 igpm (1.06 l/sec)
Available drawdown (H): 42 ft (12.8 m)

Aquifer parameters:
Transmissivity (T): 1125 igpd/ft (16.8 m^3/d/m)
20-year safe yield (Q_{20}): 22 igpm (1.67 l/sec)

3. Location: Lsd 1, Sec 33, Tp 45, R 23, W 5th Mer
Owner: Alberta Research Council
Driller: All-Rite
Total depth: 200 ft
Status: abandoned

Depth (feet)	Lithology
0-24	red-brown clayey gravel
24-76	interbedded light grey salt and pepper sandstone and dark brown oxidized sandstone, medium- to fine-grained
76-88	coal
88-93	black fissile shale
93-96	grey, fine-grained, non-calcareous sandstone
96-112	pyritic, fissile shale interbedded with silty shale; some slickensiding
112-118	coal
118-132	brown, fine-grained calcareous sandstone becoming silty towards 132 ft
132-133	coal
133-150	grey siltstone
150-170	light grey, medium-grained calcareous sandstone, becoming finer-grained towards 170 ft
170-179	thinly-bedded grey siltstone and shale; occasional white bentonite beds
179-200	grey, medium-grained, non-calcareous salt and pepper sandstone

Geological unit: Lower Cretaceous Luscar Formation
Water-bearing intervals: 56-62 ft
180-200 ft
Construction: open hole 27-200 ft
Depth to water in finished well: 16 ft

Pump test:
Length of drawdown record: 360 min
Length of drawdown record: 0 min
Pumping rate: 40 igpm (3.8 l/sec)
Available drawdown (H): 45 ft (13.7 m)

Aquifer parameters:
Transmissivity (T): 595 igpd/ft (11.1 $m^3/d/m$)
20-year safe yield (Q_{20}): 16 igpm (1.2 l/sec)

4. Location: Lsd NE, Sec 15, Tp 37, R 8, W 5th Mer
Owner: J. Brown, David Thompson Resort
Driller: All-Rite
Total depth: 175 ft
Status: production well

Depth (feet)	Lithology
0-125	clay, till and boulders
125-135	pea gravel, sand and silt
135-170	clayey till and boulders
170-175	black, carbonaceous shale

Water-bearing interval: 125-135 ft

Construction: cased to 155 ft (bottom sealed)
screen set at 125-135 ft

Depth to water in finished well: 111 ft

Pump test:

Length of drawdown record: 360 min

Length of recovery record: 0 min

Pumping rate: 8 igpm

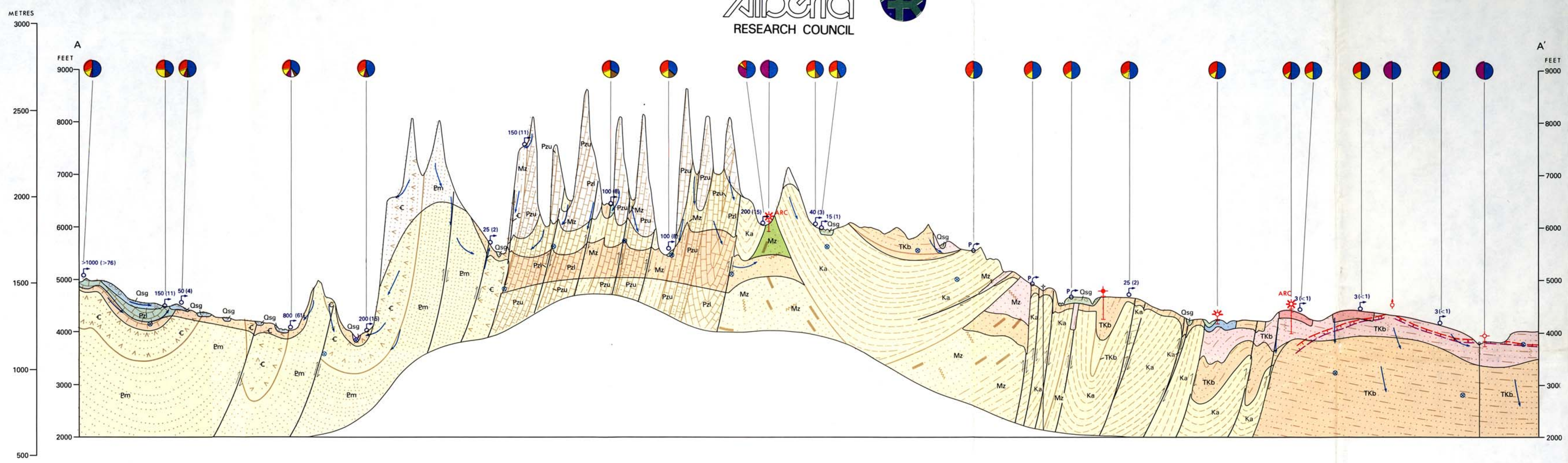
Available drawdown: 15 ft

Aquifer parameters:

Transmissivity (T): 3700 igpd/ft (55.2 m^3/d/m)

20-year safe yield (Q_{20}): 20 igpm (1.5 l/sec)

ALBERTA RESEARCH COUNCIL



MAIN MAP LEGEND

Topography

Surface contours and elevation in feet (interval 100 feet)

Geology

Geological boundary
Axis of syncline
Thrust fault (teeth on upper plate)
Fault, direction of movement shown

QUATERNARY

- Qg — Gravel
- Qsg — Sand and gravel

CRETACEOUS – TERTIARY

- TKb — Brazeau Formation

CRETACEOUS

- Ka — Alberta Group

MESOZOIC

- Mz — Lower Cretaceous, Jurassic, Triassic

PALEOZOIC

- Pzu — Upper Paleozoic
- Pzl — Lower Paleozoic
- € — Lower Cambrian

PRECAMBRIAN

- Pm — Proterozoic

Lithology

Gravel
Sand and gravel
Sandstone
Quartzite
Siltstone
Shale
Limestone
Fractured rocks
Coal

Hydrography

Lake or slough, perennial
Lake or slough, seasonal
Icefield
Large closed depression
Area inundated during floods
Stream, perennial
Stream, intermittent
Natural pond or water hole (no surface outlet), permanent (P) or temporary (T)
Surface water divide

Hydrometry

Stream gauging station
Stream data:
Mean annual discharge in cubic feet per second — 1879
Year of commencement of observations — 1970
Number of years averaged for mean annual discharge figure — 3
Drainage area in square miles — 728

Hydrogeology

Spring, flow rate unknown, permanent (P) or temporary (T)
Spring, flow rate in igpm (l/sec) — 100(8)
Spring information
1. Characteristic feature of springs:
   VI — buried karst spring
2. Nature of rock openings:
   F — fault controlled   C — conduit

Direction of groundwater flow
Component of groundwater flow perpendicular to profile:
out of profile (towards reader)
into profile (away from reader)
Groundwater divide
Direction of horizontal component of groundwater flow
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.)

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 short-comings 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: FEET 0, 100, 200, 300, 400 — Depth to water — Depth of well or seismic shot hole

Water well, nonflowing
Water well, flowing
Water well, nonproducing
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 hydraulic conditions
Locations of Alberta Research Council test well — ARC
Shothole, flowing
Gas well*
Suspended well*, drilled for oil or gas
Abandoned well*, drilled for oil or gas
Structure testhole*
Dam and hydroelectric station
Line of hydrogeological profile — A A′

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

Hydrochemistry

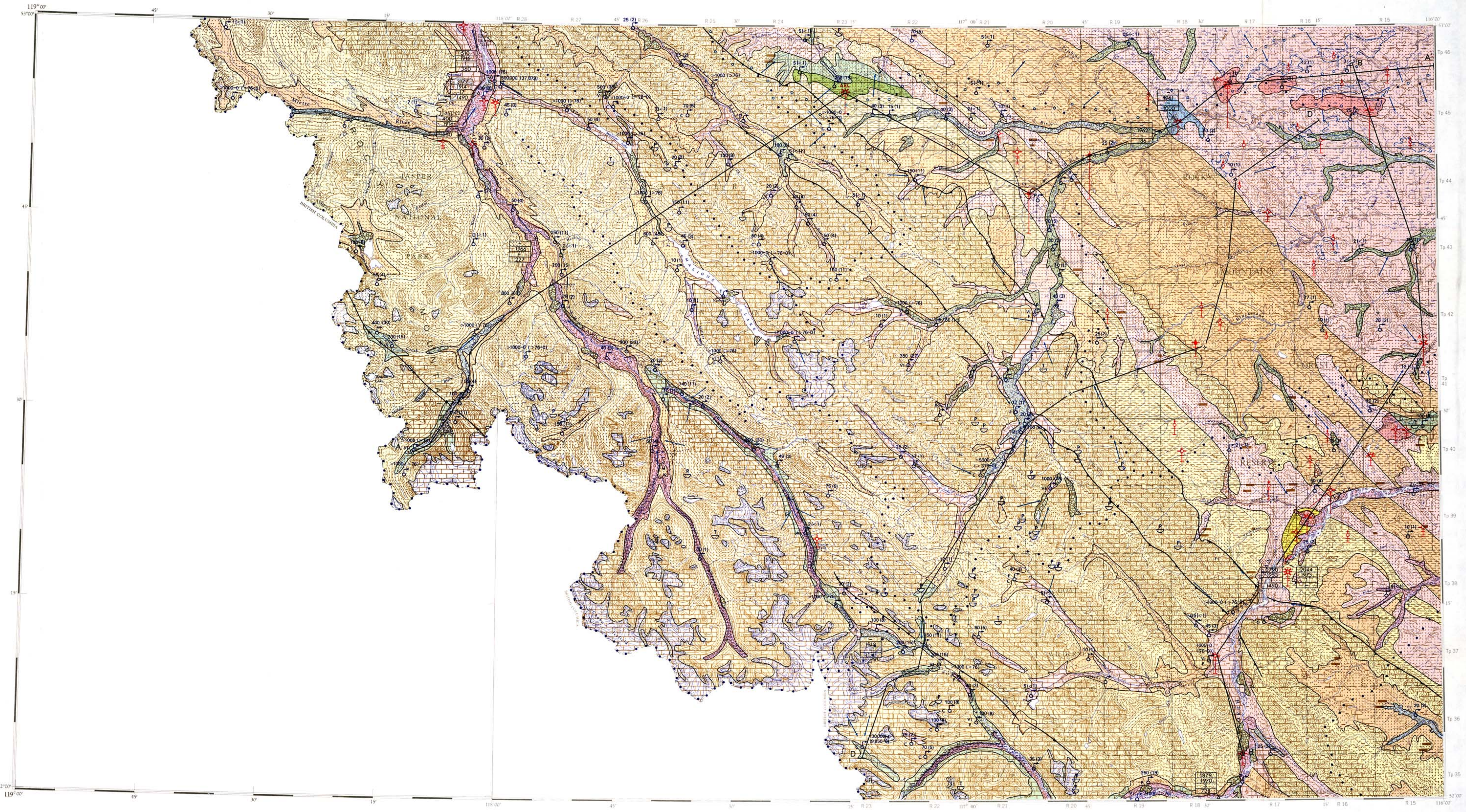
Calcium, Magnesium, Sodium + potassium (Cations) | Carbonate + bicarbonate, Sulfate, Chloride, Nitrate (Anions) — 0, 50%, 100%

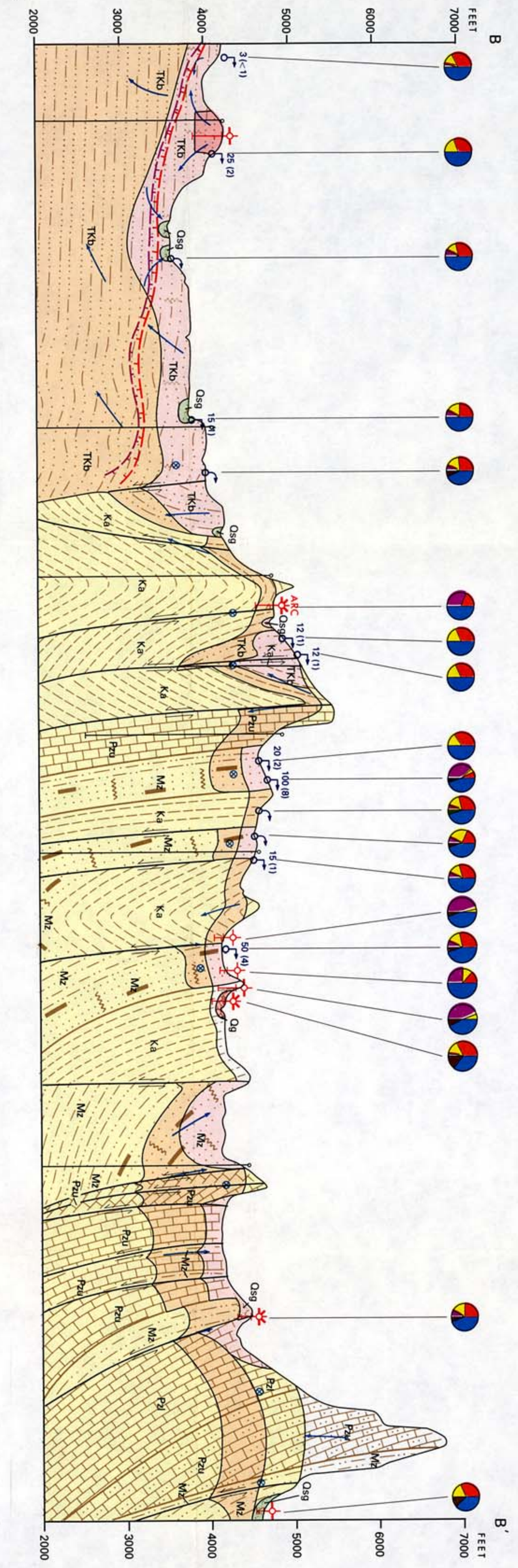
Note: When the yellow Mg pie sector is absent, Ca + Mg are represented as a unit by the red pie sector.

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

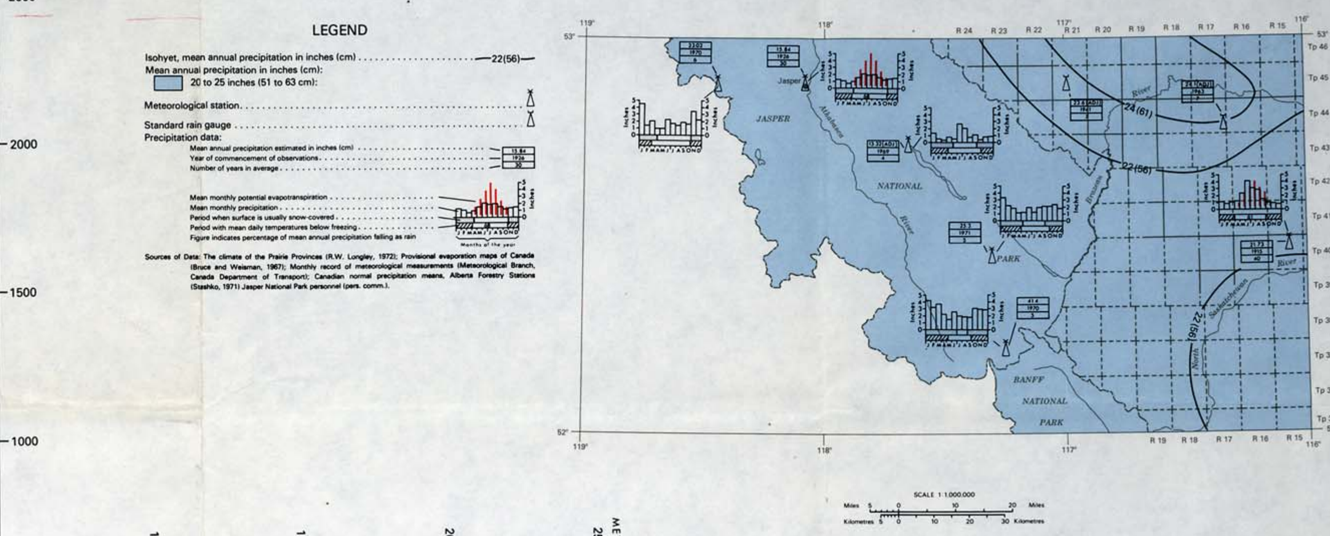
Isogram along which sodium + potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium + potassium content, approximate

*determined on equivalents per million basis

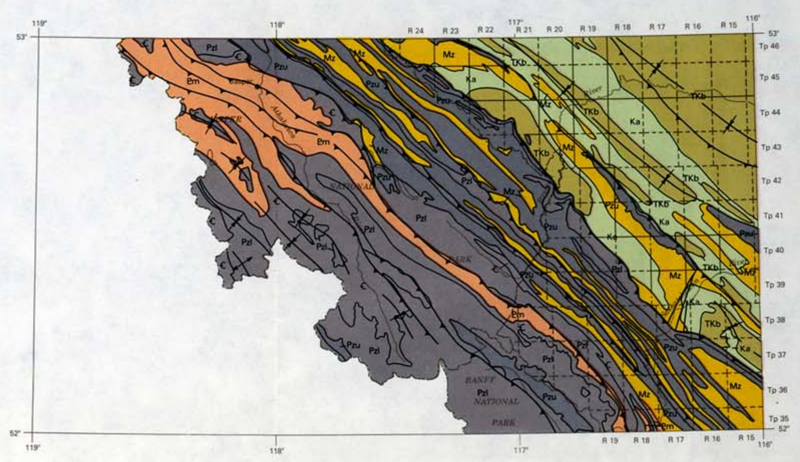




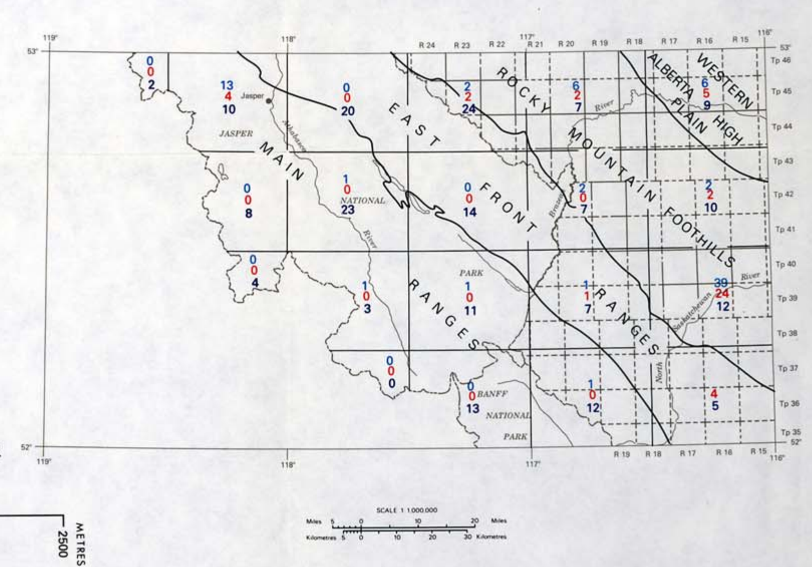
METEOROLOGY



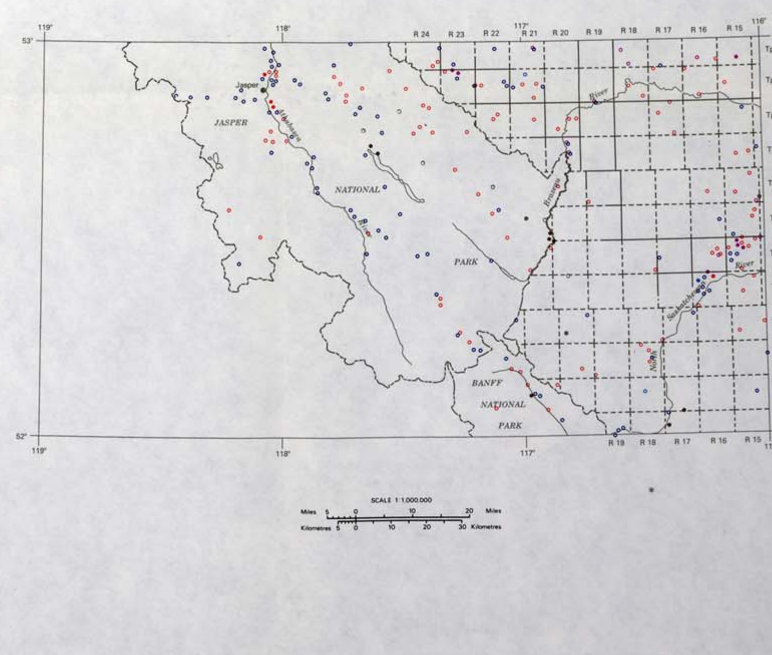
GEOLOGY



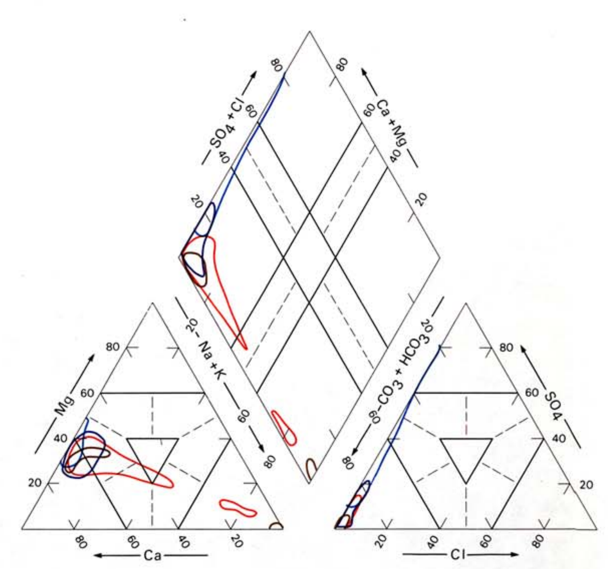
DATA DENSITY AND PHYSIOGRAPHY



HYDROCHEMISTRY



CHARACTERISTIC HYDROCHEMISTRY OF GROUNDWATER

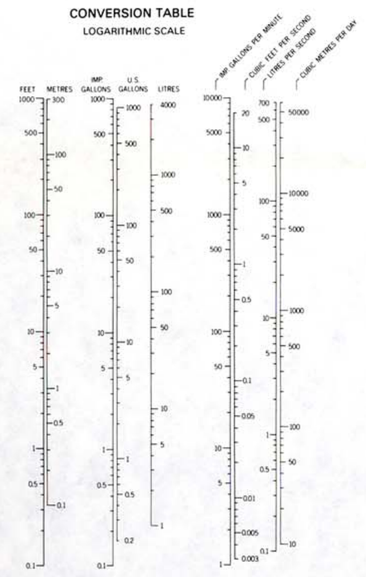


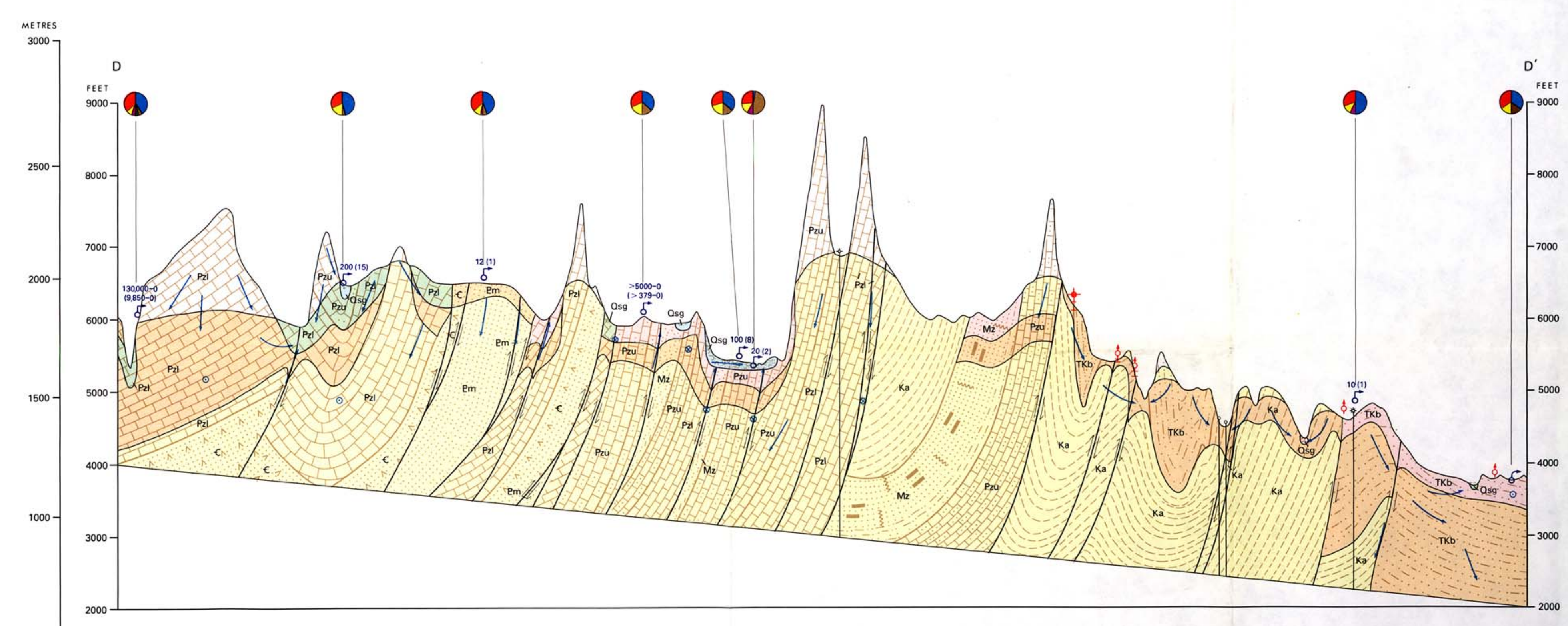
LEGEND

Groundwaters from:	Number of data control points	Range of total dissolved solids in parts per million	Average total dissolved solids content in parts per million: Shallow Wells	Springs
Surficial aquifers	52	105-483	257	193
The Brazeau Formation of the Western Alberta High Plains	13	120-458	367	275
The Cretaceous, Jurassic, and Triassic of the Rocky Mountain Foothills	48	123-884	427	297
The Paleozoic and Cambrian carbonate terrains of the Rocky Mountain Front and Main Ranges*	48	56-484	–	201

*Excluding seven sulfur springs with total dissolved solids ranging from 671-2231 parts per million and an average total dissolved solids of 1540 ppm.

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 20X.

An expanded legend and explanatory notes (Report 72-12) for use with this hydrogeological map series is available from Publications, Alberta Research Council, 11315 - 87 Avenue, Edmonton, Canada T6G 2C2.

Map to accompany Report 77-5.

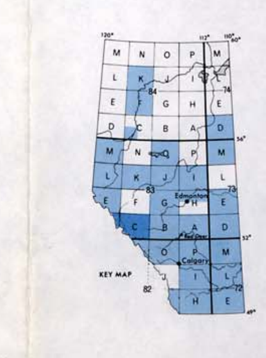
Hydrogeology by R. Barnes.

Drafted by R.W. Swenson.

Cartographic editing by A.R. Campbell.

HYDROGEOLOGICAL MAP
BRAZEAU–CANOE RIVER
ALBERTA

NTS 83C–83D



KEY MAP