Earth Sciences Report 82-4

Hydrogeology of the Clear Hills-Chinchaga River area, Alberta

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Alberta
RESEARCH COUNCIL
Natural Resources Division

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ABSTRACT

The 20-year safe yield for about four-fifths of the area is 0.1 to 0.4 L/s (1 to 5 igpm). Only in small isolated alluvial areas along the Peace River is the potential yield greater than 8 L/s (100 igpm). Tertiary and Quaternary sands and gravels are capable of yielding 0.4 to 2 L/s (5 to 25 igpm), most notably at Whitelaw. Along the northeastern margin of the area, the Dunvegan sandstone may yield 0.4 to 2 L/s (5 to 25 igpm). A 20-year safe yield of even 0.1 L/s (1 igpm) is not probable in portions of the area's lowland and along the steep slopes of the upland. Generally, the relatively productive and conveniently located aquifers are composed of surficial deposits. Marginal aquifers may be the Lower Kaskapau-Dunvegan and the Wapiti Formations. The former, however, proved to be unsatisfactory at several places, and the latter is situated in an unpopulated upland.

The shallow groundwater is of good chemical quality over most of the central and northern parts of the area. This water is a calcium or sodium bicarbonate type and generally contains 500 mg/L or less total dissolved solids. Shallow groundwater quality is less than satisfactory in extensive areas in the south due to a high dissolved solids content (2000 to 4000 mg/L), high sulfate concentrations, or both. The quality of the formation waters is undesirable. These waters are of sulfate or chloride type with total dissolved solids concentrations up to 30 000 mg/L.

INTRODUCTION

The Clear Hills - Chinchaga River area (map sheets 84D and 84E, respectively) is located in northern Alberta, between longitudes 118 degrees and 120 degrees west and latitudes 56 degrees and 58 degrees north, in Tp 81-104, R 1-13, W 6 Mer. The area covers about 26 580 km^2 (10 270 sq mi). Topographic maps on a 1:50 000 scale with elevation contour lines are available for the entire area.

A field survey was performed in 1978 by car and helicopter. In addition to the usual airphoto interpretation, satellite images were studied and interpreted (Ozoray, 1975). Hydrogeological maps and profiles of the area were constructed during 1978-79. The legend accompanying these maps follows the format used for the Alberta Hydrogeological Reconnaissance Series (Badry, 1972), which is based upon the international style.

The southernmost third of the area has good access: there are several gravelled roads and an expanding network of farm roads. The paved Highway 2 crosses the southeastern corner of the area. The northern two-thirds, however, has only a few good-weather roads servicing forestry lookouts or drilling sites. There are also some forestry airstrips. Most of the northern part of the area can be reached only by helicopter.

The population is concentrated in the southern third of the area. Population figures (Travel Alberta, 1980) for the major settlements are: Fairview (2594), Hines Creek (503), Whitelaw (123), Bluesky (135), and Worsley (63). The area includes the Clear Hills Indian Reserve. Apart from some forestry personnel, and lumbering and drilling crews, the northern two-thirds of the area is unpopulated. Fairview uses both surface and groundwater for its public water supply; Bluesky uses surface water (Alberta Environment, 1976).

The vegetation of the area is mainly forest or parkland of aspen poplar. Treed muskeg (sphagnum moss and black spruce) is widespread on the hills, but areas of white spruce, black spruce, and lodgepole pine forest are also present. Farming has changed much of the natural vegetation in the south (Government and University of Alberta, 1969).

Farming and lumbering are important and still expanding activities in the southern and northern parts of the area, respectively. There is considerable natural gas production in the area. Hydrocarbon prospecting is presently very active all over the area. Sand and gravel is quarried at places. The proven iron ore resources of the Clear Hills area are not mined.

PREVIOUS WORK

Groundwater studies covering some of the southern parts of the area were done by Rutherford (1930), Jones (1966), and Tokarsky (1967). A small scale overview relevant to the entire area is given by Ozoray (1978). The hydrogeological conditions of the neighboring areas are represented on seven hydrogeological maps of the Hydrogeological Reconnaissance Map Series, Alberta Research Council. Local studies were carried out by the Alberta Department of the Environment (1971), Yoon (1973), and Znak (1975). Water well records were published by Jones (1962), and data regarding surface waters by Reeder *et al.* (1972) and the Inland Waters Directorate (1976).

TOPOGRAPHY AND DRAINAGE

The map area lies within the Alberta High Plains, which is part of the Interior Plains. Subunits within the area are the Clear Hills Upland, and the Fort Vermilion and Peace River Lowlands (Government and University of Alberta, 1969, p. 9). These physiographic units are shown on the chemistry side map. The upland area is an undulating tableland dissected by deep and wide river valleys. The Clear Hills and Naylor Hills have sharp escarpments and are skirted by about 300 m (1000 ft) high, steep (100-125 m/km) slopes. The Fort Vermilion Lowland is a gently rolling plain with an elevation of 600-700 m (2000 to 2300 ft) amsl. The Peace River and its tributaries cut 200 to 250 m (700-850 ft) deep, steep flanked (200 to 250 m/km) valleys into the surrounding plain.

The highest elevation in the map area is more than about 1100 m (3600 ft) amsl in the Clear Hills. The lowest point is in the south where the Peace River leaves the area at about 375 m (1230 ft) amsl. The Chinchaga River leaves the area in the north at the only slightly higher elevation of 420 m (1380 ft) amsl. The maximum difference in elevation within the map area is about 725 m (2370 ft).

The entire area was covered by the Wisconsin ice sheet; consequently, the landforms are mostly glacial, glaciofluvial or glaciolacustrine (Bayrock, in Lindsay *et al.,* 1958). Fluting and ice-disintegration features are widespread (Gravenor and Kupsch, 1959; Stalker, 1960). Well-developed meanders and oxbow lakes are characteristic of the Chinchaga River. Recent river erosion and gully development are prominent in the Peace River Lowland.

The entire area belongs to the Mackenzie River-Arctic Ocean drainage system. The three main sub-basins within the area are those of the Peace, Hay, and Liard Rivers (Fig. 1). Watersheds of some important tributaries are delineated on the attached hydrogeological map.

The numerous lakes in the area are smaller than 10 km^2 (4 sq mi). Muskeg is widespread in the plateau areas and the valley of the Chinchaga River. The ribbed fen phenomenon is restricted to the highest ground.

CLIMATE

Most of the area is in the "short, cool summer" (Dc) Koeppen zone; the zone of the "long, cool summers" extends just into the Peace River valley (Longley, 1972, Fig. 53). The northern margin of the area is within the zone of the discontinuous permafrost and is described as the "southern fringe of permafrost region" by Brown (1967). The entire area is described by Lindsay and Odynsky (1965) as a "climafrost area" in which the frozen condition is temporary, but frequently lasts for more than a year.

Isohyets (modified to fit orography and accommodate summer rain gauge observations) after Longley (1972, Fig. 47) are shown on the meteorological side map. Ten summer rain gauges (which operate only from May to September) are located in the area (Stashko, 1971). October to May precipitation was calculated by using the same percentage as was observed at Fairview, the only meteorological station in the area. Unfortunately, these summer rain gauge observations are available only for 6 to 8 years. These data, though not directly comparable to the 30-year means used by Longley (1972) to construct the annual precipitation map of the prairie provinces, indicate that the Clear Hills area is more humid than its surroundings and the main valleys are in a rain shadow. The elevated areas receive more than 508 mm (20 in) of precipitation per year, while small areas of the Chinchaga and Peace River valleys receive less than 406 mm (16 inches).

The area is snow covered from the end of October to the end of April (Potter, 1965, charts 2 and 5). At Fairview, the mean January, July, and annual temperatures are -16.4°C, 16.9°C, and 1.1°C respectively (Canada Department of Transport, 1967). The potential evaporation, estimated from maps by Bruce and Weisman (1967), exceeds the mean annual precipitation and also the monthly means from May to October.

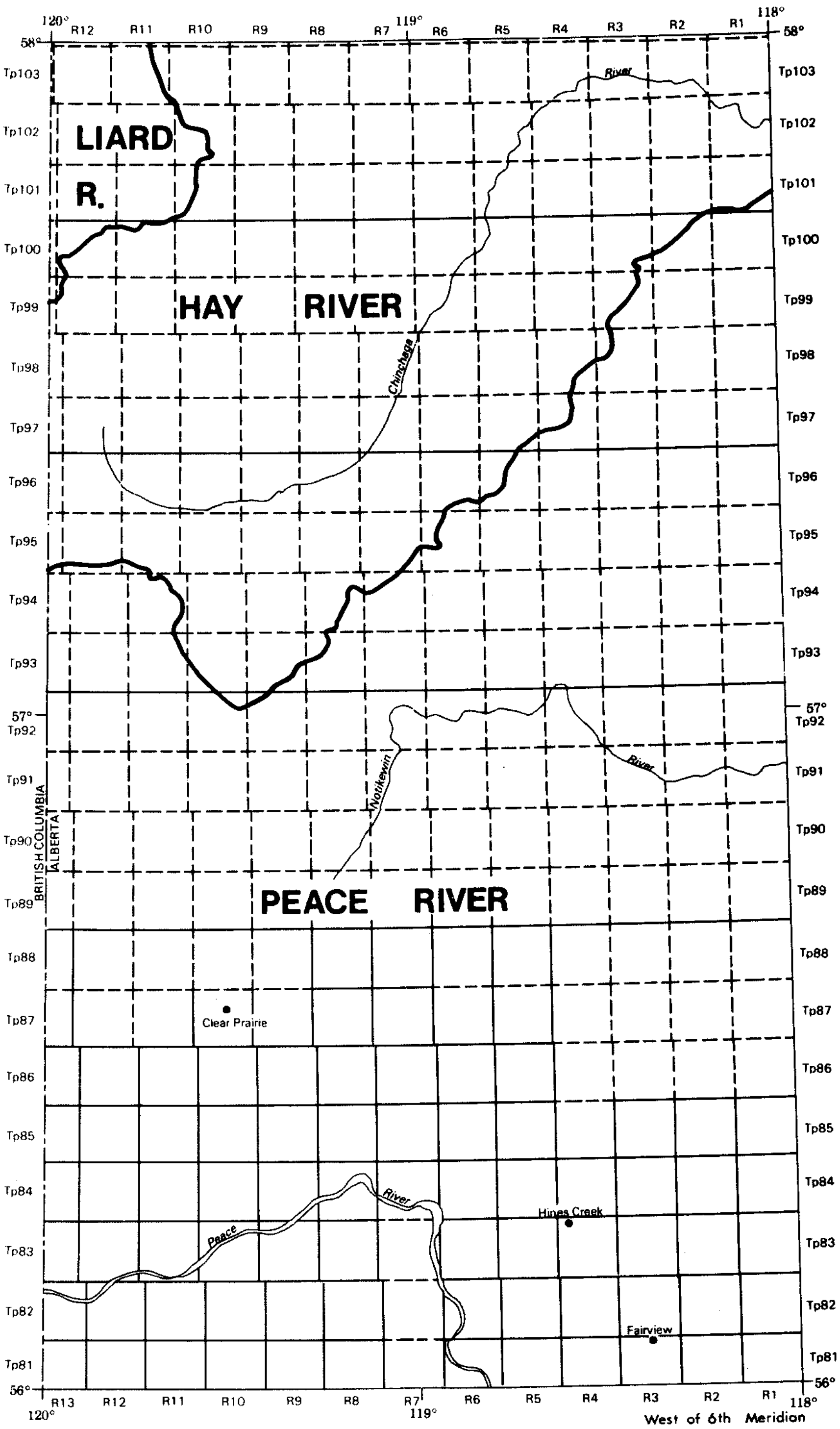

FIGURE 1. Sketch map of the main drainage basins, Clear Hills-Chinchaga River area, Alberta

GEOLOGY

Geological investigations in the map area began in the last century (Dawson, 1881). The geology of the southernmost part of the area was investigated by Rutherford (1930), and that of the remaining part in greater detail by Green and Mellon (1962). Iron ore occurrences are discussed by Kidd (1959) and Mellon (1962). Soil surveys were performed by Lindsay *et al.* (1958) and Reeder and Odynsky (1965).

BEDROCK GEOLOGY

The bedrock geology of the area is represented on a 1:1 000 000 scale side map and also on the four profiles. Borehole data (including electric logs and lithologs) and information from published literature were used to construct the maps and profiles. Most data were generated by hydrocarbaon prospecting or geophysical operations. Bedrock outcrops are limited to stream cuts, slump scars and the like.

The geological side map and some formation descriptions are based primarily in the "Bedrock geology of Alberta" map (Green *et. al.,* 1970), which projects rock-unit boundaries to the land surface. The present geological map, however, shows subcrop boundaries. These different methods cause differences between the two maps where drift cover is thick. Also, on the geology side map, the lower sandstone member of the Kaskapau Formation (K_{kl}) is differentiated and the lower and upper members of the Shaftesbury Formation are shown to be separated by the base of the fish scales marker horizon.

The oldest (and the only Paleozoic) beds shown on the profiles are the Lower Mississippian limestones and shales of the Banff Formation. The topography and stratigraphy of the top of the Paleozoic (the pre-Cretaceous erosional surface) shown on the geology side map is based on Energy Resources Conservation Board maps (1963, 1973).

Only Cretaceous strata exist between the pre-Cretaceous erosional surface and the Tertiary-Quaternary unconsolidated surficial deposits. The base of the fish scales marker horizon is interpreted as the boundary between the Lower and Upper Cretaceous deposits. The pre-Cretaceous erosional surface dips nearly 20 m/km (100 ft/mi) to the southwest. The dip of the rock units lying immediately above this surface (Bluesky-Gething Formation) is the same, but the dips of units higher in the stratigraphic column become milder: the base of the fish scales horizon dips about 5 m/km (25 ft/mi). The Upper Cretaceous formations have dips of lower angles (depending on local conditions) and perhaps of different directions.

The following brief description of the bedrock units is based mainly on Green *et al.* (1970).

Bluesky-Gething Formation: 3 to 50 m (10 to 150 ft) of sandstone, silty sandstone and shale, deposited over the pre-Cretaceous erosion surface and its depressions, rising above mean sea level only in the northeastern part of the area.

Loon River Formation: dark gray fossiliferous silty shale and laminated siltstone, ironstone nodules and partings; marine. It is about 200 m (600 ft) thick under the Clear Hills.

Peace River Formation: marine. This unit is present in the southern two-thirds of the area and is best developed to the south where its three members are differentiated on the profiles. The Notikewin Member (lower) consists of fine-grained glauconitic sandstone with silty interbeds and is 30 m (100 ft) thick. The Harmon Member (middle) comprises 15 m (50 ft) of dark gray silty shale. The Cadotte Member (upper) is fine-grained quartzose sandstone and is 60 m (200 ft) thick. This formation thins to the north as the Cadotte Member shales out and the Harmon Member pinches out. The top of the Peace River sandstone is the top of the Cadotte Member to the south and of the Notikewin Member in the central part of the map area.

Shaftesbury Formation: dark gray fish scale bearing shale, silty in the upper part; numerous nodules and thin beds of concretionary ironstone; bentonite partings; interbedded locally in the lower part with silty and sandy intervals; marine. The formation is about 250 to 450 m (750 to 1350 ft) thick. The Shaftesbury Formation is the oldest known outcrop (or even subcrop) in the area. The base of the fish scales marker horizon, regarded as the boundary between the Upper and Lower Cretaceous, divides the Shaftesbury Formation into two members, the lower one being somewhat thicker. Structure contours of the base of the fish scales (modified after Energy Resources Conservation Board, 1969) are shown on the geology side map.

Dunvegan Formation: gray fine-grained feldspathic sandstone with hard calcareous beds, laminated siltstone and gray silty shale; deltaic to marine. The formation is 140 to 180 m (450 to 600 ft) thick where it has remained intact; at places, however, it has been partly or entirely eroded.

Kaskapau Formation: dark gray silty shale, ironstone partings, interbedded in lower part with fine-grained quartzose sandstone and thin beds of ferruginous oolitic mudstone; marine. The lower member of this formation consists mainly of sandstones. It is differentiated on the geology side map and on the profiles, except in the northernmost part of the area where the data are too sparse. The top of the Dunvegan Formation (including the Kaskapau Formation, Lower Member) is contoured on the geology side map.

Bad Heart Formation: fine-grained quartzose sandstone, ferruginous oolitic sandstone and mudstone; marine. Restricted in extent and thickness; a 5 to 15 m (15 to 45 ft) thick occurrence is shown on profile C-C′.

Puskwaskau Formation: dark gray fossiliferous shale, silty in upper part; marine. Occurs only in the higher hills of the area where its uneroded thickness is about 60 to 120 m (200 to 400 ft).

Wapiti Formation: gray carbonaceous feldspathic sandstone, silty shale, bentonite; thick coal beds; nonmarine.

BEDROCK TOPOGRAPHY AND SURFICIAL GEOLOGY

The bedrock topography investigations of Jones (1966, Fig. 16) cover a part of the area. A bedrock topography side map of the Clear Hills (84D) area (southern half of the entire mapping area) accompanies the hydrogeology map. Most of the basic data were collected by V. A. Carlson.

Bayrock states (in Lindsay *et al.*, 1958) that the present general topography of the northern and central part of the area is similar to the preglacial topography. Present and preglacial topography, however, are different along parts of the southern margin of the area. The buried Shaftesbury channel contains 200 m (600 ft) of fill and between the Hines Creek and the mouth of the Montagneuse River is entirely masked by surficial sediments.

The thickness of the surficial sediments on the hilltops and plateaus is known only at a few points, and varies between 5 and 50 m (15 and 150 ft). The surficial sediment cover is thin over the slopes of the upland and is 30 to 50 m (about 100 to 150 ft) thick in the valleys. The Peace River Lowland has uneven surficial sediment cover varying from 5 to 100 m (15 to 300 ft).

The surficial geology of the area is only generally known. Preglacial unconsolidated gravels were identified on the higher hills by Green and Mellon (1962).

Tokarsky (1967) describes three levels of buried sand and gravel in the Grimshaw area, which neighbors the mapping area to the southeast. The same levels were recognized within the area by Yoon (1973):

1. "Grimshaw gravels," pebble-sized, well sorted, well rounded, mainly quartzite gravels with interbedded sands 15 to 30 m (50 to 100 ft) thick;
2. intermediate level sands and gravels with interbedded clays, sporadically distributed;
3. deeply buried channel deposits with sand and gravel, but mainly consisting of clay and silt.

The Grimshaw gravels seem to be preglacial. The intermediate level might represent terraces along deep (and now buried) channels. The intermediate and deep channel deposits contain some glacial materials, but their deeper parts might be preglacial. The sand and gravels, where shown on the profiles, are marked as "Tertiary and/or Quaternary sands and gravels" (TQsg) without any attempt at separation. These sands and gravels are very silty or clayey in several parts of the area.

Most of the area is covered by glacial deposits, mainly till of ground or hummocky dead-ice moraine. Glaciolacustrine deposits, mainly clay and silt with rafted debris, are widespread and sometimes thinly cover the till (Bayrock, in Lindsay *et al.*, 1958). Outwash deposits of well-sorted sands with pebble lenses were oberved in the northwest part of the area and in the valleys of the Notikewin and Whitemud Rivers (Green and Mellon, 1962).

Recent alluvium is found along the streams, those of the islands and shoals of the Peace River deserve mention as aquifers. Peat and organic soil accumulate on the hills.

HYDROGEOLOGY

DATA USED IN MAP PREPARATION

Altogether 6255 data points were used in the preparation of the various maps and profiles. The distribution of the geological and especially the hydrogeological data is very uneven. In some northern and central areas, observation and sampling of the surface phenomenon were the main data sources.

The hydrogeological map is based on 994 data points. These include 27 springs and surface features, 22 wells with yield data, 34 dugouts or wells with water levels, and 911 wells and testholes with stratigraphic data, electric and/or lithologs only.

The bedrock topography side map of the Clear Hills (84D) area was constructed using 3647 data points. The chemical analyses of 1614 water samples were considered for the chemistry representations. Samples collected during the field work include 59 for major ion, 44 for trace elements, and 44 for isotope analysis. The Groundwater Department files included 25 additional shallow groundwater analyses; 1442 deep formation water analyses were available.

The scale of the hydrogeological map, the bedrock topography map, and the horizontal scales of the profiles are 1:500 000. This scale best suits the available data density and the local topography. The scale of the side maps is 1:1 000 000.

AQUIFER LITHOLOGY

The generalized lithology of each rock unit is represented on the hydrogeological profiles. The generalized lithology of the best aquifer within the uppermost about 300 m (1000 ft) is shown on the main map.

DISCHARGE FEATURES

Groundwater discharge in the area is mainly diffuse: the groundwater feeds surface waters (streams, lakes, muskegs) or is consumed by phreatophytic vegetation. There are only a few typical springs (that is, pointlike concentrated groundwater discharge sites) in the area. Pooled springs form a transition between typical springs and groundwater-fed ponds and lakes.

Slumps are often associated with groundwater discharge. There are numerous slumps along the slopes of the deep valleys of the Peace River and its tributaries and a few along the steep slopes of the uplands. The slumps around the Clear Hills seem to be more or less stabilized. Groundwater often seeps, trickles, or flows from the slump sites which can be considered as special kinds of springs. A pool, or backpond, of water often forms in depressions behind slump blocks. This backpond may be fed by groundwater, precipitation, surface water, or a combination of all three. Slumping promotes oxidation of the mineral content of the rocks by breaking up the beds and exposing greater rock surface areas to air and oxygen-rich water. The dark shales and tills of the area contain reduced sulfur. Slumping in these rock materials results in sulfur oxidation, so the discharging water contains sulfate. Mineral precipitates are often present on fragment surfaces and in the joints, cracks, and bedding of the slumping or exposed shale. Groundwater outflow at the slump sites may be secondarily enriched in mineral content by dissolving such precipitates.

Semi-diffuse discharge features of the area are the quasi-springs: muskegs with an outflow or springs masked by muskeg (Ozoray, 1974). Their water is often low in total dissolved solids, ($\geq$20 ppm). Nitrate might be a relatively significant anion in the waters with very low dissolved salt content. Cation-anion imbalance may indicate the presence of organic acids and colloides. An example for the special chemistry of the muskeg waters is discussed in the section on "Hydrochemistry."

Examples of groundwater discharge features follow:

There is an interesting iron-depositing cold spring on the plateau of the Clear Hills (Lsd 15, Sec 30, Tp 88, R 9, W 6th Mer) at an altitude of 1050 m (3440 ft) amsl. The bedrock (Wapiti Formation) is overlain by drift. The area is covered by conifer forest, and the actual spring-site is surrounded by moss and sedge. The spring discharges from the top of a mound about 30 m (100 ft) in diameter and 3 m (10 ft) high. The yield was about 0.75 L/s (10 igpm). The water temperature was 2.3°C (August 14, 1978, air temperature 20°C). The low temperature in late summer indicates discharge from a deeper local flow system, or contribution of melting ground ice, or both. The low total dissolved solids content (108 mg/L) and calcium-magnesium bicarbonate chemical type of the spring water is consistent with water of a local groundwater flow system in sulfur-poor rocks and ground ice-melt contribution. The outlet and the surrounding area are rust red from an ochre-like mineral deposit that forms either a soft mass or miniature dams and pools resembling rimstone. The chemical composition of the mineral matter is as follows (analyzed in the laboratory of the Alberta Research Council, by J. Nelson):

constituent	Si	Al	Fe	Ca	Mg	K	CO_2	S
percent	2.1	<0.1	47.5	0.8	0.1	<0.1	1.3	0.1

X-ray investigation of the larger than clay-size fraction was done by D. Scafe of the Alberta Research Council. Crystalline minerals were not found, which suggests the presence of amorphous iron hydroxide.

Several springs in the lowlands discharge from buried or outcropping sand and gravel. A series of crescent-shaped ponds cover a gravel outcrop near Whitelaw. A 10 m (30 ft) diameter and 3 m (10 ft) deep pond was sampled in Lsd 2, Sec 36, Tp 81, R 1, W 6 Mer, at an elevation of 625 m (2050 ft) amsl. The pond had clear water, a reddish-yellowish algal bottom, and a water temperature of 14.8°C (on August 12, 1978, at an 18°C air temperature). Total dissolved solids content was 272 ppm of calcium-magnesium bicarbonate character. These data suggest that the discharge pond is fed by a short, local flow system. Some springs, discharging from sand and gravel, are described in the literature (Jones, 1966; Alberta Department of the Environment, 1971).

Small groundwater-fed ponds in the valleys of the upland usually form sets of crescent-shaped ponds or pools, have red or yellow algal bottoms, often deposit minerals, and have a more or less strong hydrogen sulfide (rotten egg) smell. Water chemical type varies from sodium bicarbonate to sodium sulfate. Total dissolved solids content varies from about 900 to 3200 mg/L. A typical example is located in Lsd 5, Sec 10, Tp 92, R 1, W 6 Mer, at an elevation of about 625 m (2060 ft) amsl.

Groundwater-fed ponds and lakes are common all over the area. A good example of a groundwater-fed small lake is in the upland (Lsd 11, Sec 17, Tp 102, R 10, W 6 Mer) at an elevation of about 845 m (2770 ft) amsl. It has surface outflow but no visible inflow and is surrounded by muskeg and spruce forest. The water temperature was 9.9°C on August 20, 1978 (16°C air temperature); the water type was magnesium bicarbonate and the total dissolved solids content was 94 mg/L.

A spring on the left bank of the Peace River (Lsd 3 and 4, Sec 13, Tp 84, R 7, W 6 Mer; 395 m [1300 ft] amsl) has features of both contact springs and slump-seepages. There is a small terrace of heavily slumped dark Shaftesbury shale; the scar above it is formed by about 3 m (10 ft) of rust colored gravel, 1.5 m (5 ft) of yellow sand, and 25 m (75 ft) of till. About 0.15 L/s (2 igpm) of water trickles from the slumping gravel. This sun-warmed water (16.8°C water and 26°C air temperature on August 11, 1978) is a sodium bicarbonate-sulfate type with a total dissolved solids content of 1164 mg/L (see Table 1 and Fig. 2).

GROUNDWATER LEVELS AND FLOW SYSTEMS

Groundwater level contours were not constructed because of lack of data. Some flow lines are shown on the profiles and on the map. Chemical and pressure data, lithology of the aquifers, and topography were used to delineate these flow lines.

Water wells are situated mainly in the southeastern corner of the area. The water level in these wells varies from 3 to 30 m (10 to 100 ft) below the land surface. A few flowing shotholes have been reported in different parts of the area, but flowing water wells are not known.

The presence of muskeg indicates that the groundwater table is very near to the surface. Although locally this may mean only a perched water table, the abundance of muskegs is considered to indicate that the greater part of groundwater movement occurs in the upper 1 to 3 m (3 to 10 ft) of the soil (mostly organic deposits). The very shallow nature of flow is due to extensive periods of soil frost. Such a groundwater movement is mainly parallel to the surface in contrast to the steeply descending and ascending limbs of the normal groundwater flow systems. The elongated crescents of ribbed fens or other solifluction phenomena are sometimes noticeable on the surface.

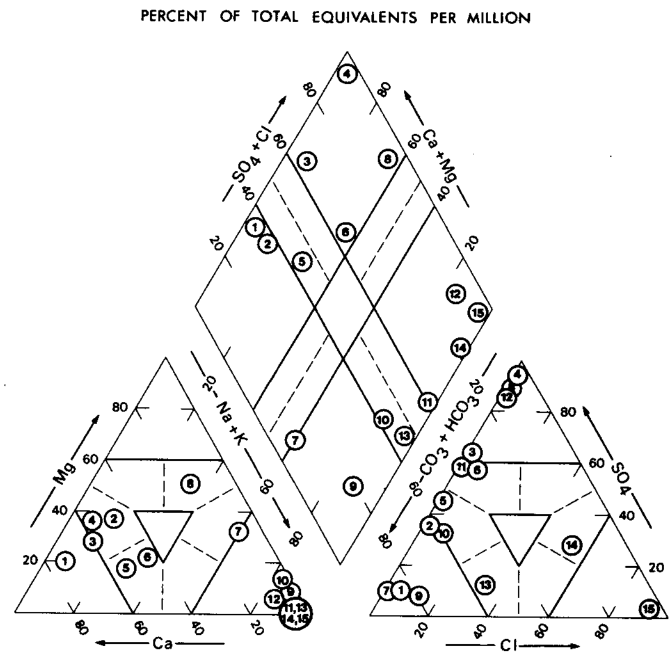

FIGURE 2. Chemical character of selected water samples, Clear Hills - Chinchaga River area, Alberta

HYDROGEOLOGICAL PROFILES

Four hydrogeological profiles were constructed. Stratigraphy, generalized aquifer lithology, generalized flow directions, groundwater chemistry, important observation points (wells, springs, testholes), and 20-year safe yields are shown on the profiles. The horizontal scale is 1:500 000; the vertical scale is 1:12 192, and the vertical exaggeration is about 40 times. Individual aquifers within the important rock units are not differentiated on the profiles. The color coded main map shows the sum of the yields of the formations in the upper 300 m (1000 ft); however, because of the logarithmic scale of the yield categories, these are essentially equal to the yield of the most productive unit.

TABLE 1.
List of water samples shown on Figure 2

Serial No.	Location Lsd Sec Tp R W of 6 Mer	Surface Elevation m (ft) amsl	Sampled depth or interval m (f) below surface	Geological symbol	Sampled formation and its lithology	Origin of sample	Total dissolved solids mg/L	Chemical type
1	12-32-83-3-6	665 (2175)	-8 (-24)	Q	Quaternary sand	well	220	Ca/HCO_3
2	4-36-81-1-6	640 (2100)	surface	Q	Quaternary sand and gravel	spring	178	$Ca\text{-}Mg/HCO_3$
3	1-27-82-2-6	675 (2215)	-19 (-62)	T Qsg	Tertiary and/or Quaternary gravel	town well	456	Ca/SO_4
4	11-7-89-2-6	745 (2450)	shallow	Q/K_k	Quaternary sand and silt over Kaskapau shale	handpumped well	2372	$Ca\text{-}Mg/SO_4$
5	2-23-102-5-6	490 (1600)	surface	--	----	Chinchaga River	204	$Ca\text{-}Na/HCO_3\text{-}SO_4$
6	9-25-86-9-6	640 (2100)	-12 (-40)	Q	Quaternary till	well	110	$Ca\text{-}Na/SO_4\text{-}HCO_3$
7	10-30-98-7-6	695 (2280)	surface	Q	Quaternary till	dugout	312	$Na\text{-}Mg/HCO_3$
8	16-33-81-2-6	650 (2125)	-15 (-50)	Q/K_k	Quaternary sand over Kaskapau shale	well	8984	$Mg\text{-}Na/SO_4$
9	7-13-100-7-6	715 (2340)	surface	Q	Quaternary silt and peat	discharge pond	892	Na/HCO_3
10	3-13-84-7-6	395 (1300)	surface	Q	Quaternary gravel	spring	1164	$Na/HCO_3\text{-}SO_4$
11	12-11-96-1-6	650 (2125)	surface	Q/K_d	Quaternary sand and silt over Dunvegan sandstone	discharge pond	2080	$Na/SO_4\text{-}HCO_3$
12	13-31-86-5-6	670 (2200)	55-98 (180-320)	K_d	Dunvegan sandstone	well	4816	Na/SO_4
13	6-35-85-3-6	786 (2579)	713-719 (2340-2358)	K_l	Loon River shale under Notikewin sandstone and siltstone	shut-in gas well	1771	$Na/HCO_3\text{-}Cl$
14	10-25-102-4-6	500 (1645)	442-450 (1450-1475)	K_b	Bluesky sandstone	shut-in gas well	10 271	$Na/Cl\text{-}SO_4$
15	14-24-82-9-6	707 (2320)	646-659 (2120-2162)	K_{pc}	Cadotte sandstone	shut-in gas well	29 341	Na/Cl

Remarks:

The serial numbers are consistent with those on Figure 2.
The geological symbols are those shown on the hydrogeological profiles.
Chemical symbols are:
Ca — calcium; Mg — magnesium; Na — sodium; HCO_3 — bicarbonate; SO_4 —sulfate; Cl — chloride

GROUNDWATER PROBABILITY

The total available 20-year safe yield from the upper 300 m (1000 ft) is shown on the main map by color coded areas. The 20-year safe yields of individual rock units are indicated by color on the hydrogeological profiles. "Probable" yields, estimated from qualitative information such as lithology, electric logs, topography, and surface phenomena, are represented by pale colors.

Yields of over 8 L/s (100 igpm) may be expected in small patches from the sand and gravel islands, shoals, and alluvial deposits of the Peace River. These yields are made possible by induced infiltration. Yields of 2 to 8 L/s (25 to 100 igpm) are expected from sands and gravels in the southeastern corner of the area near Whitelaw, and in small areas in the Clear River valley and north of the Chinchaga River. The town well No. 1 of Fairview was pump tested in 1962 under the supervision of the Alberta Research Council (Jones, 1966); a 20-year safe yield of 16.5 L/s (217 igpm) was determined. A much smaller pumping rate of 1.14 L/s (15 igpm) rate was proposed by R. J. Clissold in a consultant's report in 1969. Considering these and other (such as springs) data, a value of 2 to 8 L/s (25 to 100 igpm) was chosen to represent these aquifers.

Yields of 0.4 to 2 L/s (5 to 25 igpm) are expected from sand and gravel at Eureka River (Znak, 1975) and in the lower Chinchaga and Keg River valleys. A yield of this magnitude is also possible from Dunvegan sandstone along the northeastern margin of the area.

Yields of 0.1 to 0.4 L/s (1 to 5 igpm) are expected over most of the area from the Dunvegan sandstone and (generally) from the surficial deposits.

Less than 0.1 L/s (1 igpm) is expected in several small patches of land or elongated belts where the Dunvegan Formation was proven to be barren, does not exist, or is deeper than 300 m (1000 ft). Surficial sediments also have low yields where they are thin or clayey. This is the situation along the steep slopes of the Clear Hills and Naylor Hills, the deep-cut valleys of the Peace River and its tributaries, and at several places in the lowlands.

The Mississippian limestones are not color coded on the profiles because the yield of limestones varies so much that they cannot be characterized without detailed study. Massive limestones can be without effective porosity and could be classified as yielding less than 0.1 L/s (1 igpm). Fractures in limestones, especially fractures that are expanded by solution (karstic limestone), might considerably increase the yield. Northern Alberta has numerous known examples of capricious yields from limestone.

The Loon River, Shaftesbury and Puskwaskau Formations, the Kaskapau Formation (except its separately represented lower member), the Harmon Member of the Peace River Formation (and the Cadotte Member in the central part of the area) are composed of shale and a 20-year safe yield of less than 0.1 L/s (1 igpm) is predicted from them.

The Bluesky-Gething Formation, the Notikewin, and (in the southern part of the area) the Cadotte Members are composed of sandstone or sandstone and siltstone. Hydrocarbon prospecting drilling indicates that they contain some water. Sandstone in these units, however, is usually of low porosity. As an areal average, a 0.1 to 0.4 L/s (1 to 5 igpm) 20-year safe yield is predicted for these units. They are, however, not practical aquifers as they are located too deep and contain water of undesirable chemical quality.

The Dunvegan Formation-Lower Member of the Kaskapau Formation (considered here as one hydrogeological unit) constitutes the major bedrock aquifer in the area. It is about 180 to 230 m (600 to 750 ft) thick and contains abundant sandstone beds. The sandstone is, however, fine grained with little porosity and is interbedded with hard calcareous beds and shale. The subcrop belt of the Dunvegan-Lower Kaskapau beds does not show high discharge to the surface. Considering this information, and comparing it to observations elsewhere in northern Alberta, a yield of 0.1 to 0.4 L/s (1 to 5 igpm) is predicted for the Dunvegan-Lower Kaskapau in most of the area. Higher yields were measured in some sandstone beds at the top of the Dunvegan Formation in the neighboring Bison Lake (84F) area (Tokarsky, 1972). These higher yielding beds do not seem to extend far into the current mapping area. The Dunvegan beds seem to be drained and practically dry near the deep valley cut of the Peace River and its tributaries. They also proved to be barren at some test sites (see C-C′ and D-D′ profiles). These parts of the Dunvegan Formation are coded as having yields of less than 0.1 L/s (1 igpm).

The Wapiti Formation also contains sandstones and is expected to supply 0.1 to 0.4 L/s (1 to 5 igpm). It is probably drained along the steepest slopes of the Clear Hills (see C-C′ profile).

HYDROCHEMISTRY

A side map of the chemistry of the near-surface (mainly drift) groundwater and of the groundwater fed surface waters was constructed at a scale of 1:1 000 000. The variation in chemical composition in vertical and horizontal directions is shown on the profiles.

Three general trends of groundwater chemical type distribution are noticeable in Alberta:

1. calcium-magnesium waters changing along the flow path to sodium bicarbonate waters are often found in shallow, local flow systems with little available sulfate supply;
2. sodium sulfate waters are often found in similar systems where sulfate minerals are abundant;
3. sodium chloride waters are found in deep, regional systems.

There are, however, some differences from this general pattern in the Clear Hills-Chinchaga River area. There are some nitratic waters of very low total dissolved solids content in the area. They are stored or moving in organic deposits (muskeg, peat). The brownish water of a pool in a ribbed fen (Lsd 9, Sec 24, Tp 95, R 7, W 6 Mer; 980 m, 3220 ft amsl), for instance, contains mixed cation (neither cation reaches 40 percent) bicarbonate-nitrate type water. This water contains only 20 mg/L total dissolved solids, and the epm% of nitrate is 33.8.

Sulfate minerals are readily available for dissolution in groundwater in most parts of the area. Consequently, the trend of chemical change in the local and intermediate flow systems of these parts of the area is:
calcium bicarbonate → calcium sulfate → sodium sulfate.

The sodium bicarbonate stage does not develop. Before a considerable quantity of sodium can be picked up, the predominant anion is already sulfate.

Some characteristic chemistries are shown on Fig. 2 on a modified Piper diagram and are listed in Table 1. The directions of the chemical changes can be followed on the diagram by connecting the relevant numbered points on both of the triangles:

1. from calcium bicarbonate to sodium bicarbonate: 1→ 9;
2. from calcium bicarbonate to sodium sulfate: either 1→5, 6→12, or 1→3→6→ 12;
3. from calcium or sodium bicarbonate, or sodium sulfate to sodium chloride: 1 or 9→ 13→ 15, or 12→ 14→ 15.

It must be noted, however, that the samples represent different flow systems; sample No. 5 was taken from a stream (the Chinchaga River) for the sake of comparison.

The deep formation water of the area is characteristically a sodium chloride (common salt) brine. Total dissolved solids content is usually very high. Sample No. 15, taken from Cadotte sandstone, for example, contained 29 341 mg/L total dissolved solids.

The Red Earth region, about 160 km (100 mi) east from the Clear Hills area, was investigated by Tóth (1978). He found three superimposed hydrodynamic zones. Cross-formational flow did exist throughout the entire profile but pressure conditions, groundwater chemistry, and recharge conditions were different for each hydrodynamic zone.

Formation water chemistry, as represented on the profiles, makes it reasonable to assume that a similar situation may exist in the Clear Hills - Chinchaga River area. Only the upper hydrodynamic zone (surficial deposits and Upper Cretaceous) discharge groundwater to the surface within the area, while the basal zone (Bluesky-Gething sandstone and Mississippian limestone) does not. The middle zone (Peace River Formation) seems to be separate in the upland areas but perhaps is not distinct from the upper zone in the southeastern part of the area.

These considerations explain the hydrochemical picture represented on the profiles and the chemistry side map. The water of the local flow systems in the upland drift is predominantly of calcium bicarbonate chemical type with low total dissolved solids content: the map shows that this water covers most of the central and northern parts of the area. Local and intermediate flow systems in shale (especially in slumped, weathered shale), shale and sandstone, and silty lowland drift discharge calcium or sodium sulfate chemical type of water with high total dissolved solids content. This type of water is commonly found in the southern part of the area. Fresher water is found in the less silty Tertiary-Quaternary sands and gravels. Extrapolation of data from outside the map area indicates that sodium bicarbonate chemical type groundwater is also present along the southern margin of the area.

CONCLUSIONS

The best aquifers in the area are the isolated occurrences of alluvial sands and gravels along the Peace River where production could be enhanced by induced infiltration. These aquifers, however, are of little practical importance because of their geographic isolation in an unpopulated deep valley flanked by steep slopes. The best practical aquifers in the area are the less silty bodies of Tertiary and / or Quaternary sands and gravels. Yields of 2 to 8 L / s (25 to 100 igpm) can be expected from these sands and gravels at Whitelaw and near the Clear River, and yields of 0.4 to 2 L / s (5 to 25 igpm) at Eureka River. The surficial sediments are expected to yield 0.1 to 0.4 L / s (1 to 5 igpm). They form a thin cover on the steep slopes of the upland and may be more or less eroded away from the high banks of the Peace River. In some parts of the lowland, even 0.1 L / s (1 igpm) yields are not possible from surficial sediments.

The bedrock formations are not promising aquifers in the area. The Wapiti Formation and most of the Lower Kaskapau-Dunvegan Formations are likely to yield 0.1 to 0.4 L / s (1 to 5 igpm). At several places in the lowland, the Lower Kaskapau-Dunvegan proved to be barren. The sandstones of the Peace River and Bluesky-Gething Formations are too deep to be practical aquifers. The Mississippian limestones are both too deep and untested.

The chemical quality of the shallow groundwater is good over most of the central and northern part of the area: it generally contains less than or slightly more than 500 mg / L dissolved salts and is of calcium or sodium bicarbonate type. Such waters can be found in the populated southern part only in isolated locations. Fortunately, the areas of high yield usually coincide with those of better chemical quality. The groundwater in the southern part of the area generally contains high sulfate concentrations and the total dissolved solids content often exceeds 2000 or even 4000 mg / L. The waters of the bedrock are of poor quality. Waters of the Dunvegan Formation are of sodium bicarbonate or sulfate chemical character. The deep formation water is of the sodium sulfate or chloride chemical type and contains 10 000 to 30 000 mg / L total dissolved solids.

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MAIN MAP LEGEND

Topography

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

Geology

Geological boundary ....

QUATERNARY

- Qd — Unconsolidated deposits

QUATERNARY AND TERTIARY

- TQsg — Tertiary and/or Quaternary sand and gravel

CRETACEOUS

- Kwt — Wapiti Formation
- Kpw — Puskwaskau Formation
- Kbh — Bad Heart Formation
- Kk — Kaskapau Formation
- Kkl — Kaskapau Formation, Lower Member
- Kd — Dunvegan Formation
- Kshu — Shaftesbury Formation, Upper Member
- Kbfs — Base of the Fish Scales marker horizon
- Kshl — Shaftesbury Formation, Lower Member
- Kpc — Peace River Formation, Cadotte Member
- Kph — Peace River Formation, Harmon Member
- Kpn — Peace River Formation, Notikewin Member
- Kl — Loon River Formation
- Kb — Basal Cretaceous, Bluesky and Gething Formations

MISSISSIPPIAN

- M — Mississippian

Lithology

Sand and gravel ....
Sandstone ....
Shale ....
Shale and sandstone ....
Sandstone and siltstone ....
Limestone ....

Hydrography

Lake or slough, perennial ....
Lake or slough, seasonal ....
Stream, perennial ....
Stream, intermittent ....
Natural pond or water hole ....
Surface water divide ....
Area of noticeable salt precipitates ....

Hydrogeology

Spring, flow rate unknown ....
Spring, flow rate known, L/s (igpm) 1 (15)
Direction of groundwater flow ....

Groundwater Probability†

Range of average expected yield of wells in L/s (igpm)

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

L/s	(igpm)
8 - 38	(100 - 500)
2 - 8	(25 - 100)
0.4 - 2	(5 - 25)
0.1 - 0.4	(1 - 5)
<0.1	(<1)

Boundary of yield area ....

†The indicated average expected yields to wells are predictions based on the best data available at the time of map completion; 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

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

Water well, nonflowing ....
[illegible] depth ....
Alberta Research Council test well .... ARC
Water well, 20-year safe yield calculated from apparent transmissivity ....
Water well, 20-year safe yield calculated from a good bail test or a short pump test ....
Water well, 20-year safe yield calculated from a pump test of sufficient length to reflect regional hydraulic conditions ....
Water well, feature was dry when visited .... D
Shot hole ....
Shot hole, flowed, known depth ....
Dugout or borrow pit ....
Gas well ....
Suspended well, drilled for oil or gas ....
Abandoned well, drilled for oil or gas ....
Structure testhole ....
Depth of testhole ....

Line of hydrogeological profile .... A A′

Hydrochemistry

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

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

Total dissolved solids in milligrams per litre (mg/L):
defined 500
approximate 500

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

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

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

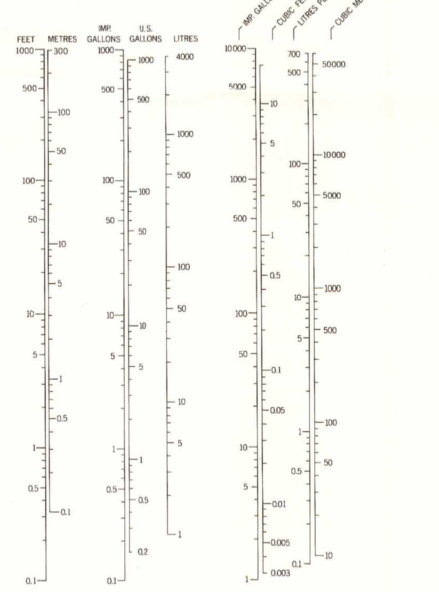
Isogram along which sulfate constitutes 60 percent of total anions*; teeth indicate direction of lesser sulfate content:
defined ....
approximate ....

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

*determined on equivalents per million basis

CONVERSION TABLE

LOGARITHMIC SCALE



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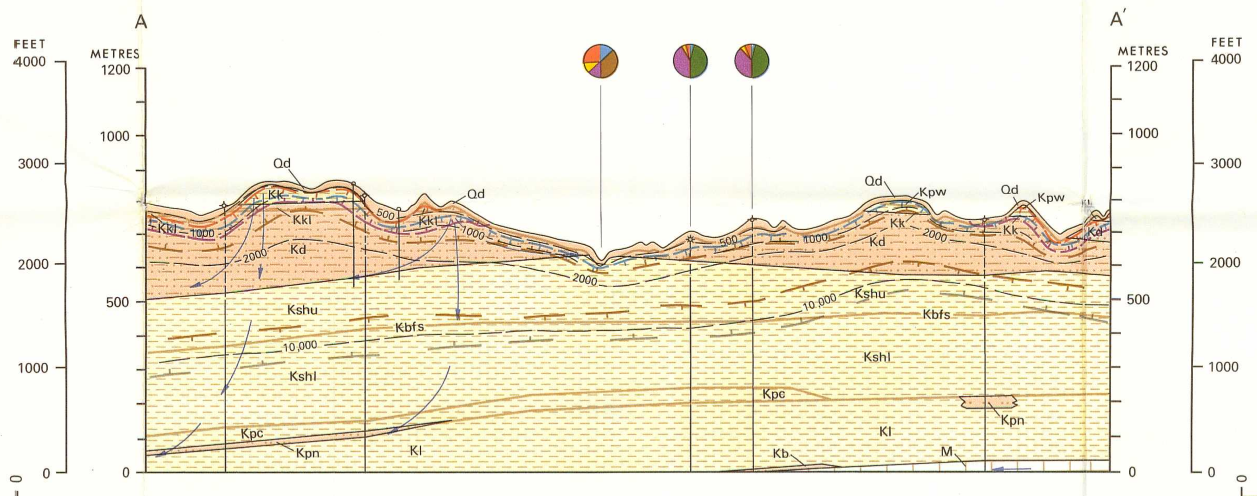
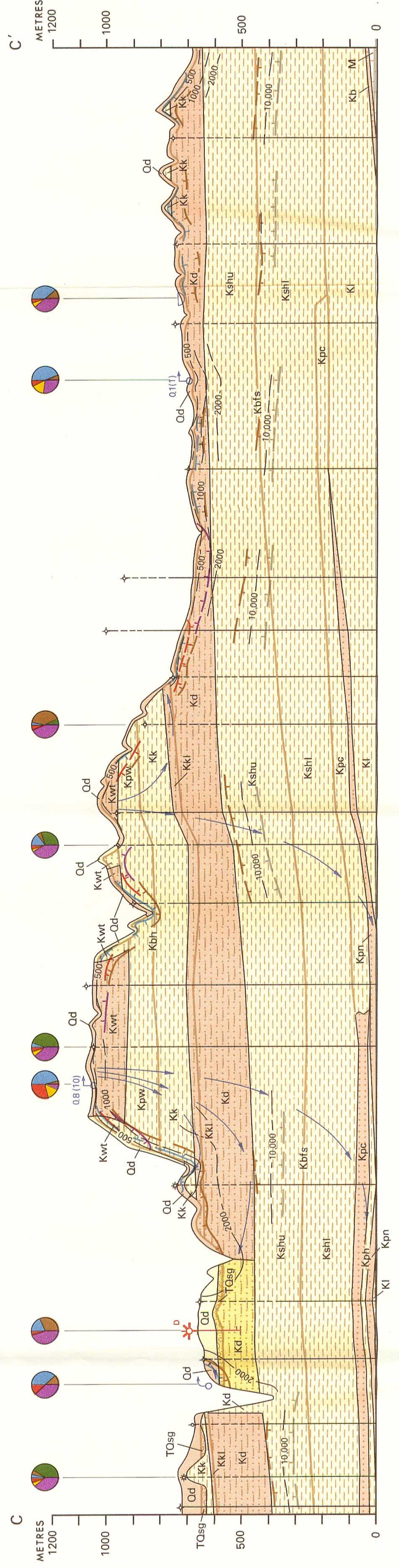
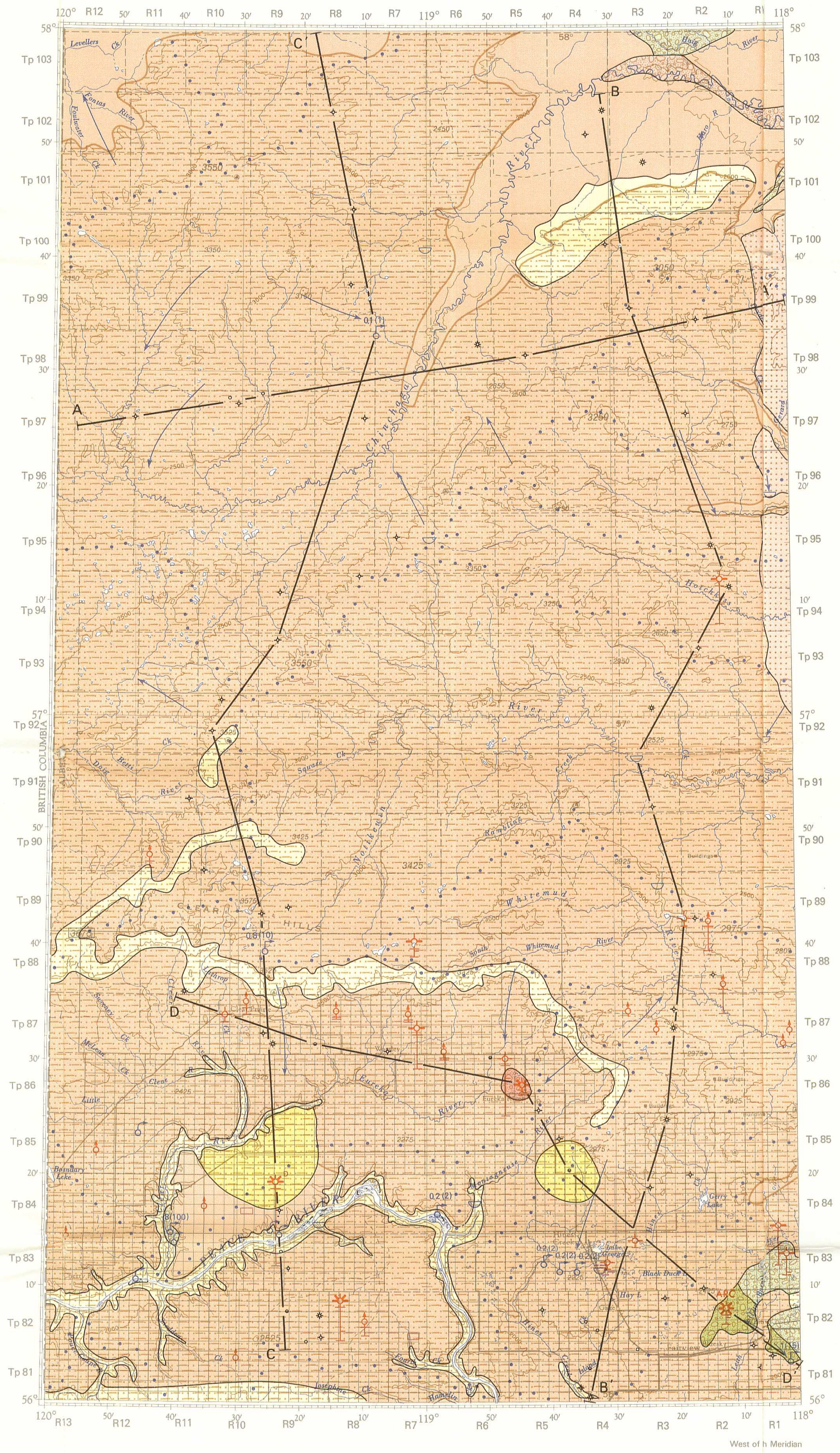
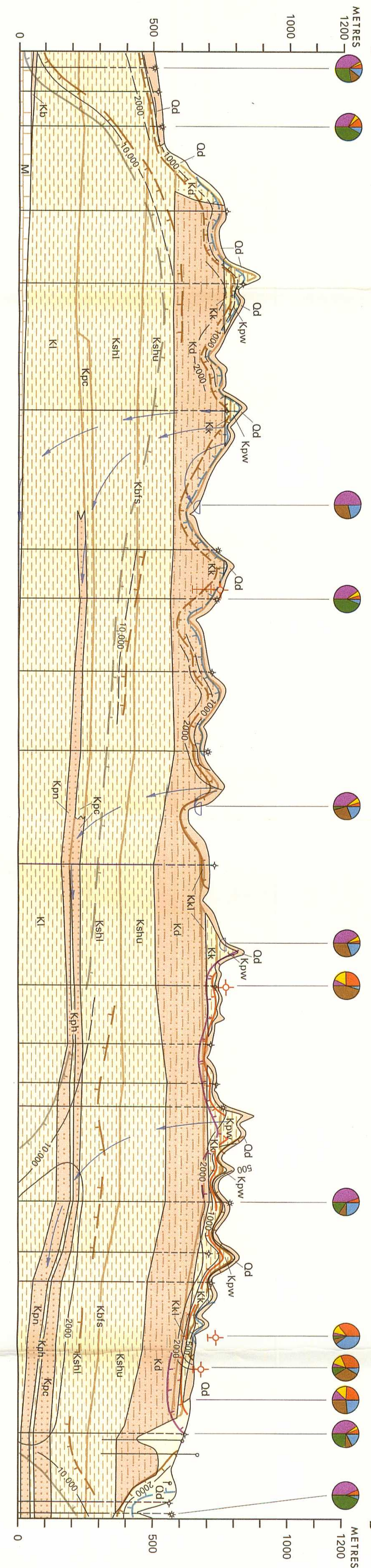
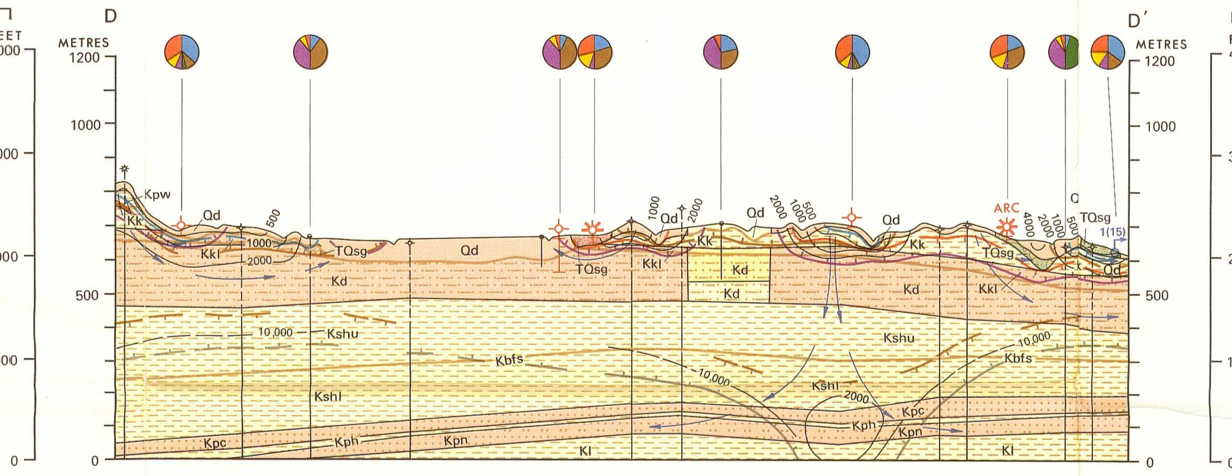
RESEARCH COUNCIL









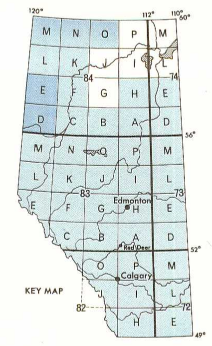


SCALE 1:500,000
Miles 5 0 5 10 15 20 Miles
Kilometres 5 0 5 10 15 20 25 30 Kilometres

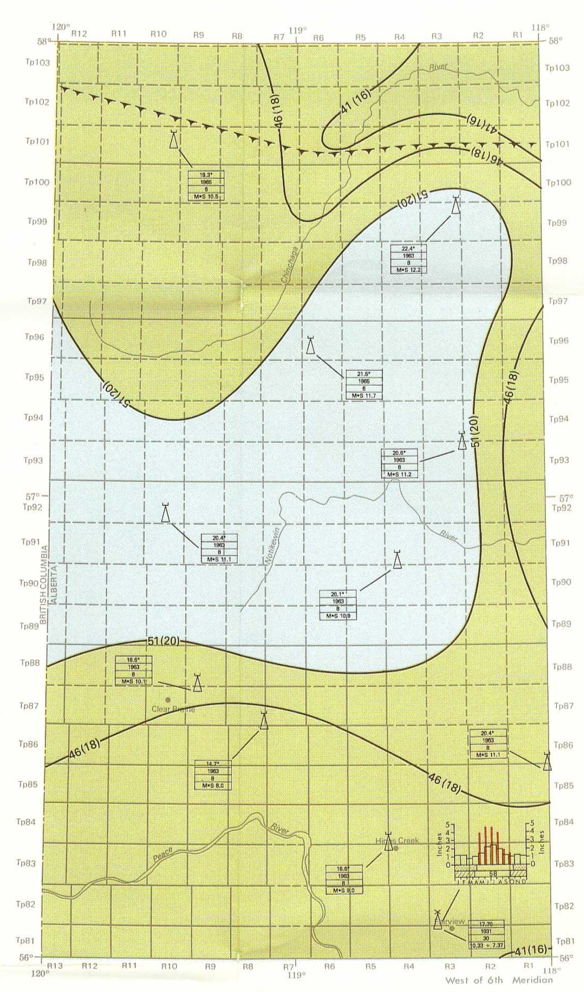
All elevations in feet and metres above mean sea level.
Vertical exaggeration of the hydrogeological profiles is approximately 40X.
An expanded legend and explanatory notes (Earth Sciences Report 72-12) for use with this hydrogeological map series is available from Alberta Research Council, Edmonton, Alberta, Canada.
Map to accompany Earth Sciences Report
Hydrogeology by G. Ozoray.

HYDROGEOLOGICAL MAP
CLEAR HILLS - CHINCHAGA RIVER
ALBERTA

NTS 84 D-E



METEOROLOGY



SCALE 1:1,000,000
Miles 5 0 10 20 Miles
Kilometres 5 0 10 20 30 Kilometres

LEGEND

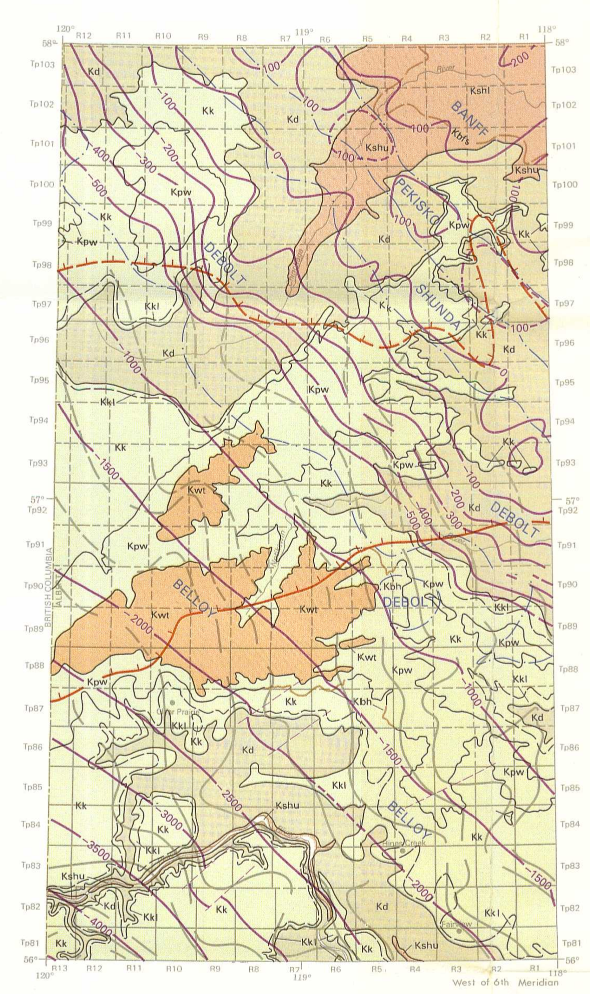
Isohyet, mean annual precipitation in centimetres (inches) .... 56(22)
Boundary of discontinuous permafrost ....
Mean annual precipitation in centimetres (inches):
- 38 to 51 cm (15 to 20 inches)
- 51 to 64 cm (20 to 25 inches)

Meteorological station ....
Standard rain gauge ....
Precipitation data:
Mean annual precipitation in inches* 16.6*
Year of commencement of observations 1963
Number of years of record averaged to determine mean annual precipitation figure 8
May to September precipitation, inches (M-S 12.2)* .... M•S 9.0
precipitation fallen as rain + snow, inches (10.33 + 7.5)* .... 10.33 + 7.37
*estimated

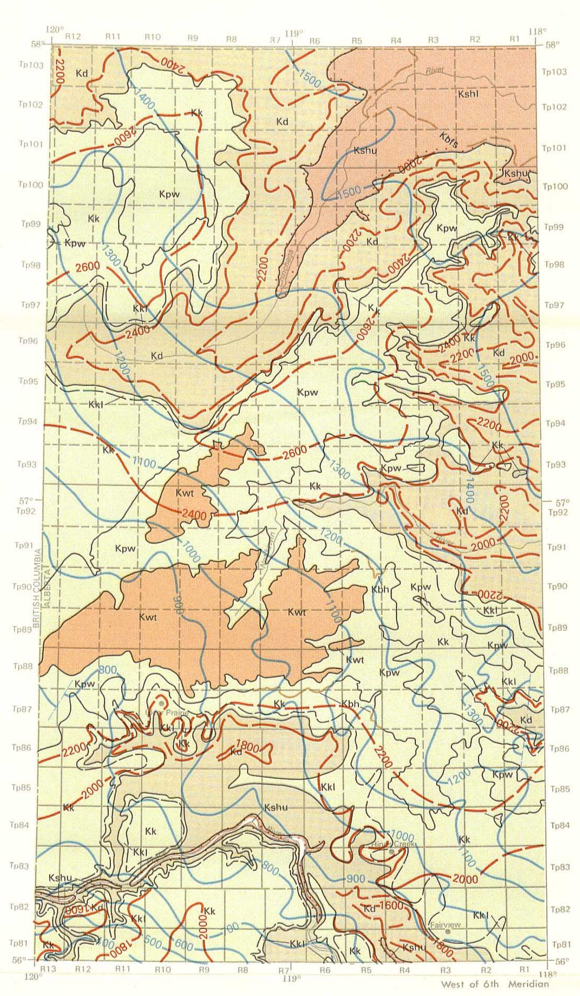
Mean monthly potential evapotranspiration ....
Mean monthly precipitation ....
Period when surface is usually snow-covered ....
Period with mean daily temperatures below freezing ....
Figure indicates percentage of mean annual precipitation falling as rain

Source: The Climate of the Prairie Provinces (Longley, 1972);
Temperature and Precipitation Tables for the Prairie Provinces, Vol. III (Canada Department of Transport, 1967);
Provisional Evaporation Maps of Canada (Bruce and Weisman, 1967);
Snow Cover, Climatological Studies No. 3 (Potter, 1965);
Precipitation Means, Alberta Forestry Stations, May to September, 1963-1970 (Stashko, 1971);
Permafrost in Canada (Brown, 1967)

GEOLOGY I



GEOLOGY II



SCALE 1:1,000,000
Miles 5 0 10 20 Miles
Kilometres 5 0 10 20 30 Kilometres

LEGEND

CRETACEOUS

Wapiti Formation: *grey feldspathic, clayey sandstone; grey bentonitic mudstone and bentonite; scattered coal beds; nonmarine.* (Kwt)

Puskwaskau Formation: *dark grey fossiliferous shale, silty in upper part; marine.* (Kpw)

Bad Heart Formation: *fine-grained quartzose sandstone, ferruginous oolitic sandstone and mudstone; marine.* (Kbh)

Kaskapau Formation: *dark grey silty shale, ironstone partings; marine.* (Kk)

Kaskapau Formation, Lower Member (where separable): *fine grained quartzose sandstone and thin beds of ferruginous oolitic mudstone, interbedded with dark grey silty shale, ironstone partings; marine.* (Kkl)

Dunvegan Formation: *grey fine-grained feldspathic sandstone with hard calcareous beds, laminated siltstone and grey silty shale; deltaic to marine.* (Kd)

Shaftesbury Formation, Upper Member: *dark grey fish scale-bearing shale, silty in the upper part; numerous nodules and thin beds of concretionary ironstone; bentonite partings; marine.* (Kshu)

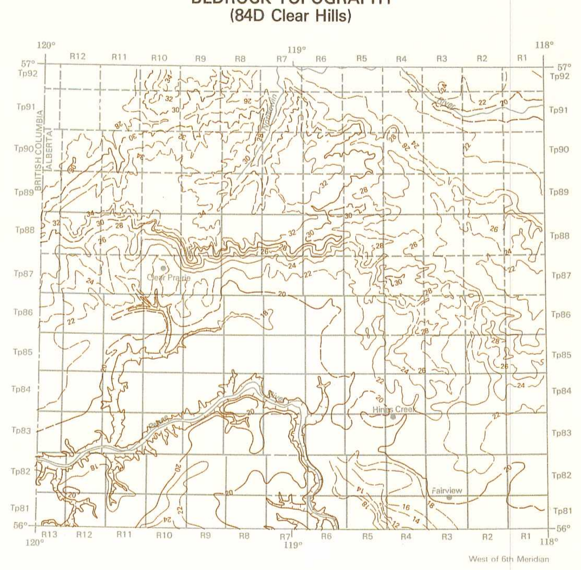
Base of the Fish Scales marker horizon. (Kbfs)

Shaftesbury Formation, Lower Member: *dark grey shale; nodules and thin beds of concretionary ironstone; bentonite partings; interbedded locally with thin silty and sandy intervals; marine.* (Kshl)

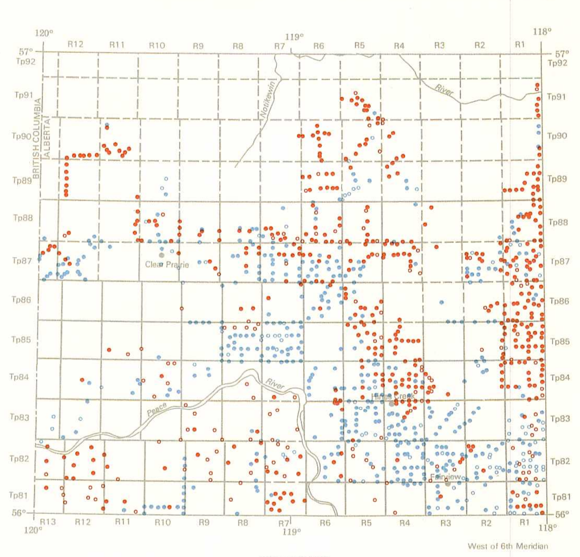
Rock unit boundary
defined ....
approximate ....
Structure contour on top of the Kaskapau Formation Lower Member—Dunvegan Formation sandstones (ft. amsl)
defined 2000
approximate 2000
Boundary of occurrence of the Kaskapau Formation Lower Member—Dunvegan Formation sandstones ....
Structure contour on top of the Base of the Fish Scales 1400
Structure contour on top of the Peace River sandstones facies
Cadotte Member (ft. amsl) 700
Notikewin Member (ft. amsl) 600
Boundary of Peace River sandstones facies
Cadotte Member ....
Notikewin Member ....
Structure contour on top of the Paleozoic Surface (ft. amsl) 300
Boundary of Paleozoic Formations (subcrop under Cretaceous) ....

(Remark: Kkl + Kd crops out or is covered only by thin colluvium or slump material in steep-flanked valleys cut into the formation; no contour lines shown there.)

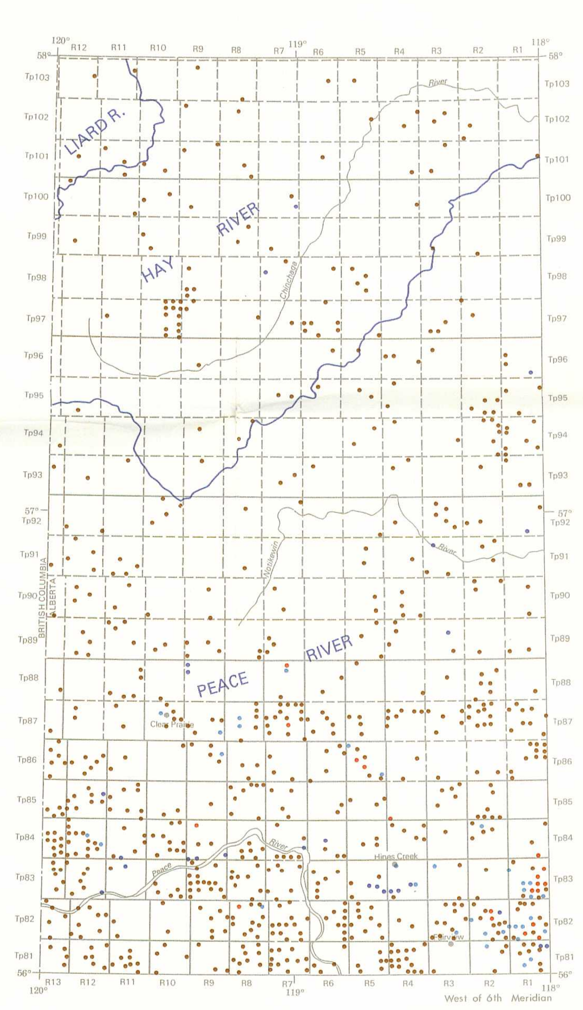
BEDROCK TOPOGRAPHY
(84D Clear Hills)



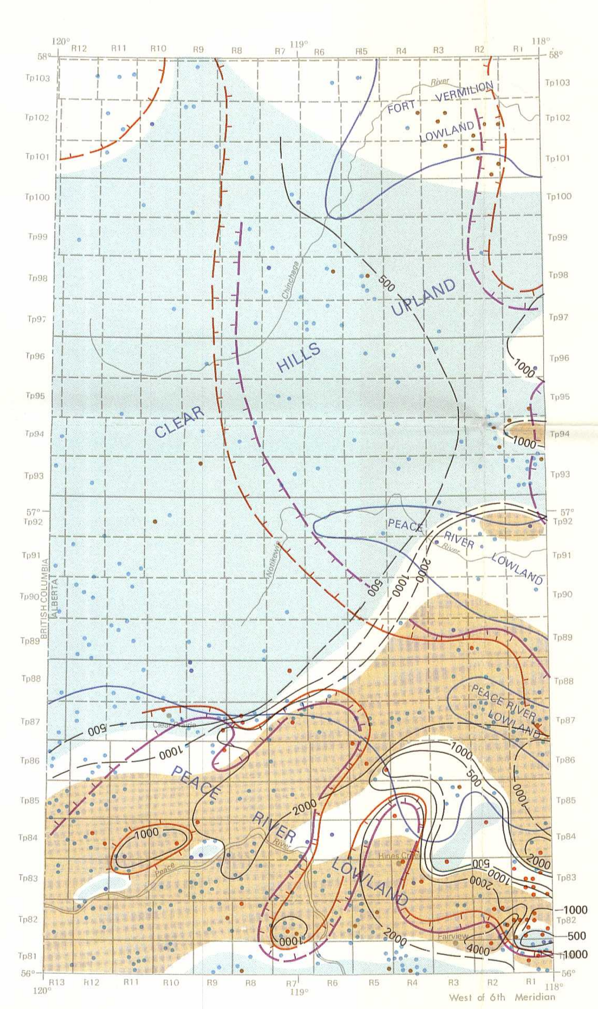
DATA POINTS FOR BEDROCK TOPOGRAPHY



DATA DENSITY AND MAIN DRAINAGE BASINS



HYDROCHEMISTRY AND PHYSIOGRAPHIC UNITS



SCALE 1:1,000,000
Miles 5 0 10 20 Miles
Kilometres 5 0 10 20 30 Kilometres

LEGEND

Data control point marking the location of a well with yield information ....
Data control point marking the location of a well with water level information only ....
Data control point marking the location of hydrogeological surface features ....
Data control point marking the location of lithological information only ....
Main drainage basin boundary ....

LEGEND

Data control point marking the location of a well, dugout ....
Data control point marking the location of a spring, discharge feature ....
Data control point marking the location of deep formation water sample above mean sea level ....
Data control point marking the location of deep formation water sample below mean sea level ....
Total dissolved solids in milligrams per litre (mg/L):
defined 500
approximate 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 ....
approximate ....
Isogram along which sodium + potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium + potassium content
defined ....
approximate ....
Boundary of physiographic unit ....

*determined on equivalents per million basis.

LEGEND

Steep-flanked valley cut into bedrock; on the slopes bedrock crops out, or is covered only by thin colluvium or slump material ....
Contour line (numbers in hundred feet)
approximate 5
assumed 5
Hole with lithologic or electric log:
reached bedrock ....
reached bedrock with more than 10 feet of sand, sand + gravel or gravel observed ....
stopped in surficial deposits ....
stopped in surficial deposits with more than 10 feet of sand, sand + gravel or gravel observed ....

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